Simulation of diffraction of vortex beams on curvilinear diffraction gratings

A.B. Dubman

Introduction

Optical vortex (OV) beams [1] are effectively used in the capture and manipulation of microparticles [2] and optical communications [3]. In these applications, for example, when multiplexing optical information transmission channels [4], it is necessary to simultaneously form several OV beams of different orders.

Recently, there have been several publications initiated to research of the formation and dissemination of optical vortices [5].

In this work, on the basis of numerical simulation, we study the diffraction of vortex beams on curved fork-shaped gratings, including those outside the focal plane.

Simulation of vortex beam diffraction

A phase-optical element with a complex transfer function was chosen to create "curved fork" gratings. This element looks like this [6]:

$$\tau(r,\varphi) = e^{i\alpha r + im\varphi} e^{i\beta r\cos(\varphi)}, r < R \qquad (1)$$

where $e^{i\alpha r + im\varphi}$ is the helix axicon that forms the m-order of the Bessel vortex beam; $e^{i\beta r\cos(\varphi)} = e^{i\beta x}$ is a prismatic constituent, which satisfies to the linear bearing. It deviates the beam from the optical axis.

In further simulation results, we will apply the binary equivalent of the diffractive element (2). It is characterize as follows:

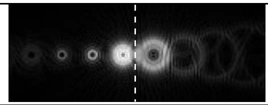
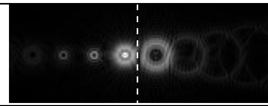
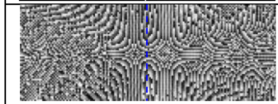
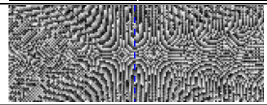
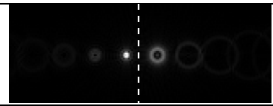
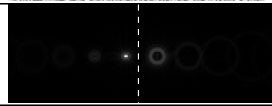
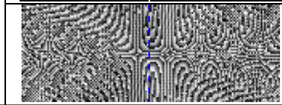
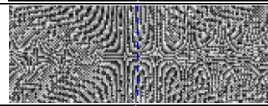
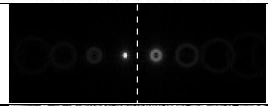
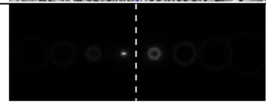
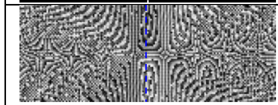
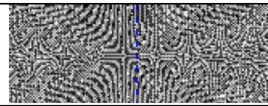
$$\tau(r,\varphi) = e^{i\frac{\pi}{2}(sgn[\cos(\alpha r+\beta r\cos(\varphi)+m\varphi)]-1)}, r < R. \qquad (2)$$

In [41], the shaping of a kit of vortex conical beams was considered using a DOE with a complex transmission function (2). In this article, we analyze the diffraction by DOE (2) of vortex beams of the form $e^{im_0\varphi}$. In this case, when modeling, a field of the form is considered as an input field:

$$\tau_*(r,\varphi) = \tau(r,\varphi)\cdot e^{im_0\varphi}. \qquad (3)$$

The succeeding parameters were taken in the simulation: incident radiation wavelength λ=532 nm, element radius R = 1 mm, lens focus f = 800 mm. Simulation results of vortex beam diffraction on binary curvilinear gratings described by equation (2) are shown in Table II. Calculation options: *m*=1, $\alpha = 5$ mm^{-1}, $\beta = 30$ mm^{-1}, as well as the results of the construction calculated by (3) for $m_0 = 1$.

TABLE I. OUTCOMES OF SIMULATION THE DIFFRACTION OF VORTEX BEAMS ON CURVILINEAR DIFFRACTION GRATINGS FOR M= 1 AND M$_0$= 1

	Amplitudes and phases of the field $\tau(r,\varphi)$ at different z	Amplitudes and phases of the field $\tau_*(r,\varphi)$ at different z
z= 400 mm		
		
z= 1000 mm		
		
z= 2000 mm		
		

In Table I, we observe a correlation peak. In this case, the calculated grating makes it possible to detect the availability of a vortex phase in the illuminative beam of the 1st order from the correlation peak.

Conclusion

Scrutinize of the diffraction of vortex beams on binary curvilinear diffraction gratings showed the possibility of detecting the vortex order outside the focal plane. We can understand from the outcomes that correlation peaks are observed only for odd positive values of m0. This is due to the well-known fact that binary gratings form only odd diffraction orders [7] if the band widths are the same.

References

[1] A. P. Porfirev, A. A. Kuchmizhak, S. O. Gurbatov, S. Juodkazis, S. N. Khonina, and Yu. N. Kul'chin, "Phase singularities and optical vortices in photonics," Phys. Usp., vol. 8, July 2021.

[2] M. J. Padgett, and R. Bowman, "Tweezers with a twist,' Nat Photon, vol. 5, pp. 343–348, May 2011.

[3] S. V. Karpeev, V. V. Podlipnov, N.A. Ivliev, and S.N. Khonina, "High-speed format 1000BASE-SX/LX transmission through the atmosphere by vortex beams near IR range with help modified SFP-transmers DEM-310GT," Computer Optics, vol. 44 (4), pp. 578–581, July 2020.

[4] S. V. Karpeev, V. S. Pavelyev, V. A. Soifer, S. N. Khonina, M. Duparre, B. Leudge, and J. Turunen, "Transverse mode multiplexing by diffractive optical elements," Proc. SPIE, vol. 5854, pp. 1–12, June 2005.

[5] S. N. Khonina, N. L. Kazanskiy, S. V. Karpeev, and M. A. Butt, "Bessel Beam: Significance and Applications–A Progressive Review," Micromachines, vol. 11(11), pp. 997, October 2020.

[6] S. N. Khonina, A. V. Usinov, M. S. Kirilenko, A. A. Kuchmizhak, and A.P. Porfirev, "Application of a binary curved fork grating for the generation and detection of optical vortices outside the focal plane," J. Opt. Soc. Am. B, vol. 37, pp. 1714–1721, May 2020.

[7] S. N. Khonina, and A. V. Ustinov, "Binary multi-order diffraction optical elements with variable fill factor for the formation and detection of optical vortices of arbitrary order," Applied Optics., vol. 58(30), pp. 8227–8236, October 2019.

ИСОИ РАН [1] IMAGE PROCESSING SYSTEMS INSTITUTE
151, Molodogvardeyskaya st., Samara, Russia (www.ipsi.smr.ru)

САМАРСКИЙ УНИВЕРСИТЕТ SAMARA UNIVERSITY [2] SAMARA NATIONAL RESEARCH UNIVERSITY
34, Moskovskoye shosse, Samara, Russia (www.ssau.ru)