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The propagation characteristics of the conical hollow beams in the turbulent atmosphere

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ABSTRACT

In this paper, by using the Collins formula and the Rytov method, the model used to descript the propagation properties of the conical hollow beams(CHBs) in the turbulent atmosphere is firstly constructed and the simulation is made by the numerical method. The results show that the initial transmission angle has important influence on the propagation properties. Beside these, the index structure constant and the order number also can influence the transverse intensity distribution. So according to the model, the intensity distribution of the conical hollow beams in the turbulent atmosphere can be controlled by adjusting these parameters.

1. Introduction

With the development and application of laser technology, hollow beams with zero intensity in its center were widely applied in biology, laser processing, atomic cooling, etc. [1–3]. Up to now, the hollow laser beams with different intensity distributions were generated by different methods [4–12], and there are several mathematic models have been used to describe the hollow beams, for example, the TEM_{01}^{*} beam [13], the high-order Bessel beam [14], and the Laguerre–Gaussian modes [15]. Beside these, the propagation characteristics of laser beams in the atmosphere is very important for remote sensing, tracking and long distance optical communication applications. In the last decade, the properties of laser propagation was aroused extensive attention due to the application of laser communications, and the hollow beams has also been become the object of attention because of it is a special kind of higher-order laser beams. The propagation properties of controllable dark hollow beams and vortex hollow beams in the free space was researched using the ABCD transfer matrix [16,17], the propagation properties of inverse-Gaussian beams was researched using the diffraction integral theory [18], and the elliptical symmetry hollow beams, the double half-Gaussian hollow beams, and partially coherent hollow beams also had been studied [19–21]. Most recently, the propagation properties of partially coherent anomalous hollow beams [22], controllable hollow flat-topped beams [23], were also investigated. However, all the reported propagation properties of the hollow beams are under the condition of the divergence angle is zero at the initial position, except the propagation properties of the conical double-half Gaussian beams in the free space has been reported [24], without any other papers about the influence of divergence angle to the propagation properties have been researched. In this paper, the model used to descript the propagation properties of the conical hollow beams(CHBs) in the turbulent atmosphere is firstly constructed and the propagation properties is made by the numerical method.

2. The model of conical hollow beams in the turbulent atmosphere

The electric field of the CHBs at the original plane z=0 can be expressed as follows [25]:

$$E_n(r,0)=\sum_{n=1}^{N}\frac{(-1)^{n-1}}{N}\binom{N}{n}\left[\exp\left(-\frac{nr^2}{\omega_0^2}\right)-\exp\left(-\frac{nr^2}{\upsilon_0^2}\right)\right] \tag{1}$$

where N (N=1,2,3,4…) stands for the order number of the CHBs, $\binom{N}{n}$ is the binomial coefficient, $\omega=\omega_0\sqrt{1+\frac{(\theta\times z)^2}{\omega_0^2}}$ is the spot radius at the propagation distance z basing on the geometrical optics, and ω_0 is mainly the beam waist width at the initial position, θ is the divergent angle of the CHBs, $\upsilon=\gamma\omega_0$ and $\gamma<1$.

Under the paraxial condition, propagation of Gaussian beams in paraxial optical system conforms to the Collins formula, and the Collins formula in cylindrical coordinate system of rotational

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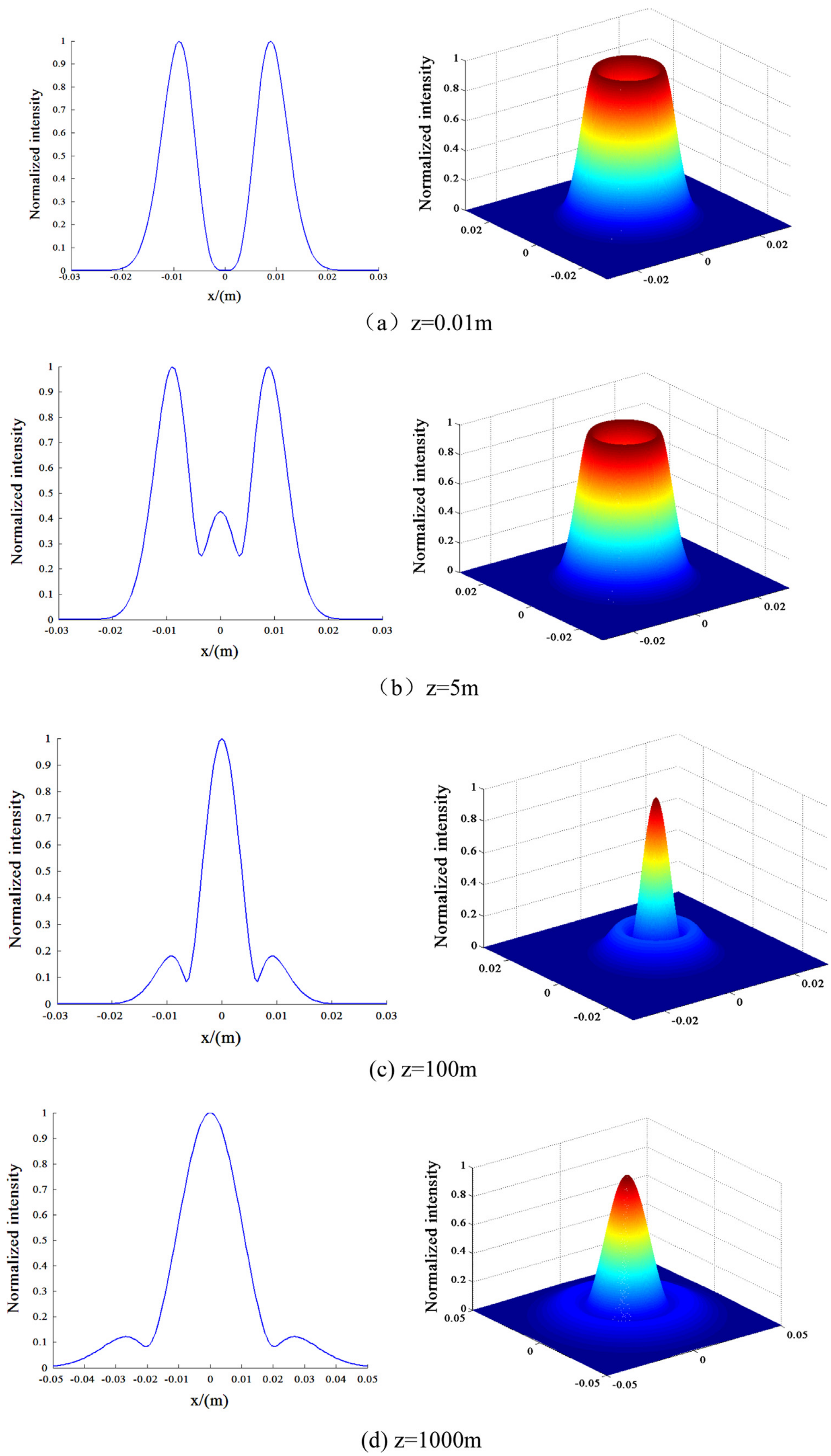

Fig. 1. The propagation properties of hollow beams in turbulent atmosphere when $\theta=0$. (a) z=0.01 m, (b) z=5 m, (c) z=100 m, (d) z=1000 m.