Elliptic zone plate – investigation of imaging properties

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The main goal of this work was to investigate imaging parameters of zone plate with elliptically shaped zone borders (Fig.1) in numerical way. Such zone plate is characterized by different focusing abilities in meridian and sagittal plane, leading to astigmatism. These properties enable to use it as an aberration corrector in complex optical systems. Also chromatic aberration can be reduced in such optical systems. The potential application of elliptic zone plate is to correct astigmatism of human eye as astigmatic spectacle lenses and intraocular astigmatic lenses.

1 Introduction

Diffraction optical elements become more and more popular. New constructions of such elements are developed. Typical zone plate used for optical imaging is an element with zone borders of circular shape. Change in their shape offers another imaging properties. Elliptical shape causes astigmatism, it means – two different foci are observed.

2 Material and Methods

Elliptic zone plate is numerically designed similarly to holographic lens. It is based on interference of spherical waves originating from points *Pa* and *Pb* (with coordinates *za* and *zb*, respectively) located on optical axis . Next two parameters are *a* and *b* - coefficient of axes scaling (*a*x* and *b*y*). Formulas to design the fringes and their spatial frequency in *x* and *y* direction are given below (1-3):

$$\frac{2\pi}{\lambda}\left(R_a - R_b\right) = m \cdot 2\pi$$

$$R_a = signum(za)\cdot\sqrt{(a\cdot x)^2 + (b\cdot y)^2 + za^2}$$

$$R_b = signum(zb)\cdot\sqrt{(a\cdot x)^2 + (b\cdot y)^2 + zb^2} \qquad (1)$$

$$D_x = \frac{\lambda}{\left(\frac{1}{R_a} - \frac{1}{R_b}\right)\cdot a^2 x} \qquad (2)$$

$$D_y = \frac{\lambda}{\left(\frac{1}{R_a} - \frac{1}{R_b}\right)\cdot b^2 y} \qquad (3)$$

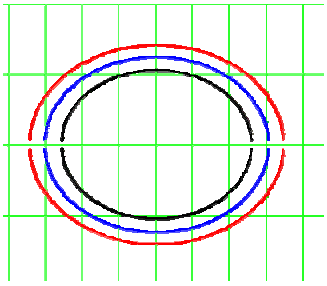

Fig. 1 *Elliptically shaped zone borders*

The imaging properties of elliptic zone plate depend on local spatial frequencies *Dx* and *Dy* values according to the formula (values of *Dx* and *Dy* are taken as *D*) (4):

$$n'\cdot\sin(i') - n\cdot\sin(i) = \frac{\lambda}{D} \qquad (4)$$

Where *i*- angle of incident ray, *i'*- angle of refracted ray, *n*, *n'*-indexes of refraction.

Analysis is based on spot diagrams observations and quantitative evaluation of spot.

3 Results

Two projects of elliptic zone plate were examined.

First: for *za*=-200 and *zb*=200 (Fig.2)

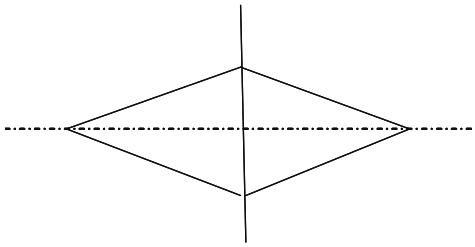

Fig. 2 *Illustration of imaging of first zone plate project*

Second: for *za*=-∞ and *zb*=100 (Fig.3)

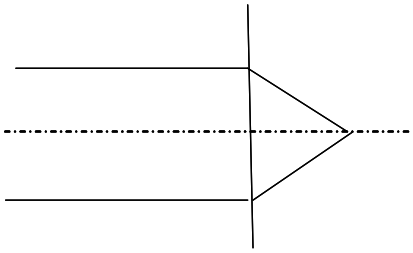

Fig. 3 *Illustration of imaging of second zone plate project*

There are two foci observed. One of them called meridian is recognized in spot diagram as thin vertical line, and second - sagittal - as thin horizontal line.

3.1 Test for object point on the optical axis

a=0,972 b=1,035 *Za=-200 zb=200*	*a=0,976 b=1,026* *za=-∞ zb=100*
zi=175	zi=95
zi= 225	zi=105

Tab. 1 *Test for object point on the optical axis (1)*

a=1,035 b=0,972 *Za=-200 zb=200*	*a=1,026 b=0,976* *za=-∞ zb=100*
zi=175	zi=95
zi= 225	zi=105

Tab. 2 *Test for object point on the optical axis (2)*

3.2 Test for object point outside of the optical axis

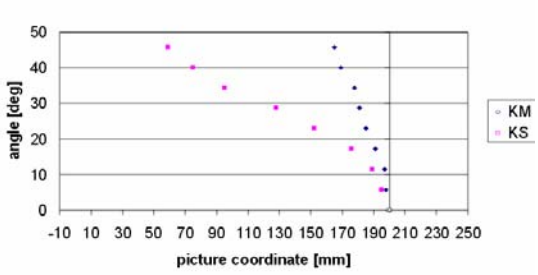

Fig. 4 *Results for a=1 b=1(typical zone plate – circular shape of fringes), za=-200 zb=200*

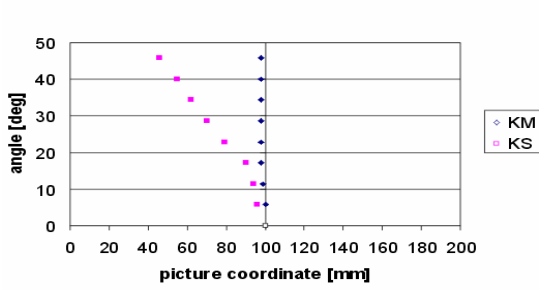

Fig. 5 *Results for a=1 b=1 (typical zone plate — circular shape of fringes), za=-∞ zb=100*

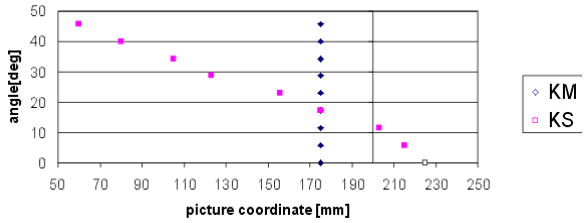

Fig. 6 *Results for a=1,035 b=0,972 za=-200 zb=200*

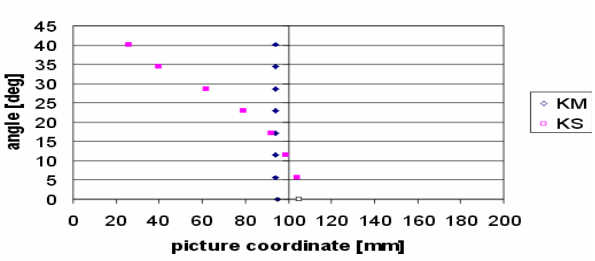

Fig. 7 *Results for a=1,026 b=0,976 za=-∞ zb=100*

4 Conclusion

Observed properties of elliptic zone plate show a dependence between parameters of its construction and imaging quality. Figures 4-7 show differences of imaging for two projects of plate with different shapes of fringes (circles – Fig.4-5 and ellipse – Fig. 6-7). Elliptic shape of fringes causes substantial astigmatism.

References

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