ISSN 1068-798X, Russian Engineering Research, 2016, Vol. 36, No. 10, pp. 826–830. © Allerton Press, Inc., 2016.
Original Russian Text © V.V. Lapshin, E.M. Zakharevich, S.V. Grubyi, 2016, published in Vestnik Mashinostroeniya, 2016, No. 7, pp. 60–65.

Machining of Linear Negative Matrices for Fresnel Lenses and Prisms

V. V. Lapshin[a], E. M. Zakharevich[a], and S. V. Grubyi[b, *]
[a] *OAO VNIIInstrument*
[b] *Bauman Moscow State Technical University*
**e-mail: grusv@yandex.ru*

Abstract—The structure of linear negative matrices for the manufacture of Fresnel lenses and prisms is analyzed. The requirements on the equipment and cutting tool for the machining of negative matrices are discussed. A manufacturing technology for the matrices is outlined, and test results are presented.

Keywords: diamond cutter, ultraprecision machining, negative matrices, Fresnel lens, Fresnel prism
DOI: 10.3103/S1068798X16100105

PURPOSE OF THE MATRICES

Today, many precision instruments and machines include components with structured surfaces, such as matrices for the manufacture of Fresnel lenses and prisms, which are used for magnification and collimation and also for the concentration of solar energy [1–3]. Two basic configurations are employed: linear and circular. Circular matrices have parallel channels, in which solar light is focused on a line [4]. Such lenses are used in photoelectric modules of solar batteries in spacecraft. Optical concentrators reduce the area of solar elements and extend battery life, since the concentrators protect the solar elements from the action of cosmic rays.

At Ioffe Physicotechnical Institute, Russian Academy of Sciences, a method of manufacturing Fresnel lenses for photoelectric concentrators has been developed [5]. In this method, a negative matrix is produced, and positive copies of the linear Fresnel lens are removed from it. The negative matrix is made by diamond thinning of strip attached around the end surface of a drum. The positive copies of the linear Fresnel lens are produced by filling the gap between the negative matrix and the plane glass plate with a liquid silicon elastomer. After vulcanization of the elastomer is complete, the lens is reduced. This method ensures a light lens of high optical quality.

At OAO VNIIInstrument, in collaboration with Bauman Moscow State Technical University, a technology has been developed for the machining of such negative matrices.

A negative linear Fresnel matrix is a strip (thickness 2 mm, width 69.6 mm) with a machined profile. Such components may be made from polycarbonate, optical organic glass, M0b copper, and AMg6 aluminum alloy. The profile of the Fresnel matrix consists of parallel sections (width 25 mm), each of which consists of two symmetric segments. Each segment contains 50 channels of depth h and inclination δ. Thus, the profile of the Fresnel matrix consists of four segments with a total of 200 channels (Fig. 1). Segment 2 is the mirror image of segment *1*, while segment *4* is the mirror image of segment *3.* The channel depth h varies from 2.3 to 185 μm and the inclination δ from 0.53 to 36.4° (Table 1).

A promising application of Fresnel matrices is the production of elastic prisms for vision correction. In prismatic lenses, the beams deviate toward the base of the prism. Therefore the image is shifted to its peak. This effect is used to restore the direction of the beams when the optical axis of one eye has deviated from the common focal point.

Table 1. Parameters of a linear negative Fresnel matrix

Channel	δ°	h, μm
1	0.5	2.31
2	1.5	6.93
3	2.6	11.55
4	3.7	16.17
⋮	⋮	⋮
25	23.1	106.94
26	23.9	110.79
⋮	⋮	⋮
49	36.0	182.16
50	36.4	184.51

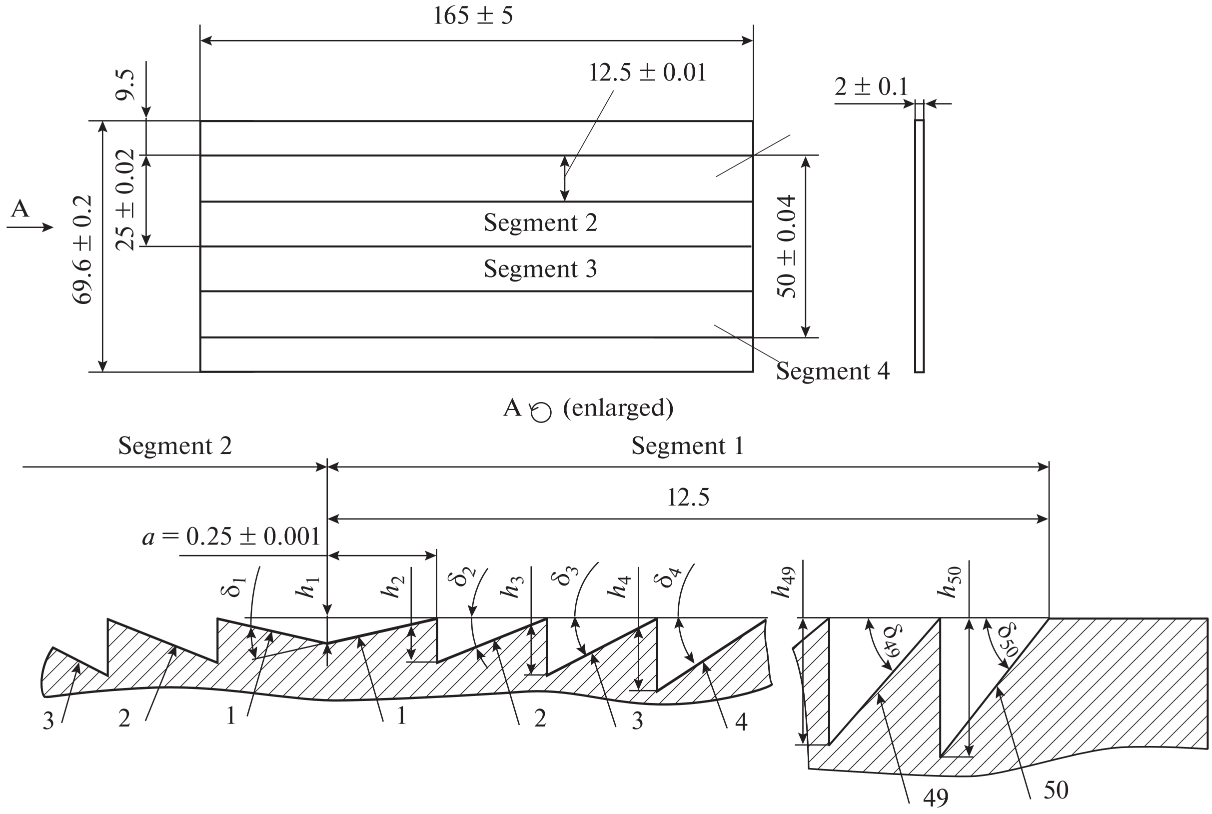

Fig. 1. Linear negative Fresnel matrix.

The prisms are thin plate of flexible transparent polymer, in which one surface is smooth, while the other is a prismatic grating. They are applied to the eyepiece lenses, where they are held tightly by adhesion.

The matrices for Fresnel prisms are made of M0b copper or AMg6 aluminum. The profile of the matrix consists of a series of identical channels with spacing $a = 1.2$ mm. The inclination and depth vary in the ranges $1.11 < \delta < 33.3°$ and $0.0233 < h < 0.7892$ mm (Fig. 2).

Table 2 presents the h and δ values for matrices used in the manufacture of Fresnel prisms.

Negative matrices for the production of linear Fresnel lenses and prisms must meet strict requirements in terms of surface quality and manufacturing precision. The roughness of the machined surfaces must not exceed $Ra = 0.01$ μm. The tolerances on h and a must not exceed 1 μm.

MACHINE TOOL FOR MATRIX PRODUCTION

The matrices are machined by means of an ultraprecision numerically controlled Asferika machine tool [6, 7]. This system is designed for the diamond thinning and milling of ultraprecision components and permits the machining of complex axisymmetric surfaces, ensuring optical quality, such as axial fibers and aspherical and Fresnel optics.

The machine tool has aerostatic bearings for the main shaping components. Low-vibration synchronous linear drives are employed. The frame is mounted on vibration-suppressing bearings. The numerical control system ensures positioning error of less than 0.1 μm. The metrological system permits positioning of the tool at the center of rotation of the table. In machining optical elements, the surface

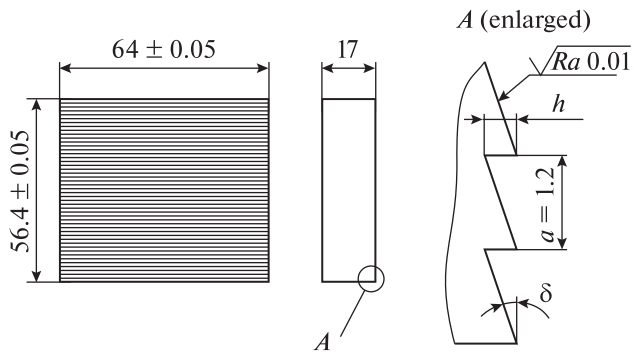

Fig. 2. Matrix for manufacture of Fresnel prisms.

Table 2. Parameters of matrices for the manufacture of Fresnel prisms

Matrix	Diopter	δ°	*h*, μm
1	1	1.11	0.23
2	2	2.22	0.46
⋮	⋮	⋮	⋮
7	7	7.77	0.164
8	8	8.88	0.188
⋮	⋮	⋮	⋮
14	25	27.77	0.632
15	30	33.33	0.789

roughness must be $Ra < 0.01$ μm; the shape error must be no more than 1 μm.

CUTTING TOOLS

Monocrystalline diamond cutters with special geometry are employed. The roughness of the cutters' working surfaces is $Ra < 0.01$ μm. The rounding radius ρ of the cutting edge must be 30–50 nm. The cutter radius at the tip must be much smaller. With increase in radius at the tip, the distortion of the profile at the bottom of the machined channel will be greater. We know from the literature that ρ = 1 μm for the best cutters. Only cutters made from monocrystalline natural diamond meet this standard.

Sharply ground Russian diamond cutters and Contour diamond cutters with a tip radius of 20 μm (the Netherlands) are used to machine the negative Fresnel matrices (Fig. 3). The error of the radius at the tip of the Contour cutter is <1 μm. The use of a tool with a specified tip radius permits the introduction of the necessary radial correction in the control program and increase in the machining precision.

Sharply ground Russian diamond cutters are used to machine the matrices for the Fresnel prisms (Fig. 4).

MACHINING OF NEGATIVE MATRICES FOR LINEAR FRESNEL LENSES

Copper, organic-glass, and aluminum are used in the matrices. A strip (width 70 mm, length 1055 mm) is mounted on a cylinder (diameter 350 mm) and tightened by a special mechanism so as to ensure adhesion to the cylinder surface. The diamond cutter is mounted on a rotary table. The tool height may be adjusted so as to precisely match the height of the spindle centers.

After establishing the strip in the machine too, it must be ground to the required thickness and width. The external radius is reduced by means of a diamond cutter (tip radius 2 mm), while the ends are trimmed by a sharp roughing cutter. Then, the diamond cutter

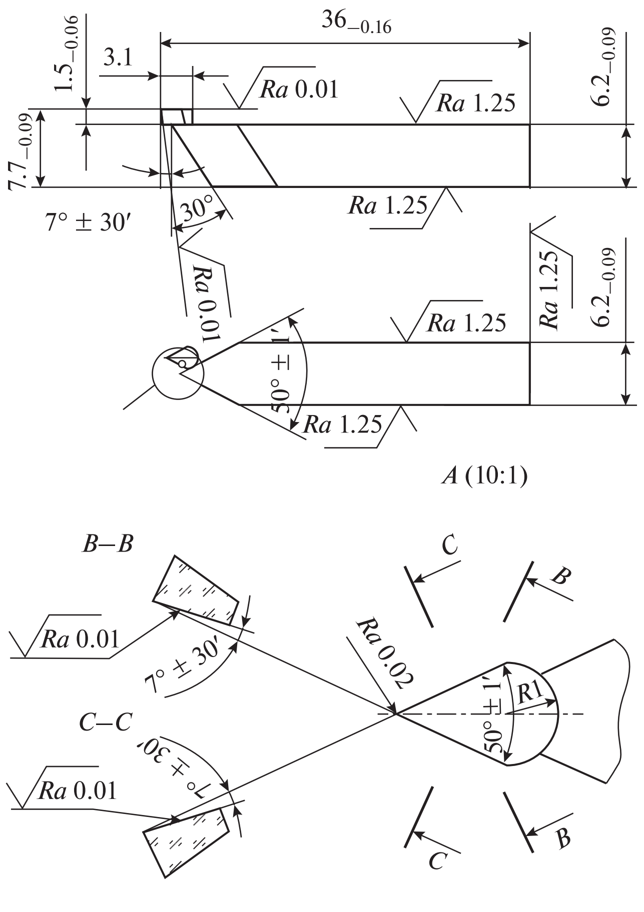

Fig. 3. Diamond cutter for machining a negative Fresnel matrix.

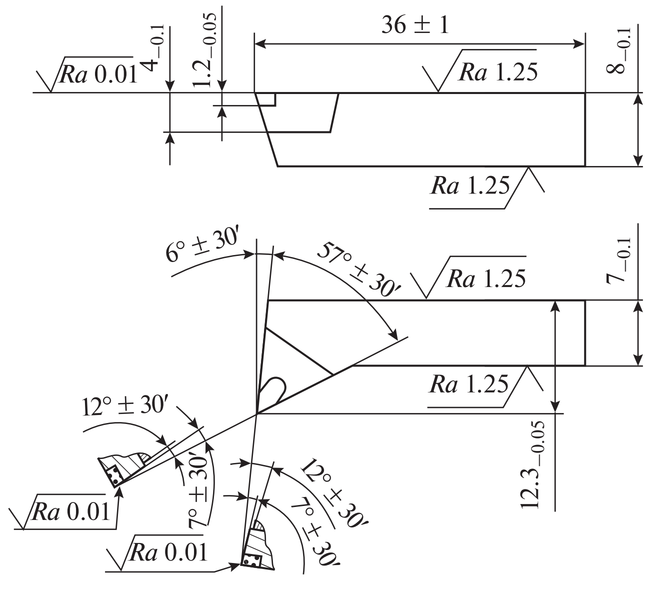

Fig. 4. Diamond cutter for matrices used in the manufacture of Fresnel prisms.

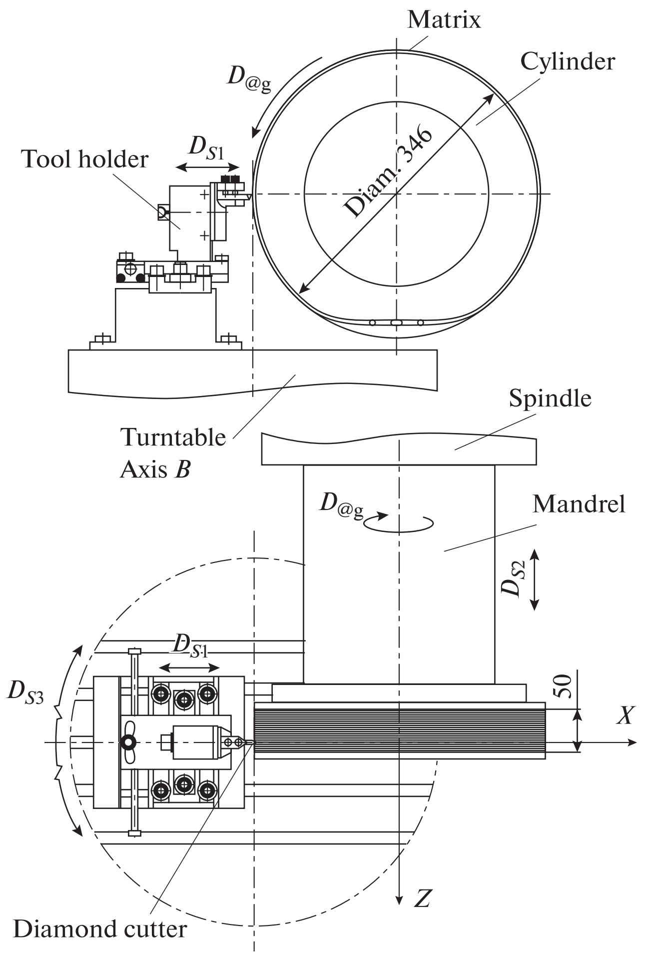

Fig. 5. Machining system for matrices used in the manufacture of Fresnel lenses.

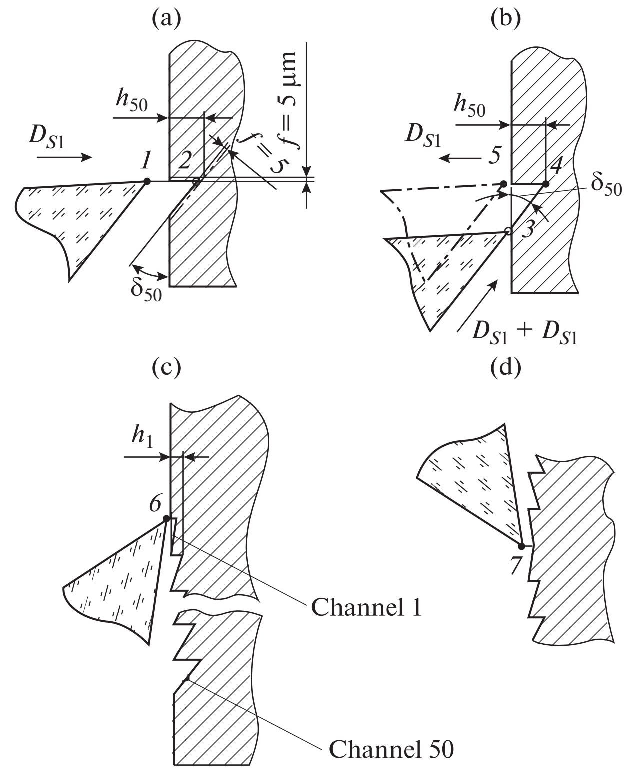

Fig. 6. Sequence of shaping operations (*1*–*7*) for channel 50 in the profile of a matrix used in the manufacture of Fresnel lenses.

is installed for machining of the matrices. The tool tip is aligned with the center of table rotation by means of a microscope, after preliminary adjustment by means of a centering device.

The next step is to establish the tool position in the coordinate system relative to the part to be machined. To that end, a magnifier is used to determine the contact of the tool with the part and also to ascertain the angular coordinates at which the tool's right and left cutting edges are parallel to the generatrix of the machined strip. After preliminary operations in the numerical control system, correctors specifying the required coordinate systems are introduced.

The machining sequence is as follows:

(1) advance of the cutter to the starting position and assignment of the required inclination;

(2) machining of the first channel by incision, with tolerance t in the final pass;

(3) advance of the cutter to the starting position for profile machining of the channel;

(4) profile machining of the channel;

(5) finishing of the channel end;

(6) machining of the second symmetric section with channels.

Steps 1–5 are repeated for all n channels.

The machining system is shown in Fig. 5. The sequence of shaping operations is shown in Fig. 6.

The best machining conditions are as follows: spindle speed $n = 270$ rpm; supply $S = 2$ μm/turn.

MACHINING OF MATRICES FOR LINEAR FRESNEL PRISMS

In machining matrices for the manufacture of Fresnel prisms, we use milling by a single-cutter diamond head. The diamond cutter is mounted in a special rotary system for adjusting the channel inclination δ. The blank is mounted on a table which may be adjusted vertically so as to regulate h. After setting the inclination δ, the tool is brought in contact with the blank. Then the table is raised to the required height h.

The part is mounted in a transverse-supply carriage. After machining the first channel, the carriage with the single-cutter diamond head is shifted by one step a and the next channel is machined (Fig. 7). The

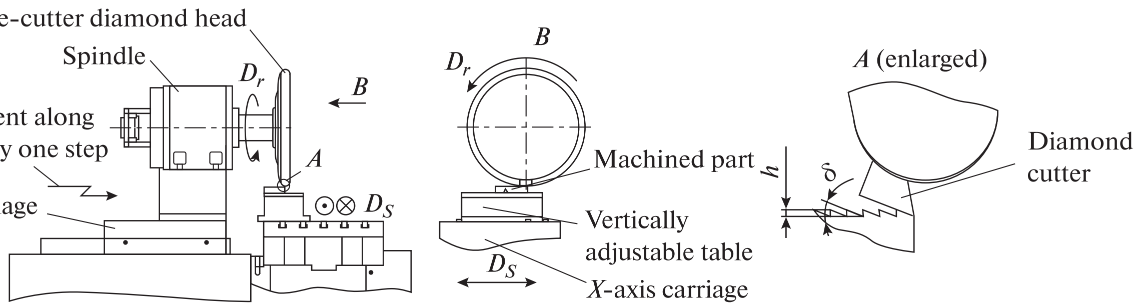

Fig. 7. Machining system for matrices used in the manufacture of Fresnel prisms.

best machining conditions are as follows: spindle speed n = 500 rpm; longitudinal supply S_m = 30 mm/min.

MONITORING AND TESTING

After machining, the following parameters of each matrix are monitored: the roughness Ra of the machined surface; the distance a between the channels; and the channel inclination δ. The NanoFocus® μSurf instrument employed is a confocal microscope.

For contact-free measurement of the surface topography, the matrix is positioned on a precision measurement table and the surface is scanned. The scan is shown on the computer screen and special software measures the roughness.

Under contract with Ioffe Physicotechnical Institute, Russian Academy of Sciences, this technology has been used to machine negative Fresnel matrices made of polycarbonate, organic glass, and copper, by means of sharply ground diamond cutters and also adjustable radial cutters. The best results are obtained for the organic-glass matrix: $Ra = 0.015$ μm; $a < 1$ μm; $\delta < 0.3°$.

Testing of batches of Fresnel lenses and prisms confirms the effectiveness of the proposed method. Further improvement in the machining of structured surfaces on precision parts will be possible when using more precise machine tools.

ACKNOWLEDGMENTS

Financial support was provided by the Russian Ministry of Education and Science (contract 14.579.21.0042, August 25, 2014; identifier RFMEF157914X0042).

REFERENCES

1. Davis, A. and Kühnlenz, F., Optical design using Fresnel lenses. Basic principles and some practical experiment, *Opt. Photonics*, 2007, no. 4, pp. 52–55. 1
2. Gaurav, A. Madhugiri and Karale, S.R., High solar energy concentration with a Fresnel lens: a review, *Int. J. Mod. Eng. Res.*, 2012, vol. 2, pp. 1381–1385.
3. Sierra, C. and Vázquez, A.J., High solar energy concentration with a Fresnel lens, *J. Mater. Sci.*, 2005, vol. 40, pp. 1339–1343.
4. Khamooshi, M., Salati, H., and Egelioglu, F., A review of solar photovoltaic concentrators, *Int. J. Photoenergy*, 2014, vol. 14, pp. 1–17.
5. Andreev, V.M., Ionova, E.A., Kalinovskii, V.S., Pokrovskii, P.V., Rumyantsev, V.D., and Khazova, E.V., RF Patent 2456645, *Byull. Izobret.*, 2012, no. 20.
6. Grubyi, S.V. and Lapshin, V.V., Simulation of the process and the technology development of high precision processing of flat reflectors of single-cutter diamond milling head, *Nauka Obraz.*, 2014, no. 2. doi 10.7463/0214.0699743
7. Lapshin, V.V. and Grubyi, S.V., Improvement of accuracy and quality of diamond edge cutting of plane surfaces, *Vestn. Mashinostr.*, 2015, no. 5, pp. 57–62.

Translated by Bernard Gilbert

SPELL: 1. ok