Optik 157 (2018) 93–98

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Full length article

Focusing properties of radially polarized helico-conical Lorentz-Gauss beam with radial phase wavefront

Zhenyi Zhang[a,b], Yu Miao[a], Guanxue Wang[a], Guorong Sui[a], Xiumin Gao[a,*]

[a] School of Optical-Electrical and Computer Engineering, University of Shanghai for Science and Technology, Shanghai 200093, China
[b] The Third Research Institute of Ministry of Public Security, Shanghai 200031, China

ARTICLE INFO

Article history:
Received 13 September 2017
Accepted 8 November 2017

Keywords:
The focusing properties
Radial phase wavefront
Helico-conical Lorentz-gauss beam
Radial phase parameter

ABSTRACT

Radially polarized helico-conical Lorentz-gauss beam with radial phase wavefront modulation can change the optical properties of the focal region in focusing optical system, which has tremendous research significance and application value in a host of territories, such as exotic optics, optical micromanipulation and so on. In this paper, by the utilization of the vector diffraction theory, the focusing properties of radially polarized helicon-conical Lorentz-Gauss beam with radial phase wavefront are investigated theoretically and numerically. Results show that focus shift is considerably influenced by changing the charge number m, eccentric parameter K, the numerical aperture NA and the radial phase parameter n, and simultaneously, unconspicious changes can be observed if we only alter the radial phase parameter m without the changes of m, K or the numerical aperture NA.

1. Introduction

On account of some peculiar characteristics and wide application foreground, the vector optical is developing rapidly in the optical field [1–5], and scientists are constantly trying to digging more and more unknown secrets that have a great impact on human beings. Lorentz-gauss beam as a kind of widely vector beams have been used in different field, the properties of Lorentz-gauss beam had been analyzed by so many researchers. Gao et al. did some interesting and significant researches on the properties of Lorentz- Gauss beam by analyzing the variations of the physical parameters m, NA, n, K that present variations of the modulation of phase wavefront, and there were so many novel and interesting phenomena appeared when the parameters changed [6–11]. In recent years, a new kind of beam has been invest- tigated that is known as Helico –conical beam, which can produce many novel propagating and focusing properties, eapecially the Helico –conical Lorentz-gauss beam. Such as, Bareza N and the co-authors analyzed the propagation dynamics of vortices in helico-conical optical beams [12]. Shen et al. analyzed the focusing of helico-conical cosh-Gauss beam [13]. N. Hermosa and the co-author given the Helico-conical optical beams self-heal [14]. In addition, Miao, Gao et al. have done some remarkable work on the focusing properties of radially polarized helico- conical Lorentz-Gauss beam [15].

In this article, focusing properties of radial varying polarized helico-conical Lorentz-Gauss beam with radial phase modulation are investigated in detail. In Section 2, the principle of the focusing system is given. Simulation results and discussions are shown in Section 3. Conclusions are summarized in Section 4.

* Corresponding author.
E-mail address: gxm@usst.edu.cn (X. Gao).

https://doi.org/10.1016/j.ijleo.2017.11.059

2. Radially polarized Helico-conical Lorentz-Gauss beam with radial phase wavefront

The wavefront of radially polarizedHelico-conical Lorentz-Gaussian vortex beamis in the form of,

$$\psi(r,\varphi) = m\varphi\left(K - r/\mathrm{r}_0\right) = \exp\left[im\varphi\left(\mathrm{K}\frac{\sin\theta}{NA}\right)\right] \tag{1}$$

Where m, the charge number of the optical vortex, is an integer that determines the number of 2π-phase shifts that occur across one revolution of the azimuthal angle, φ. K is a constant that takes a value of 1. r_0 is a normalization factor of the radial coordinate, r. According to variables and coordinate transformations, the focusing radially polarized Helico-conical Lorentz-Gaussian beam radial phase wavefront can be determined as [16–19],

$$E_0\left(\theta,\varphi\right) = \exp\left[-\frac{\cos^2(\varphi)\cdot\sin^2\left(\theta\right)}{NA^2\cdot w_x^2}\right]\cdot\frac{1}{1+\frac{\sin^2(\varphi)\cdot\sin^2(\theta)}{NA^2\cdot\gamma_y^2}}$$

$$\cdot\exp\left[im\varphi\left(K - \frac{\sin\theta}{NA}\right)\right]\cdot\exp\left[i\pi\cdot\sin(n\cdot\theta)\right] \tag{2}$$

As mentioned by Eq. (2), $w_x = \omega_0/r_p$ is called relative beam waist in y coordinate direction and also called as relative Gauss parameter. $\gamma_y = \gamma_0/r_p$ is addressed as the relative beam waist in x coordinate direction, which is also named as the relative Lorentz parameter, r_p is the outer radius of optical aperture in focusing system. The $1/e$-width of the Gaussian distribution and the half width of the Lorentzian distribution are defined as ω_0 and γ_0 respectively. NA is the numerical aperture of the focusing system and $\vec{r}$ is vector unit of the radial coordinate. n is the radial phase parameter that indicates the change frequency of phase along radial direction.

According to vector diffraction theory, the electric field in focal region of radially polarized Lorentz-Gaussian vortex beam with sine-azimuthal variation wavefront is [20–22],

$$\vec{E}(\rho,\phi,z) = E_\rho\vec{e}_\rho + E_\phi\vec{e}_\phi + E_z\vec{e}_z \tag{3}$$

Where $\vec{e}_\rho$, $\vec{e}_\phi$, and $\vec{e}_z$ are the unit vectors in the radial, azimuthal, and propagating directions, respectively. Cylindrical coordinates (ρ,ϕ,z) with origin $\rho = z = 0$ located at the paraxial focus position are employed. E_ρ, E_ϕ, and E_z are amplitudes of the three orthogonal components and can be expressed as [22,23]

$$E_\rho(\rho,\phi,z) = \frac{-iA}{\pi}\int_0^\alpha\int_0^{2\pi}\sqrt{\cos\theta}\cdot\sin\theta\cos\theta\cos(\varphi-\phi)$$

$$\cdot\exp\left[-\frac{\cos^2(\varphi)\cdot\sin^2\left(\theta\right)}{NA^2\cdot w_x^2}\right]\cdot\frac{1}{1+\frac{\sin^2(\varphi)\cdot\sin^2(\theta)}{NA^2\cdot\gamma_y^2}}$$

$$\cdot\exp\left[i\pi\cdot\sin(n\cdot\theta)\right]\cdot\exp\left[im\varphi\left(K-\frac{\sin\theta}{NA}\right)\right]$$

$$\cdot\exp\left\{ik\left[z\cos\theta+\rho\sin\theta\cos(\varphi-\phi)\right]\right\}d\varphi d\theta \tag{4}$$

$$E_\phi(\rho,\phi,z) = \frac{-iA}{\pi}\int_0^\alpha\int_0^{2\pi}\sqrt{\cos\theta}\cdot\sin\theta\cos\theta\sin(\varphi-\phi)$$

$$\cdot\exp\left[-\frac{\cos^2(\varphi)\cdot\sin^2\left(\theta\right)}{NA^2\cdot w_x^2}\right]\cdot\frac{1}{1+\frac{\sin^2(\varphi)\cdot\sin^2(\theta)}{NA^2\cdot\gamma_y^2}}$$

$$\cdot\exp\left[i\pi\cdot\sin(n\cdot\theta)\right]\cdot\exp\left[im\varphi\left(K-\frac{\sin\theta}{NA}\right)\right]$$

$$\cdot\exp\left\{ik\left[z\cos\theta+\rho\sin\theta\cos(\varphi-\phi)\right]\right\}d\varphi d\theta \tag{5}$$