Automated technology of forming high-precision aspheric optics for multipurpose optical systems

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Abstract. The report presents modern manufacturing technology of high-precision optical parts used in optical-electronic systems for various purposes. The report also presents the complex technology of automated shaping (TESAF) of aspherical, including off-axis surfaces of optical elements for optical-electronic systems. In this paper we consider various methods of forming optical parts with virtually any aspherization value and with different values of the off-axis parameter (off-axis aspheric), with the achievement of surface shape accuracy in the limit \( \lambda / 60 \div \lambda / 100 \) \((\lambda = 0.6328 \, \mu m)\), by the criterion of the standard deviation. Optical systems manufactured by TESAF technology are already being successfully used at present.

1. Introduction

Significant role in the formation of comprehensive information environment is played by the systems equipped with optical-electronic complexes (OEC), used in scientific research, navigation and telecommunication systems, communication systems, control and coordination (scheduling), as well as for multipurpose tasks of observing the Earth’s surface and atmosphere.

As a rule, in modern OEC aspherical mirrors are used to achieve the diffraction quality image of the object under study, including optical elements from monolithic ultrathin (1:50 - 1:100 mirror-to-diameter), lightweight (up to 90%), high aperture (1:1) mirrors, off-axis aspheric mirrors of various configurations and etc. The type of material is selected in accordance with operating conditions, as well as the required specifications [1]. The range of overall parameters of optical components is from 300 to 6000 mm. Also, the OEC for these purposes requires high quality image of the object under study, i.e. optical elements must comply with the requirements for the quality of the surface shape, according to the criterion of the standard deviation \( \sigma_{sd} = \lambda / 60 \div \lambda / 100 \) \((\lambda = 0.632 \, \mu m)\).

2. Tasks

The following items are used to increase optical systems resolution and aiming accuracy, as well as to reduce its weight and size characteristics (by reducing the number of optical components of the device, using lightweight optical elements):

- Aspherical surfaces of the second and higher orders;
- Adaptive elements to control the shape of the system wave front;
- Composite components of optical elements (main mirrors) of aspherical shape, with different configuration of the outer perimeter (n-faceted mills);
- Off-axis aspherical elements of a circular and arbitrary perimeter configuration;

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Lightweight optical elements made from traditional materials (glass, quartz) and non-traditional materials, including high modulus (SIC silicon carbide).

When manufacturing complex aspherical mirrors with high asphericity and accuracy, it is necessary to use an integrated technology of shaping optical parts with a guaranteed achievement of shaping accuracy used in OEC, operating in different spectral ranges.

The actual task of creating a technology for the production of these parts, is to create a controlled process of shaping optical surfaces at various stages, including minimizing technological transitions, creating for this purpose optical equipment with computer control of the entire technological cycle and obtaining, as a result of its use, optical-electronic systems (OEC) of a new generation based on Cook, Korsch, Richie-Chretien and others optical schemes, with a diffraction quality of resolution [2]. Experts of JSC "NPO Optics" successfully solved this task, developed and implemented complex automated technology for forming aspherical surfaces (TESAF) using abrasive, magnetorheological and ionic methods of interaction on the processed surface of optical parts of any sizes [3] (Figure 1).

Figure 1. Integrated automated technology for aspherical surfaces forming (TESAF).

3. Main tasks
The main tasks in creating a technology for manufacturing high-precision optics were:
− Creating a controlled shaping process;
− Creation of technological systems for stabilization of the surface shape and computer optimization of system parameters;
− Creating a new optical machine park with computer control;
− Creation of a gamut of interference controls that ensure objective control of the shaping process at the stages of grinding, polishing, aspherization, and finishing;
− Minimize the processing time with the achievement of accuracy parameters for the deviation of the surface shape within 3 ÷ 5 nm and roughness - 5 ÷ 10 Å.

Any technological operation should be characterized by an integral appraisal of the surface shape:
− Standard deviation - σ;
The scale of the error - P-V;
Surface error components - astigmatism, coma, trefoil.

Figure 2 shows the developed equipment for the implementation of the TESAF system.

4. Processing methods
Optical part shaping process begins with its receipt for processing into an automated complex, which consists of complex-integrated equipment for chemical-mechanical, magnetorheological [4], [5] and ion processing of the optical surface.

The processed source surface of the optical part is controlled by an interferometer of amplitude or phase type of the visible and infrared ranges. Per results of the control, the allowance for the further processing is determined, the value of which can be from a few to hundreds of micrometers. Optical part passes from one to three stages of subsequent technological cycles to achieve the nominal shape parameters and surface roughness:
• Abrasive chemical-mechanical treatment on automated machines for removing the main allowance by the method of controlled grinding and polishing the treated surface, to reach the highest possible requirements for shape deviation (5 ÷ 10 nm) and roughness of the surface (10 Å);
• Further shaping of the surface is carried out with the help of ion shaping, to achieve surface deviations of 3 ÷ 5 nm;
• Achieving minimum roughness values up to 5 ÷ 10 Å by means of magnetorheological shaping.

To achieve optimal value of one of the required parameters (shape deviation or roughness), it is possible to use the combination of these methods. Technological operations of ionic, magnetorheological and abrasive shaping are performed on newly developed equipment, which in aggregate is an automated complex with unified technological and control programs. These methods, both individually and in combination, allow obtaining the declared parameters of the treated surface, both in terms of shape deviation and roughness.

The technology of automated shaping using the abrasive method of the “small” tool developed at JSC "NPO Optika", is currently used for manufacturing high-precision aspherical optics.

Two other methods used in this technology, also successfully tested, relate to physical influence on the treated surface:
− Bombardment by ions of inert gases of the treated surface (ion shaping);
− Magnetorheological polishing with the use of a magnetic polishing suspension, the quality of which (consistency, hardness, viscosity, polishability) depends on its magnetic properties and applied magnetic field.

5. TESAF components

To implement the developed technology, the specialists of JSC "NPO "Optika" formed a gamma of automated polishing and finishing machines of the APD series (APD-250, APD-1000, APD-1000MR, APD-600, AD-1K, APD-2000, APD-3000, APD- 4000). These machines are used for automated shaping and fine-tuning aspherical surfaces of optical parts using the method of multi-position local processing and the spatial-temporal principle of shaping, with the achievement of accuracy parameters for surface deviation within the limits of λ / 60 ÷ λ / 80 (λ = 0.6328 microns). General view of one of the APD series of machines is presented in figure 3.

![Figure 3. APD machine (APD-1000MP).](image)

Gamma of interference controls of flat, spherical, aspherical and off-axis surfaces, such as "ИКИ-10.6" (infrared interferometer - 10.6 μm), "ПИК-АС" (interference control device for spherical and aspherical surfaces), "ПИКА-М" (aspheric interference control device surfaces motorized). General view of interferometers is shown in figure 4, 5, technological, and control programs that implement the
technological process of both chemical-mechanical and magnetorheological impact on the treated surface, as well as a range of technological means of basing and unloading the manufactured optics.

The developed automated technology allows reducing labor capacity of manufacturing off-axis optical elements, increasing their accuracy and reducing the weight and dimensional characteristics of optical-electronic systems, while simultaneously increasing output parameters (field angle, resolution, light transmission, increasing the width of the spectral range etc.).

Figure 4. Interference control device (ИКИ-10,6).

Figure 5. Interference control device (ПИК-АС).

6. Conclusions
Developed automated technology for shaping aspherical surfaces, based on the newly created machine equipment and metrological controls, allows obtaining precision off-axis mirrors for multipurpose OEC in the infrared, visible and ultraviolet spectral ranges. TESAF allows obtaining high-precision mirrors that are currently in demand and successfully functioning [2], confirming the high stability of the surface shape during operation. As a result of the work done, JSC "NPO Optika" produced more than 400 optical elements of various sizes with diameters from 100 to 3000 mm for various types of OEC using the TESAF system.

Reference
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