Focusing aspherical optical components for next generation megajoule laser system

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Abstract. The idea of creating a laser thermonuclear installation was considered back in 1960s by Basov N and Krokhin O. [1]. Facility for conducting research near DT-fuel ignition threshold is being commenced at the moment [2], assembly of the laser installation interaction chamber has already been completed. To focus laser sight on the target, off-axis aspherical lenses are used as part of the final optical module (FOM). These lenses are manufactured using the developed technology of forming off-axis aspherical surfaces of optical parts. Combined use of shaping technology and stand for monitoring angular deviations of the surfaces of FOM lenses, allowed us to achieve high quality off-axis aspheric optical elements both in terms of standard deviation of the surface shape, as well as the value of the scattering circle.

1. Introduction

Laser thermonuclear fusion (LTF) works are carried out by all the leading countries of the world. The point of the LTF is that a capsule with a small amount of deuterium and tritium is irradiated with powerful laser pulses. The contents of the capsule are compressed and heated, and self-sustaining reaction of thermonuclear burning is started in the mixture. Energy in the form of highly heated reaction products and neutron flux is released as a result [3].

The idea of creating a laser thermonuclear plant was proposed in the 1950s by academicians Sakharov A and Tamm I. In 1960s laser thermonuclear synthesis was initiated, and the first experiments were conducted in 1972. For almost half a century, several powerful laser installations were assembled, including such as Iskra 4, Iskra 5, and Luch [4]. Assembly of the interaction chamber (figure 1) [3] of modern Russian laser installation, with a megajoule energy level has been already completed in Sarov.

Interaction chamber is the central element of the installation, sphere with a diameter of 10 meters and weight about 120 tons, where laser radiation must interact with the target [5]. Commissioning of the first stage of the laser installation is planned for 2022. Various Russian enterprises take part in this venture.
2. Off-axis aspherical component FOM
To focus pulsed laser radiation in the channels of the interaction chamber of the installation, 192 off-axis aspherical lenses (figure 2) of the FOM are used on the target [2].

3. Automated technology for forming aspherical surfaces
The technology for manufacturing of lenses, developed by the authors, ensures the formation of off-axis aspherical surfaces of optical parts and allows achieving accuracy parameters according to the standard deviation criteria $\sigma_{RMS} = \lambda/60+\lambda/80$ ($\lambda=0.6328\ \mu m$).
This technology combines the effects of various forming methods on the processed surface – chemical-mechanical, magnetorheological and radiation (ion) [6], [7].

Chemical and mechanical processing by automated machines is designed to remove the main allowance by controlled grinding and polishing of the processed surface, with achievement of the maximum possible requirements for shape deviation and surface roughness. Ionic shaping of the surface is necessary to achieve a surface shape deviation within 3±5 nm, and the minimum roughness values up to 5±10 Å are achieved by magnetorheological shaping. Technological operations of forming are carried out on the developed equipment: computerized machines, interferometers, technological and control programs, technological means of basing and discharging.

Processed initial surface of the blank of FOM lens (figure 3) is controlled by interferometer. Control results determine the allowance for further processing.

![Figure 3. FOM lens.](image)

Milling of spherical surfaces is conducted on the machine 6T-12 (figure 4) \((R_{Sph}=22364\,\text{mm})\) with the provision of different thickness, as shown in the table 1.
Figure 4. FOM lens on the stage of spherical surface milling.

Table 1. Lens thickness along the optical axis at the specified points.

| Point № | Thickness, mm |
|---------|---------------|
| 1       | 129.221±0.05  |
| 2       | 19.171±0.05   |
| 3       | 74.257±0.05   |
| 4       | 74.257±0.05   |

Lenses spherical surfaces grinding is done using ZSHP-350 machines (figure 5).

Figure 5. FOM lens on the stage of spherical surface grinding.

Automated forming of aspherical surface (R=3646.2519 mm) with achievement of drawing requirements, is done by automated machine KFS-1000-5K (figure 6).
Interference control of lenses is performed using the designed control stand (figure 7) of FOM lenses in a horizontal position (figure 8). The stand includes:

- Twyman-Grin type interferometer with laser radiation source $\lambda=0.6328\ \mu m$;
- Lens optical system for forming a flat wave front with a diameter of 600 mm;
- Standard flat mirror with a diameter of 600 mm;
- Photodetector unit that registers spatial position and diameter of scattering circle in the plane of minimal spot, which contains 86.5% of energy.
Using the developed FOM lens control stand, deviation of scattering circle from optical axis is registered. This deviation is equivalent to a linear correction for the size of tweaking of the processed lens.

Milling of lenses along the contour is made by the machine 6T13 (figure 9), using a diamond cutter.

After the final milling of the FOM lens blank along the contour to the required dimensions, it is certified in the same control stand. Control results are shown in the table 2.
Table 2. Manufactured FOM lenses certification results.

| Parameter                                                                 | Required value | Actual value |
|---------------------------------------------------------------------------|----------------|--------------|
| Spatial position of the focused spot on the detector matrix, mm           | ≤1             | [0.1;1]      |
| Diameter of the scattering spot $d_{0.6328}$, μm                          | ≤45            | [22;40]      |
| Back focal segment $S_f$, mm                                              | 6820±10        | [6812;6820]  |
| PV (peak-to-valley), $\lambda$                                           | 0.25           | [0.18;0.2]   |
| RMS (root-mean-square deviation), $\lambda$                             | 0.06           | [0.027;0.04] |

Developed automated technology of forming off-axis and aspherical lenses surfaces, and its angular deviations control stand, allowed to achieve high quality optical elements both in terms of PV and RMS parameters (figure 10), as well as in the diameter of scattering circle value and its deviation (figure 11).

Figure 10. FOM lens interferogram in the double path of rays on Fizo interferometer ($\text{RMS} = 0.03\lambda$, $\text{PV} = 0.2\lambda$).

Figure 11. Results of FOM lens inspection in horizontal control stand.
Next stage of monitoring of angular deviations of lenses surfaces is assembly of 4 FOM lenses in a single cluster, in order to ensure the alignment of beams and system testing of the first module installation (figure 12).

![Figure 12. Cluster with 4 FOM lenses view.](image)

4. Conclusion
Developed and implemented technology of forming off-axis aspherical optical surfaces, allows achieving precision parameters following RMS criteria $\sigma_{RMS}$ of diffraction quality. Developed stand for horizontal control of angular deviations of FOM lenses surfaces, allows assembling and adjusting of FOM lenses in a single cluster, and obtaining values, which meet stated requirements of technical specification.

References
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