Optik 127 (2016) 6961–6969

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Average intensity properties of flat-topped vortex hollow beam propagating through oceanic turbulence

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ARTICLE INFO

Article history:
Received 8 March 2016
Accepted 28 April 2016

Keywords:
Oceanic turbulence
Laser propagation
Flat-topped vortex hollow beam

ABSTRACT

The average intensity for flat-topped vortex hollow beam propagating through oceanic turbulence is studied analytically based on the extended Huygens-Fresnel diffraction integral formula and the spectrum of oceanic turbulence. It is found that the beam propagation in oceanic turbulence will lose its initial dark hollow center with the propagation distance increasing; and the beam order N, the topological charge M and the parameters of oceanic turbulence affect the evolution properties of flat-topped vortex hollow beam propagating through oceanic turbulence.

1. Introduction

In the recent years, much work has been done to study the evolution properties of laser beams propagation through turbulent oceanic turbulence due to its potential application in underwater optical wireless communication and imaging systems [1–9]. Since the power spectrum of oceanic turbulence is introduced, the evolution properties of laser beam propagation through an ocean have been widely studied. The polarization evolution properties of stochastic beam propagating in turbulent clear-water ocean based on the extended Huygens-Fresnel principle and the unified theory of coherence and polarization of light, has been obtained [2]. The average intensity, the degree of polarization and coherence properties for partially coherent radially polarized doughnut beam propagating through turbulent ocean [3] have been studied. The propagation of Gaussian Schell-model vortex beams [4], stochastic electromagnetic vortex beam [5], Gaussian array beam [6], partially coherent flat-topped vortex hollow beam [7], partially coherent Hermite-Gaussian linear array beam [7], Gaussian array beam [8–11], multimode laser beams [12], multi-Gaussian Schell-model beams [13], propagating through oceanic turbulence have been obtained by using the numerical examples. However, to the best of our knowledge, there has been no analysis about the average intensity properties of flat-topped vortex hollow beam propagating through oceanic turbulence. In this work, we mainly investigate the average intensity of flat-topped vortex hollow beam in oceanic turbulence.

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http://dx.doi.org/10.1016/j.ijleo.2016.04.142

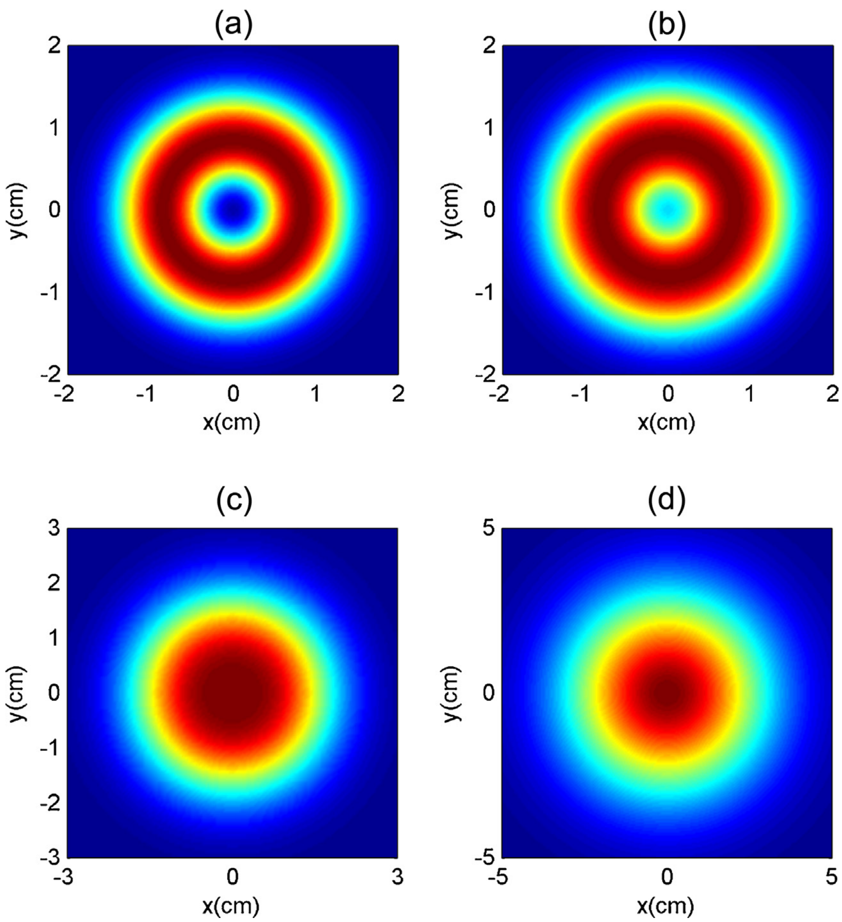

Fig. 1. Contour graphs of normalized average intensity for circular flat-topped vortex hollow beam propagating in oceanic turbulence. (a) $z = 100$m, (b) $z = 200$m, (c) $z = 400$m, (d) $z = 800$m.

2. Flat-topped vortex hollow beam propagating in oceanic turbulence

In the Cartesian coordinate system, the elliptical flat-topped vortex hollow beam propagation along the z-axis in the source plane can be written as [14]:

$$E(r_0, 0) = \sum_{n=0}^{N} \frac{(-1)^{n-1}}{N} \binom{N}{n} \exp\left[-n\left(\frac{x_0^2}{w_x^2} + \frac{y_0^2}{w_y^2}\right)\right] \left(\frac{x_0}{w_x} + i\frac{y_0}{w_y}\right)^M \quad (1)$$

where N is the order of the elliptical flat-topped vortex hollow beam, M is the topological charge, $\binom{N}{n}$ denotes the binomial coefficient, w_x and w_y are the beam width at x and y direction; and when $w_x = w_y$, the elliptical beam will become the circular beam.

According to the extended Huygens-Fresnel principle, the spectral density of laser beams propagating through the oceanic turbulence can be expressed as follows [2–10]:

$$\begin{aligned} W(\boldsymbol{r}_1, \boldsymbol{r}_2, z) = {} & \frac{k^2}{4\pi^2 z^2} \iiint\int_{-\infty}^{+\infty} W_0(\boldsymbol{r}_{10}, \boldsymbol{r}_{20}, 0) \\ & \times \exp\left[-\frac{ik}{2z}(\boldsymbol{r}_1 - \boldsymbol{r}_{10})^2 + \frac{ik}{2z}(\boldsymbol{r}_2 - \boldsymbol{r}_{20})^2\right] \\ & \times \langle \exp\left[\psi(\boldsymbol{r}_{10}, \boldsymbol{r}_1) + \psi^*(\boldsymbol{r}_{20}, \boldsymbol{r}_2)\right] \rangle d\boldsymbol{r}_{10} d\boldsymbol{r}_{20} \end{aligned} \quad (2)$$