Technology of Manufacture of the Negative Matrices for Linear Fresnel Lenses[1]

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Abstract. This article describes the main structural features of negative matrices which are intended for the production of positive copies of linear Fresnel lenses. Linear lenses are used in a space solar energy industry as solar concentrators in the photovoltaic modules. The article covers the essential requirements which are placed on the equipment and technology for the production of such matrices.

1. Introduction

The onboard power system of a spacecraft as a part of the solar battery has to to provide high specific capacity at low weight. To increase the electric capacity, radiation concentrators in the form of a linear Fresnel lens are included in the solar battery photovoltaic modules. Fresnel lenses are mainly used both as magnifying, collimating lenses and as solar energy concentrators [1 - 3]. The Fresnel lenses are available in two basic configurations: linear and circular. The linear lenses feature parallel grooves and sun light is focused in a line [4]. Such lenses are best suited to the production of composite lens panels of solar batteries for spacecraft. The use of optical concentrators allows to reduce the area of solar cells and to extend the battery life since concentrators protect the solar cells against exposure to space radiation.

Specialists at the Ioffe Physical-Technical Institute of the Russian Academy of Sciences developed a method of the production of Fresnel lenses for the concentrator photovoltaic module (RU 2456645) [5]. OJSC VNIIINSTRUMENT together with N. E. Bauman MSTU developed and implemented a technology of the production of a negative matrix for subsequent production of positive copies of a linear Fresnel lens. As is apparent from the proposed method, the matrix with a negative Fresnel profile will be fixed on a flat ground in a special appliance once it is manufactured using a diamond turning technology. A glass plate is installed in front of the processed profile, whereby from the side facing the matrix profile, a transparent adhesive coating is applied on the plate, and from the opposite side - an antireflection coating is applied. Subsequently, the gap between the plate and matrix is filled out with a liquid silicone elastomer and vulcanized. Afterwards, the ready-made positive linear Fresnel

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lens is separated from the plate. The developed technology for the production of linear lenses improves their optical quality and reduces the weight.

The negative linear Fresnel matrix (Fig.1) is a strip with the thickness of 2 mm and a width of 69.6 mm, with a cut profile. Polycarbonate, optical PMMA, oxygen-free copper or AlMg6 aluminium alloy may serve as suitable materials for the production of above mentioned parts. The profile of the Fresnel matrix consists of two equal parts, each with a width of 25 mm, located parallel to each other, each consisting of two segments symmetrical to each other. Each segment has 50 grooves with various depth and profile tilt angle. Thus, the profile of the Fresnel matrix consists totally of 4 segments and the total number of grooves is 200 pieces. Segment 2 is a mirror image of segment 1, and segment 4 – a mirror image of segment 3 (Fig. 1). The depth of profile grooves varies from 2.3 μm to 185 μm, whereby the tilt angle varies from 0.53° to 36.4°.

Matrices must meet demanding requirements for surface quality and accuracy of manufacturing. The roughness of structured surfaces should not exceed Ra 0.01 μm, tolerance on main linear dimensions *h* and *a* is less than 1 μm, tolerance on the angular size δ is 0.1°.

A diamond turning technology with an ultra-precision CNC machine is applied for the production of matrices with specified accuracy and quality requirements.

2. Requirements which are demanded from an ultra-precision machine for the production of matrices

Matrices are processed using an ultra-precision "Asferica" CNC machine. The machine is designed for diamond turning and milling of ultra-precision surfaces of parts made of various materials. The machine can process axisymmetric complex-shape surfaces with optical quality, including aspherical, axicons and Fresnel optics.

The "Asferica" machine has the following characteristics:

- aerostatic bearings in main shape-generating nodes;
- machine drives: synchronous, linear, insignificantly vibroactive drives;
- the machine frame is mounted on anti-vibration supports;
- the machine CNC system ensures a positioning error of less than 0.1 μm.

The machine features metrological equipment for setting up the tool in the rotational centre of the turntable. When processing optical elements, the machine ensures a surface roughness of less than Ra 0.01 μm and form error of less than 1 μm.

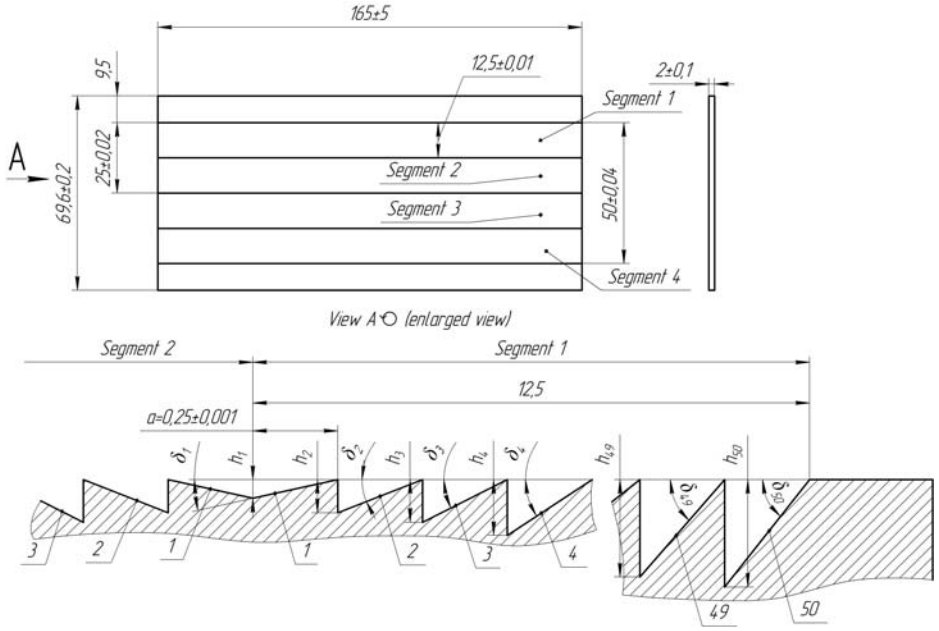


Figure 1. Linear negative Fresnel matrix

3. Cutting tool

Diamond cutters with a special geometry of the cutting point are used as cutting tool. The roughness of the working surfaces of such cutters must be less than Ra 0.01 μm, and the rounding radius of the cutting edge ρ should be 30-50 nm. Only cutters made of natural monocrystal diamond satisfy such conditions. Russian-made diamond cutters sharpened to a sharp edge (Fig. 2) and diamond cutters with a tip radius of 20 μm made by the Dutch company Contour (Fig. 3) are used for processing of matrices. Manufacturing error of the tip radius of the Dutch cutter is less than 1 μm. The use of tools with a set tip radius allows to adapt necessary radius correctors in the control software and increase the machining accuracy of the profile.

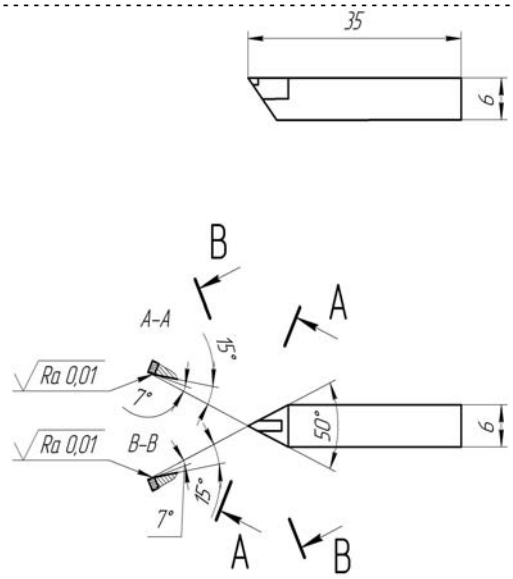


Figure 2. Diamond cutter sharpened to a sharp edge for processing of matrices

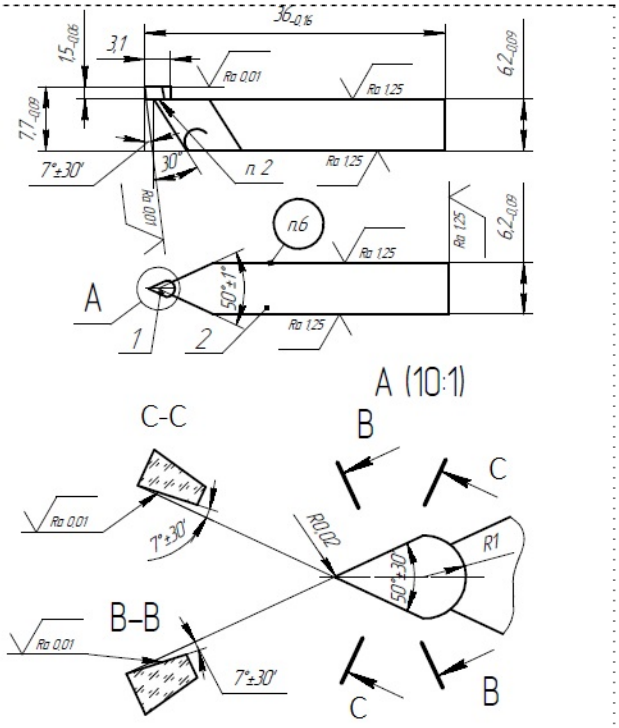


Figure 3. Diamond cutter with the radius of 0.02 mm

4. Manufacturing techniques and processing modes

Strip materials as follows are used for the production of matrices: copper, PMMA, aluminium. The strip with a width of 70 mm and a length of 1055 mm is mounted on a cylinder with a diameter of 350 mm and tensioned using a special mechanism so as to ensure a snug fit. Following the treatment, the strip is cut into 5 pieces, each with the length of 165 mm, and each of them may be used as a matrix. The diamond cutter is mounted in the cutter support which is placed on a turntable. The cutter support used makes it possible to adjust the tool height in order to precisely set up the cutter based on the height of spindle centre lines.

Prior to treatment of matrices, necessary preparatory work should be carried out. Once the strip is installed on the machine, it must be turned to the required size both in thickness and in width. Turning on the outer cylinder is performed by a diamond cutter with a tip radius of 2 mm, and end surfaces are trimmed using a rough cut tool sharpened to a sharp edge. Parts are processed at high speed modes since high precision and surface quality is not required for a pre-treatment. Subsequently, the diamond

cutter is installed in the cutter support for processing of matrices. The tool tip is aligned with the rotational centre of the turntable using a microscope whose reticule was aligned with the centre beforehand.

On the next stage, setting up is performed to determine the tool position in the coordinate system relative to the workpiece. For this purpose, a magnifying camera is placed on the machine und with the help of this camera contact of the tools with the workpiece is determined. Besides, angular coordinates are determined at which the right and left cutting edges of the cutter become parallel to the processed strip generatrix. Once the preparatory work is finished, correctors will be put in the machine CNC system which set the required coordinate systems. Due to peculiarities of setting up, the coordinate systems for left and right cutting edges of the tool must set individually. Machining pattern are shown in Figure 4.

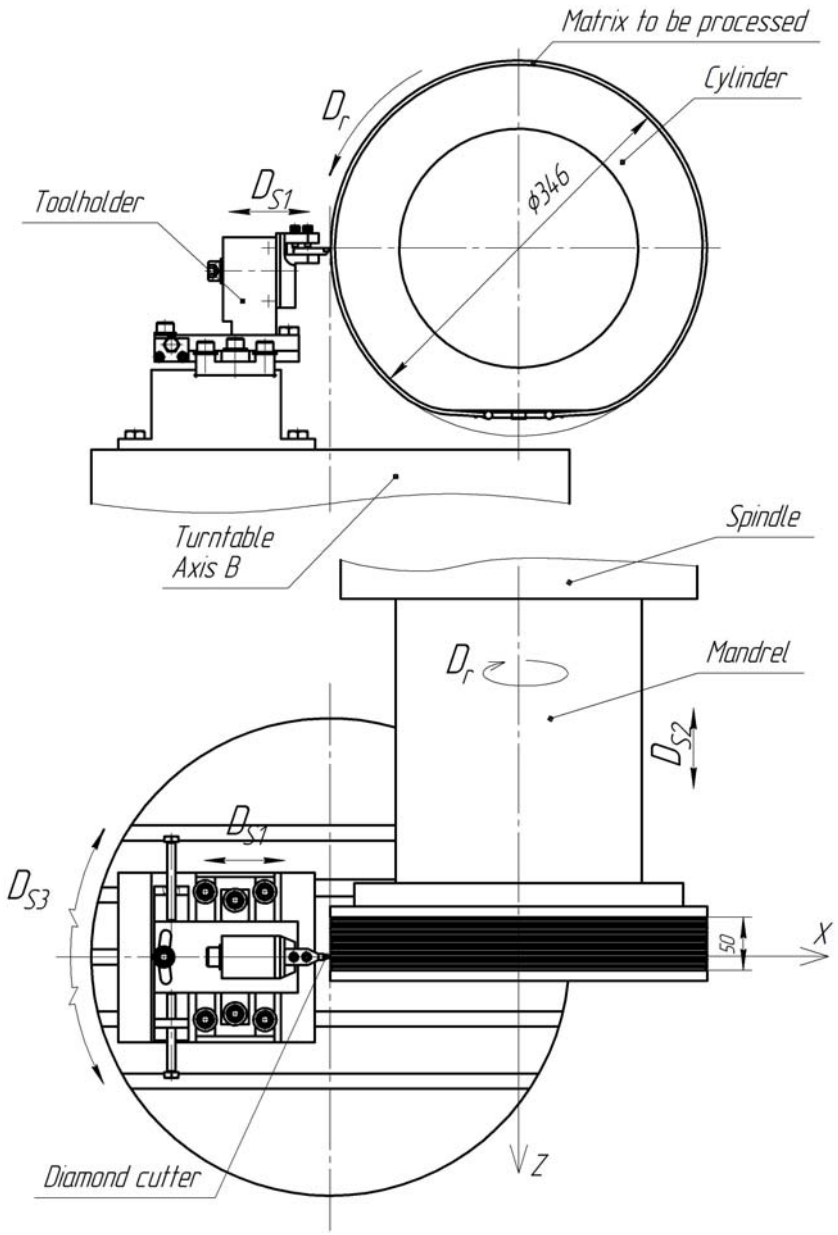


Figure 4. Kinematic diagram of the processing of matrices for Fresnel lenses

Once all preparatory setup works are finished and the program text is finalised, the profile of the matrix will be processed. The sequence of profile processing consists of the following main stages:

1. Advancing the cutter to the starting position and setting it to the desired angle.
2. Cutting of the first groove using a cut-in technology, leaving an allowance t for final cut.
3. Advancing the cutter to the starting point for machining of the groove using the profile method.
4. Processing of the groove using the profile method.
5. Final cutting of the groove end surface.
6. Steps 1 – 5 have to be repeated for the required number of grooves n, whereby each groove has different parameters δ, h.
7. Processing of the second symmetrical section with grooves (Figure 5).

Rational modes of processing are fixed: spindle rotation speed n = 270 rpm, advancing S = 2 μm/rev.

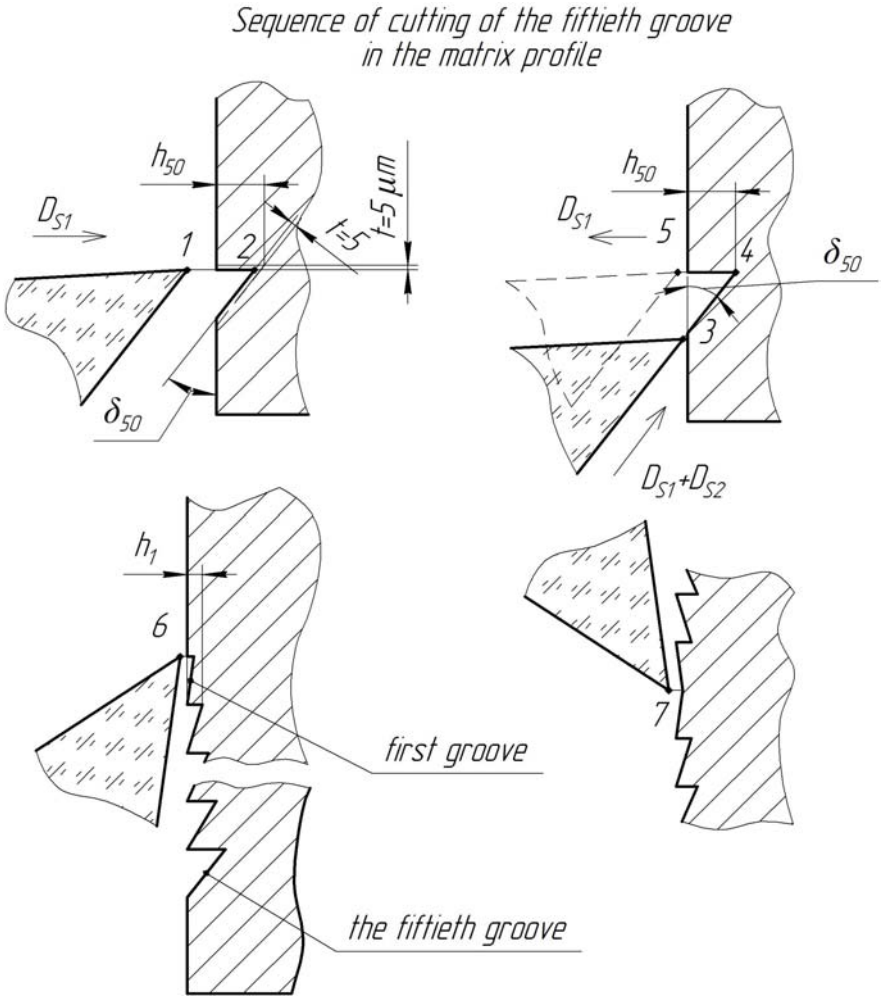


Figure 5. Cutting sequence of the matrix profiles for Fresnel lenses

5. Results

By order of Ioffe Physical-Technical Institute of the Russian Academy of Sciences, matrices made of polycarbonate, PMMA and copper were processed according to the developed technology using round-nosed cutters and cutters sharpened to a sharp edge. Following processing of each matrix,

necessary metrological control of roughness and machining precision was carried out. The NanoFocus® μSurf system was used as measuring equipment and in this system a principle of confocal microscopy was implemented. Due to the fact that this device cannot scan surfaces with large tilts, roughness and machining precision was measured on the grooves with a tilt angle of not more than 10°.

According to roughness control outcomes it was found that the best results were achieved during processing of matrices made of PMMA using a cutter sharpened to a sharp edge:

- roughness Ra – 0.015 μm;
- spacing error a - less than 1 μm;
- angle error δ - less than 0.1°.

6. Conclusions

This article describes the structural features of matrices with structured surfaces and linear Fresnel lenses which are made using such matrices. The article also provides requirements which are placed on extremely-precise equipment and diamond monocrystal cutters used for machining of structured surfaces. The article outlines the technology for matrix processing, describes the modes and conditions of diamond turning. The article contains the results of metrological control of processed matrices in terms of profile accuracy and roughness of the machined surfaces.

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