Development and research of the scanning method for testing of diffraction optical elements

Valery P. Kiryanov, Vladislav G. Nikitin, Alexander G. Verkhogliad
Laser Precision Systems Laboratory,
Technological Design Institute of Scientific Instrument Engineering,
Siberian Branch of Russian Academy of Sciences,
Novosibirsk, Russia

Abstract

The results of scanning method research for testing of diffraction optical elements are shown in this paper. The diffraction efficiency of exemplary diffraction optical element (Fresnel lens) was measured by suggested scanning method and directly (integral) method. Measured data are compared and analyzed. Results of having non-spherical wavefront transformation diffraction optical element measurement are presented and discussed. Conclusions concerning the parameters of the fulfilled phase profile for these diffractive optical elements are tested.

Introduction

The development of optical systems reduces as a rule to wavefront transformations. It means that wavefront in the initial plane of the optical system must be transformed by some way and must have the desired form of the wavefront in the final plane of the optical system. Problem of arbitrary wavefront transformation is not solved by classical (refractive) optics methods. It is possible to solve it by methods of the adaptive optics but this is expensive way. Therefore using of computer-generated optics is more expedient, in particular, diffraction optical elements (DOE). DOE is the type of optical elements, which uses light diffraction for wavefront transformation. DOE have profile modulation (phase modulation) and transmission modulation (amplitude modulation). DOE with phase modulation (phase DOE) are strongly preferred because of they don't have light absorption. Phase DOE to be working in the first diffractive order have phase function normalized to 2π. There are different ways of phase modulation. They discern sine, binary and linear phase modulation as a rule. Linear phase modulation for DOE is calling continuous phase modulation.

Important parameter of the DOE is diffraction efficiency (DE). DE is ratio of light energy in desired diffraction orders to total light energy. Phase DOE modulated by various methods have distinct DE. DE is equal to 34% for DOE with sine modulation having ideal develop of profile. For DOE with binary phase modulation maximal DE is equal to 41%. DE of DOE with linear modulation (blazed DOE) may achieve 100% [1]. Therefore DOE with linear phase modulation have the most of significance. But it is very difficult to produce such DOE. It is connected with the necessity to form the continuous profile and to achieve the high resolution in the boarders between diffractive zones during DOE production [2].

Reliable method for production of DOE doing voluntary wavefront transformation does not exist. Therefore the control of fabricated DOE quality has a large significance. To check DOE creation wavefront analogous the designed one is required. It is often very difficult or non-solvable problem because it requires of production unique optical scheme for checking each type of DOE. Apart some DOE may have a large size (300 mm diameter DOE may be fabricated by Circular Laser Writing System (CLWS) [3]), therefore their testing may be very expensive most probably.

The scanning method for DOE inspection is applied in this paper. Method consists in measurements of DE in local areas of the DOE surface and integration. Using results of these measurements, we may fix DE of whole element and profile features may be reconstructed and some conclusions about error of fabrication method may be done.

Method description

Surface of tested DOE is scanned by light beam in some spectral range nearby the designed wavelength. Light intensity in required diffraction orders is measured and normalized for full intensity of scanning beam.

As a result we receive the DE dependence on the wavelength of tested section in given spectral range. There is a maximum on this distribution. DE maximum depending on wavelength corresponds such wavelength wherein the phase shift on diffraction structure is equal to 2π. Thus we get the phase depth averaged over the measured section of DOE surface. Phase depth F is determined as

$$F = 2\pi \frac{d}{\lambda n},$$

where d is the physical depth profile, λ is the wavelength, n is the refractive index.

Next we may have the distribution of the phase depth over the DOE surface. This distribution we can use to find errors when DOE production.

The DE dependence $\eta(F)$ on the phase depth F for phase profile is determined as follows [4]:

$$\eta(F) = \frac{\mathrm{sinc}^2(F - 2\pi\ \ )}{2} \quad (1)$$

Moreover, the value of the inefficient part of diffraction zones, which has inverted slope relative to the efficient one (back slope), influences on the diffraction efficiency. The influence of the back slope value on the diffraction efficiency may be calculated by:

$$\eta(x) = (1 - \frac{x}{T})^2 \quad (2)$$

where x is the value of the back slope, T is the width of the diffractive zone.

Experiments

DE of the Fresnel lens has been measured by the suggested method. Fresnel lens is the most suitable for applied method testing, because only for given DOE class we can easily measure DE using the scanning method as well as integral one. Integral method of DE measurement implies the DE measurement over the whole DOE surface. DE for Fresnel lens is measured by detecting the light intensity in the focus and comparing it with the whole light intensity.

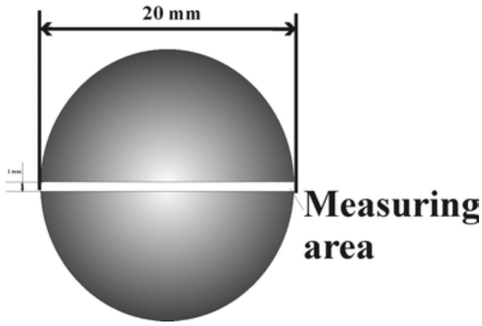

Figure 1. Measuring area of Fresnel lens.

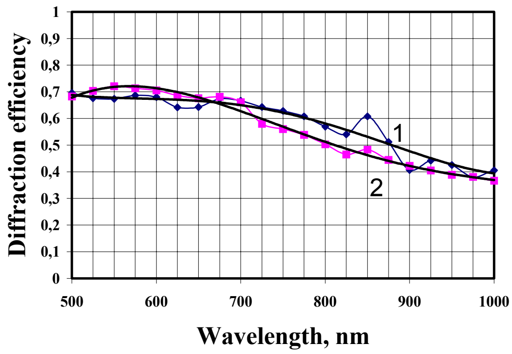

Figure 2. Two dependences of diffraction efficiency for Fresnel lens on wavelength: curve 1 is directly measured diffraction efficiency, curve 2 – diffraction efficiency found by integration of measured data in each point.

Measured Fresnel lens has been fabricated by gray-tone lithography using gray-tone photomask on the basic of LDW-glass [5]. Gray-tone photomask was produced by CLWS [6]. This lens was designed for work in the first diffraction order. Parameters of this lens are the following: focal distance – 150 mm, diameter – 20 mm, designed wavelength – 560 nanometers.

Diffraction efficiency of this Fresnel lens was measured along the diameter (see Figure 1) by scanning method. The width of the scanning beam is 1 mm, scanning step – 1 mm, spectral range – 450 ÷ 1000 nm.

Figure 2 shows DE, received by the data integration using the scanning method (curve 2) and DE, measured by the integral method

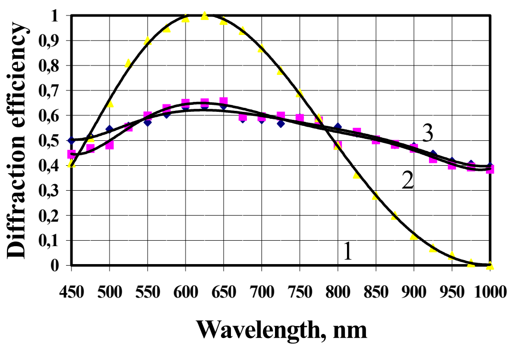

Figure 3. DE of exemplary points. Curve 1 is the theoretical value calculated by (1). Curve 2 and 3 are diffraction efficiency for experimental points of the exemplary Fresnel lens.

(curve 1). The difference of these curves is about 10%. This is because the DE was measured by scanning method not for the whole surface. Therefore scanning method is adequate for DE measurement.

We can use the results of DOE scanning to know their character changes over the DOE area. These data are of great importance for DOE application as well as for the correction of the production process to receive more qualitative DOE.

The DE dependence on wavelength for two nearby points lying near the DOE edge is shown in Figure 3. Comparing these curves one can see that theoretical and experimental data coincide qualitatively. The difference between theoretical and experimental curves is explained by another defects of fabricated profile such as back slope and profile defects inside the working part of diffraction zones.

Figure 4 demonstrates the DE dependence on coordinate for the wavelength equal to 575 nm. As is seen the diffraction zones near the edge of lens have DE less than diffraction zones into the lens. It is important because ring-shaped edge zones have bigger area. Therefore their influence on DE is stronger.

Figure 5 shows the DE dependence on averaged period of diffraction zones. We have taken the maximal diffraction efficiency for each point from the spectral range. Curve 1 represents the experimental data and curve 2 shows theoretical ones calculated by (2). The back slope x is equal to 1,7 micrometers according to the calculation. These curves are almost coinciding. By this is meant that the magnitude of the back slope and phase depth influence on the DE more than other defects of the phase profile.

The distribution of the phase depth on DOE area is important for elimination of defects when DOE production. By scanning on wavelength each point we receive the phase shift of measured points as mentioned above. This dependence is shown in Figure 6. As is seen that phase shift for measured diameter of this lens is differed on $0{,}4\pi$.

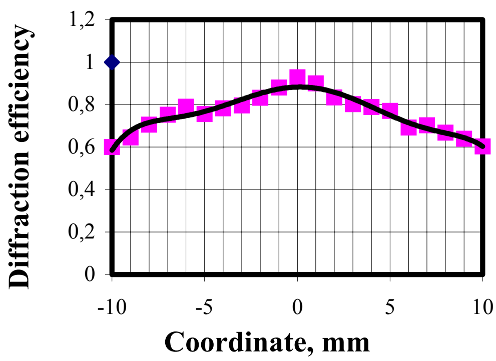

Figure 4.Diffraction efficiency dependence on radius of the exemplary Fresnel lens.

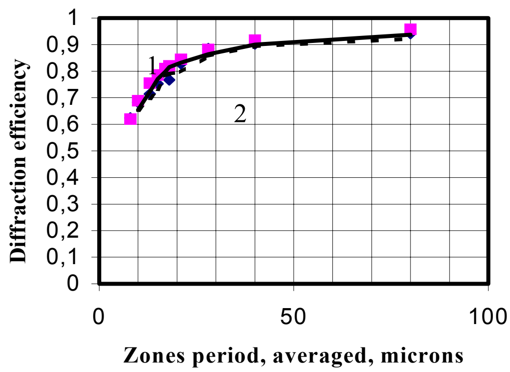

Figure 5. Diffraction efficiency dependence on the zone width. Curve 1 – theoretical curve with back slope equal to1,7 micrometers, curve 2 –averaged experimental data.

Wavelength is 560 nm for phase shift equal to 2π (designed wavelength). This fact

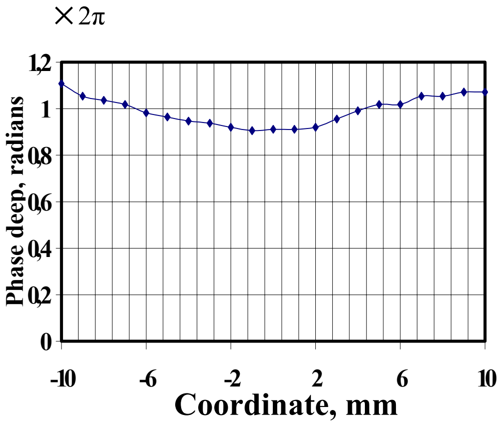

Figure 6. Phase shift dependence on the measuring coordinate

shows the error of the phase depth during production.

Similar measurements have been made for other DOE, so-called axicon [7]. Profile of this DOE was in photoresist. This DOE class has the same diffraction zones in the form of concentric circles. It transforms the plane wavefront to wavefront of conical form. This DOE has been produced by direct laser writing on the CLWS [6]. The size of diffraction zones for this DOE is 15 micrometers. Diameter of this axicon is 40 mm. Maximal diffraction efficiency in each measured point along the diameter is about 0.65 for wavelength 725-nanometer, whereas this element was designed for 632-nanometer wavelength. DE is about 0.45 for measured axicon for 632-nanometer wavelength. Thus it is concluded that error was made during the forming of phase profile relief. The back slope of this profile is about 2.9 micrometers.

Conclusions

Spectral characteristics for the sample Fresnel lens were investigated. Conclusions about some features of phase profile have been done.

The validity of proposed scanning method for the diffraction efficiency inspection of DOE is shown.

DOE efficiency with non-spherical wavefront transformation has been measured. Some conclusions about the features phase profile of this axicon produced by laser writing in photoresist have been done.

References

1. A. Cozanet, J. Fleuret, H. Maitre, M. Rousseau. “Optics and communication”, Moscow, “Mir”, 1984 (Russian)
2. V. Korolkov, V. Koronkevich, A. Malyshev, V. Nikitin, “New fabrication method for diffractive optical elements with deep phase relief”// Proc. of SPIE. 1997. V. 3010. P.180
3. V. P. Kiryanov, “Laser setup for flat optical components fabrication with submicron resolution”, Laser Application Engineering (LAE-96), Vadim P. Veiko, Editor Proc. SPIE, 1997, V. 3091, pp. 66-70
4. T. Fujita, H. Nishihara, J. Koyama, “Blazed gratings and Fresnel lenses fabricated by electron-beam lithography”, Optics Letters. Vol. 7. No. 12. 1982, P. 576.
5. V. Korolkov, A. Malyshev, V. Nikitin, A. Poleschuk, A. Kharissov, V. Cherkashin, C. Wu, “Application of gray-scale LDW-glass masks for fabrication of high-efficiency DOE”. Proc SPIE, V. 3633, 1999, pp. 129-138.
6. V.P. Koronkevich, V.P. Kirianov, V.P. Korolkov, A. G. Poleshchuk, V.V. Cherkashin, E.G. Churin, A.A. Kharissov, "Fabrication of diffractive optical elements by direct laser writing with circular scanning", Proc. SPIE 2363, pp. 290-297 1995.
7. I. A. Mikhaltsova, V. I. Nalivaiko, I. S. Soldatenkov, “Kinoforms axicons”, OPTIK, 1984, Bd 67, N 3, S 267-278.