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# MODELING THE INFLUENCE OF ABERRATIONS ON THE FORMATION OF LAGUERRE-GAUSSIAN BEAMS

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The purpose of this work is to numerically study the effects of primary wavefront aberrations on Laguerre-Gaussian beams (LG). To obtain the required beam's characteristics, various optical systems are used, including elements that can cause wavefront aberrations, which significantly complicates the development of optical systems and leads to the importance of a detailed study of aberrations, as well as to the identification of an assessment of the capabilities of the systems.

LG modes are paraxial light fields with a radially symmetric intensity form, modes of resonators and optical waveguides with a parabolic refractive index, and also retain their structure up to scale during propagating in free space and passing through lenses. The LG modes can be described by two indices: the radial index p and the azimuthal index $k$, which is also associated with a vortex phase structure.

The wave front described by one Zernike function can be represented by the expression:

$$g_{mn}(r,\varphi) = \exp[ib_{nm}Z_n^m(r,\varphi)],$$

where $b_{nm}$ – polynomial coefficient, $Z_n^m(r,\varphi)$ – Zernike polynomial of order (*n*, *m*).

The Zernike polynomial $Z_n^m(r,\varphi)$ is defined as:

$$Z_n^m(r,\varphi) = \sqrt{\frac{n+1}{\pi r_0^2}} R_n^m(r) \begin{Bmatrix} cos(m\varphi) \\ \sin(m\varphi) \end{Bmatrix},$$

where $R_n^m(r)$ is radial Zernike polynomial, $R_n^m(r) = \sum_{p=0}^{(n-m)/2} \frac{(-1)^p (n-p)!}{p!\left(\frac{n+m}{2}-p\right)!\left(\frac{n-m}{2}-p\right)!} \left(\frac{r}{r_0}\right)^{n-2p}$.

Wavefront aberration applied to LG modes can be described by multiplying the complex amplitude of the LG mode and the expression for

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one Zernike function. Each Zernike polynomial corresponds to a certain aberration. The superposition of Zernike functions is also used to represent the aberrations. In this work, the influence of aberrations on the formation of LG modes is performed by analyzing the point spread function (PSF) in the focal plane of the lens. It's known that using a lens in optics, the Fourier transform is performed: in coherent light, the distribution of the light amplitude in the rear focal plane of the lens can be represented as a two-dimensional complex Fourier transform of the distribution function of the light amplitude in the front focal plane.

a) b)

Figure 1 – The intensity distribution of the LG beam ($p, k$) in the focal plane of the lens: $(4,0)$, $w_0 = 0.391$ mm, $z = 0$; a) – original field, b) – after applying OX distortion.

In figure 1 we can see the intensity distribution of the LG beam in the focal plane of the lens without and after applying OX distortion. The simulation results showed that the presence of distortion leads to a deviation of the beam propagation relative to the center.

a) b)

Figure 2 – The intensity distribution of the LG beam ($p, k$) in the focal plane of the lens: $(2,3)$, $w_0 = 0.391$ mm, $z = 0$; a) – original field, b) – after applying astigmatism $Z_2^2$

As we can see, the presence of astigmatism significantly affects the formation of LG modes. In result, the LG beam is transformed into the Hermite–Gaussian mode. Adding an even or odd Zernike function affects the angle of inclination of the output beam.

a) b)

Figure 3 – The intensity distribution of the LG beam ($p, k$) in the focal plane of the lens: $(4,0)$, $w_0 = 0.391$ mm, $z = 0$; a) – original field, b) – after applying coma $Z_3^1$

According to the modeling, the addition of coma leads to a violation of the symmetry of the LG beam and distortion of the shape of the rings.

In the present work we have studied the primary wavefront aberrations, classical Laguerre–Gaussian modes and the changes in their properties depending on the aberration. It was shown that when astigmatism is applied, the LG mode transforms into the Hermite-Gaussian mode. When coma is added, the beam loses its shape and can no longer be considered a mode. After applying distortion, the mode shifts relative to the center. In real optical systems, a combination of all aberrations is observed, and studding the individual types of aberrations facilitates the analysis of the phenomenon.