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Generation of generalized spiraling Bessel beams by a curved fork-shaped hologram with Bessel-Gaussian laser beams modulated by a Bessel grating

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ABSTRACT

In this paper, we investigate the creation of a new type of laser beams family by illuminating a curved fork-shaped hologram, with an input Bessel Gaussian beam modulated by a Bessel grating. The theoretical and the numerical results showed that, at the output plane, a high order spiraling Bessel beam is produced. The analytical expressions of the diffracted wave field amplitude and intensities are calculated and analyzed using the stationary phase method. The numerical simulations are given to illustrate our analytical results for different parameters.

1. Introduction

In recent years, the light beams with optical vortices have been the main subject and become very important in optical micromanipulation and trapping of particles [1]. The possibility of transformation of the optical vortex diverging beam into nondiverging (“nondiffracting”) beam by the use of a phase spiral plate (SPP) was recognized by Khonina et al. [2]. The helical axicon is a hybrid of an axicon and a phase spiral plate. It was proposed for the first time and manufactured by means of photolithographic process by Khonina et al. [3]. In 2007, Kotlyer et al. [4] represent the optical vortex beam generated in the process of Fraunhofer diffraction of a plane wave and Gaussian beam, as well as Fresnel diffraction of a Gaussian beam by the Helical Axicon (HA). Furthermore, the transformation of the Gaussian wave field by a fork-shaped hologram has been studied in Refs. [5,6]. Additionally, the analytical expression of Fresnel and Fraunhofer diffractions for a Gaussian beam, diffracted by the fork-shaped gratings, have been described by Janicijevic and Topuzoski [7]. The fork-shaped holograms are applied in the optical manipulation of micrometer-sized particles, for instance, Mair et al. [8] employed them for estimation of the topological charge of the optical vortices. On the other hand, Paterson et al. [9] have demonstrated the high-order Bessel waves produced by axicon type computer-generated holograms. Furthermore, high-order Bessel beam, which can be formed with the help of an axicon irradiated by a fundamental Gaussian beam, have been discussed in Refs. [10,11]. Recently, Topuzoski et al. [12,13] have studied the transformation of higher order Laguerre-Gaussian beam (LGB) into a Bessel beam by the use of the HA. L. Stoyanov et al. [14] have confirmed experimentally the transformation of the topological charge

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of the incident vortex beam by a fork-shaped grating. Earlier, Vijayakumar et al. [15] have proposed a design to generate the high-order Bessel beam by the binary phase spiral axicon and a Fresnel zone lens. More recently, in 2016, S. Topuzoski. [16] have studied the generation of optical vortices for a Gaussian beam diffracted by using a curved fork-shaped hologram. Generations of the generalized spiraling Bessel beam of arbitrary order, by a curved fork-shaped hologram, have obtained in Ref. [17]. Ebrahim et al. [18] have been studied the theoretical conversion of the Hypergeometric-Gaussian beams into high-order spiraling Bessel-beams by a curved fork-shaped hologram. More freshly, El Halba et al. [19] have proposed the creation of a generalized spiraling Bessel beam by Fresnel diffraction of a Bessel-Gaussian laser beam. To our knowledge, the Bessel–Gaussian beams modulated by Bessel gratings (BGMBG) beams, presented in the previous paper [20], is discussed in the scalar form. On the other hand, El Halba et al. [21] have studied, the focus shaping of the cylindrically polarized BGMBG beam by a high numerical-aperture lens by vector diffraction theory. To our best knowledge, the creation of a generalized spiraling Bessel beam (GSBB) by Fresnel diffraction of a Bessel-Gaussian beam modulated by a Bessel grating (BGMBG) by Curved fork-shaped hologram (CFH) has not been studied before.

In the current work, we study for the first time the creation of generalized spiraling Bessel beams by Fresnel diffraction of BGMBG. The rest parts of the paper are organized as follows: The analytical expression of the intensity distribution of generalized spiraling Bessel beam is derived by using the stationary phase method established in Section 2. Some particular cases will be treated and discussed in Section 3. In Section 4, we present the numerical simulations and discuss our results. Finally, a simple conclusion is outlined in the end of the work.

2. Creation of the generalized spiraling bessel beam

In this paper we study in the process of the Fresnel diffraction a computer generated hologram interfering by an optical vortex wave, whose wave front corresponds to the phase retardation of the helical axicon, and a tilted plane wave [16]. The first interfering vortex beam with a constant real amplitude A_1, can be written as follows

$$U_1(r,\phi,z) = A_1 \exp\left[i\left(kz - \alpha r + p\phi\right)\right] , \tag{1}$$

and for the second beam, the plane wave with real amplitude A_2 can be described as

$$U_2(r,\phi,z) = A_2 \exp\left[i\left(kz + k_x r\cos(\phi)\right)\right] , \tag{2}$$

where r, φ and z are the cylindrical coordinates. The axicon parameter $\alpha = k(n_r\text{-}1)\gamma$ is connected to its refractive index n_r for incident beam of wavelength λ and its internal angle γ (the angle on the axicon base), and k is the wave number. The integer p is the topological charge of the HA and $k_x = 2\pi\,\sin(\varepsilon)/\lambda$ denotes the wave vector component along x axis with an angle ε. In the plane $z = 0$, the interferogram intensity distribution will be

$$I(z=0) = A_1^2 + A_2^2 + 2A_1A_2\,\cos(\alpha r - p\phi - k_x r\cos(\phi)). \tag{3}$$

When the interference pattern is computer generated, the lines of maximum phase values defined by: $\alpha r\text{-}p\varphi - k_x r\cos(\varphi)$= $2n\pi$ ($n = 0, \pm1, \pm2,\ldots\ldots$) and shown in Fig. 1 for two values of γ and the parameters $A_1 = A_2 = 1$, $p = 3$, $n_r = 1.48$ and λ=810 nm. Fig. 1(a) describes the hologram with topological charge $p = 3$ and null angle axicon $\gamma = 0°$. This Fig. shows a clear forking shape. Fig. 1(b), shows that the curved fork-shaped hologram is formed when γ is different from zero. We will define

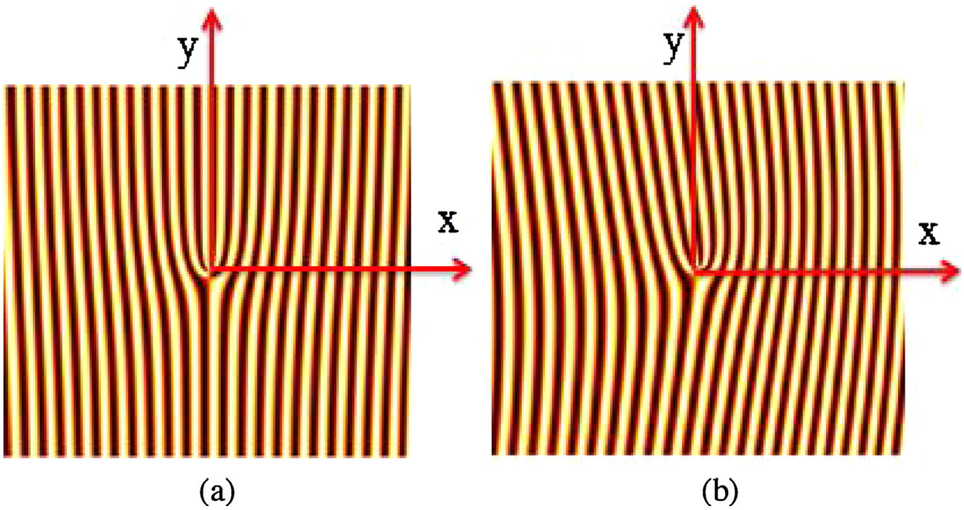

Fig. 1. Transverse intensity at $z = 0$ for (a) fork shaped hologram at $\gamma = 0°$, for (b) curved fork shaped hologram at $\gamma = 1.55°$.