Propagation Characteristics of Vortex Light

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Keywords: Vortex Light, Wavefront Phase, Laguerre Gaussian Beam, Finite-Difference Time-Domain Method, Orbital Angular Momentum, Transmission Characteristics

Abstract: Spiral beam of light is angled class such as phase vortex, with orbital angular momentum, the beam center for diffraction phase singularity secretly empty structures, because each photon of light beam is orbital angular momentum, can use this feature to realize to control the micro particles, avoids because of the traditional operating mode of particle damage, this technique is known as the "optical spanner.At the same time, the orthogonality of vortex light with different topological charges can be used to realize the multiplexing technology of optical communication and improve the transmission capacity of optical communication.In order to study the transmission characteristics of vortex light, the FDTD finite-difference time-domain method is used to analyze the most common laguerre gaussian beams, and the mathematical modeling and theoretical simulation are carried out on them.

1. Introduction

The study of vortex light began in the 19th century. In 1830, British astronomer George Biddell Airy discovered the existence of abnormal rings in the focal plane of a lens, which pushed people to study vortices from the direction of light wave energy flow.In 1952, Braunbek and Laukien observed the phenomenon of vortex when conducting diffraction experiments with plane waves and their reflected light, which promoted the discovery of vortex in the light field in the future.

Research on vortex light started late in China, but it has also achieved good results.In 2004, guochengshan studied the optimal annular helical phase structure to suppress the side lobe of vortex beam, and then generated optical vortices in the spatial frequency domain based on the helical phase spatial filte. In 2009, guo chengshan et al. observed that after the vortex light passes through the annular aperture diffraction, the number of stripes in the bright ring is consistent with the topological charge number.

2. Analysis of Optical Fiber Types and Transmission Methods

2.1 Types and Characteristics of Transmission Fiber

In terms of refractive index distribution, transmission fiber can be divided into two types: step fiber and gradient fiber. The refractive index of step fiber is abrupt and the gradient fiber is gradual. Generally, it is the fiber whose square rate distribution changes.

The number of modes can be divided into single-mode fiber and multi-mode fiber.The core of single-mode fiber is generally 8-10 microns，so single-mode fiber is generally used for long distance communication. The core size of multimode optical fiber is 50 to 100 microns. In this paper, single-mode fiber is used to simulate vortex optical transmission.

2.2 Methods of Analyzing Light Transmission in Optical Fiber

The analysis of optical fiber transmission can be divided into two methods: geometric optics method and wave optics method. The geometric optics method is relatively simple, but it cannot analyze the specific mode and phase characteristics of light wave, while wave optics can be analyzed in a more detailed way and get the results. The disadvantage is that it is more complex and needs software support.

  DOI: 10.25236/icicta.2019.012

3. Preparation and Simulation of Laguerre Gaussian Beams

3.1 Transmission Theory of Vortex Beam

After passing through the helical phase plate, a gaussian beam is converted into laguerre gaussian beam, which is a vortex beam easily obtained.Taking the emitting surface z=0 of the helical phase plate as the reference point, the optical field expression of vortex light is:

$$E(\rho, z=0)=E_0(\rho/\sigma)^l \exp\left[-\rho^2/\sigma^2\right]\exp[il\phi]$$

(2-1)

In this equation, sigma is the particle size and l is the topological load number.After the transmission for a certain distance, the polar coordinates are converted into rectangular coordinates, and (x ',y ') represents the position of the spiral phase plate, (x,y) represents the position of the observation plane, and the fenier diffraction integral formula is used to obtain

The amplitude of the vortex beam after a distance of propagation is

In order to further study the changes of vortex beams compared with the source plane after propagation for a certain distance, equation (2-2) needs to be converted into the equation in the same form as equation (2-1) : where, r and theta are polar coordinate parameters of the observation surface,

$$E(r,z)=-i^{l+1}\left(\frac{\sigma^{'}}{\sigma}\right)^{l}\exp\left[ikz+i\frac{2z}{k\sigma^2}\frac{r^2}{\sigma^{'}}\right]E_0\left(\frac{r^2}{\sigma^{'}}\right)\exp\left(-\frac{r^2}{\sigma^{'2}}\right)\exp(il\theta) \tag{2-3}$$

Where, r and theta are polar coordinate parameters and parameters of the observation surface

$$\sigma^{'2}=\sigma^2+\frac{4z^2}{k^2\sigma^2} \tag{2-4}$$

If the topological charge of vortex light generated by the spiral phase plate is negative, then the expression of vortex light field is**:**

$$E(r,z)=i^{l+1}\left(\frac{\sigma^{'}}{\sigma}\right)^{|l|}\exp\left[ikz+i\frac{2z}{k\sigma^2}\frac{r^2}{\sigma^{'2}}\right]E_0\left(\frac{r^2}{\sigma^{'}}\right)^{|l|}\exp\left(-\frac{r^2}{\sigma^{'2}}\right)\exp(i|l|\theta) \tag{2-5}$$

For the convenience of research, the radius of vortex light spot is defined as the distance from the beam center to the maximum light intensity of the spot.In order to get the size of the radius of the vortex light spot, it is only necessary to calculate the first derivative of the expression of the light field after transmission for a certain distance and set it to zero, and the maximum value is the size of the radius of the light spot.The resulting spot radius is expressed as follows:

$$r^{'}=\sqrt{\frac{|l|}{2}}\sigma^{'} \tag{2-6}$$

For the convenience of research, $\sigma^{1^2}=\sigma^2+\frac{4Z^2}{k^2\sigma^2}$ the radius of vortex light spot is defined as the distance from the beam center to the maximum light intensity of the spot.In order to get the size of the radius of the vortex light spot, it is only necessary to calculate the first derivative of the expression of the light field after transmission for a certain distance and set it to zero, and the maximum value is the size of the radius of the light spot.The resulting spot radius is expressed as follows:

3.2 Transmission Simulation of Vortex Light

To generate vortices, the helical phase plate created by the upper segment is inserted into the path of the gaussian beam in free space.In order to create a model of vortex light, FDTD solution, a finite-difference time-domain simulation software commonly used in maxwell's time-domain analysis, is used to limit its simulation area by setting its light source as gaussian beam and setting monitors at different transmission distances to observe the changes of its light field.The experimental results are shown in the figure below:

In the previous section, it has been theoretically concluded that when laguerre gaussian beam propagates in free space, the spot radius of its dark space structure gradually increases with the increase of transmission distance.Through the above figure, we can also use matlab software to simulate and simulate the effect diagram of vortex light. By changing the phase parameters input in the program, we can get the wavefront phase distribution diagram of vortex light under different topological load values.The phase distribution diagram of vortex light obtained is shown in the figure:

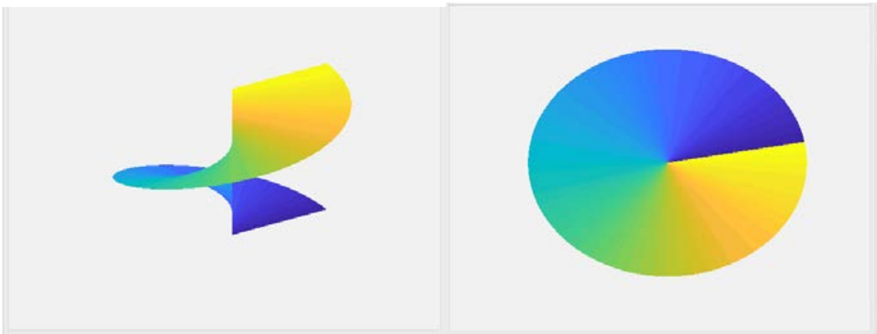

FIG. (a) spiral phase diagram of vortex light when l=-1

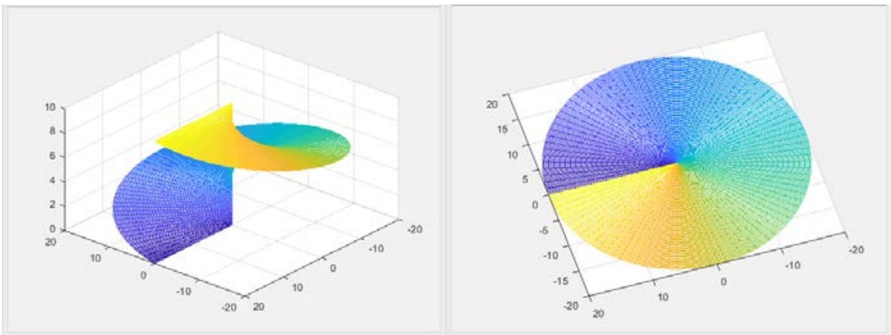

FIG. (b) spiral phase diagram of vortex light when l=1

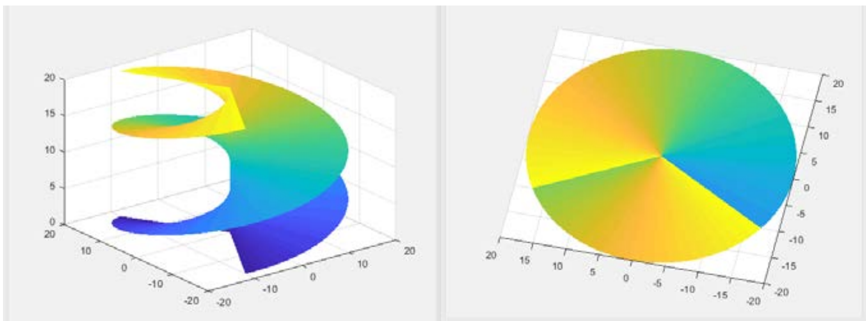

FIG. (c) spiral phase diagram of vortex light when l=-2

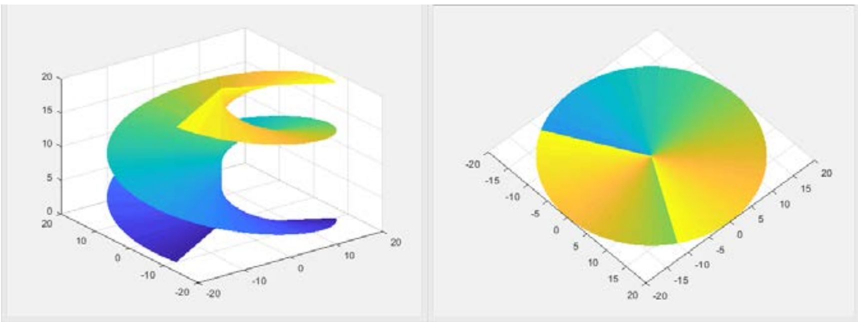

FIG. (d) spiral phase diagram of vortex light when l=2

4. Result Analysis

Through the above matlab simulation image analysis, it can be seen that the torsion direction of the front phase of vortex light wave and the number of torsion within a week are closely related to the topological load value. Because the wavefront phase vortex light has this kind of reverse structure, each photon in the vortex beam with l ħ orbital angular momentum, this is the most important properties of vortex light.

5. Conclusion

In this paper, eddy light is simulated by matlab and FDTD simulation software.First introduced the optical fiber transmission and transmission mode, focuses on using FDTD structures, spiral phase plate, the insert a spiral phase plate produce laguerre gaussian beams, by changing the spiral phase plate thickness or refractive index change with Angle spiral phase plate, in order to change the topological charge of vortex beam value, analyses the amplitude distribution of vortex light, the side lobe number, spot radius, and the direction of the vortex.Matlab software is used to simulate the wavefront phase distribution of vortex light, so as to observe and analyze the relationship between the number of radial segments, torsion times and direction of vortex light and topological load value.It can be seen from the above analysis that laguerre gaussian beam, as a kind of vortex light, when it transmits in free space, its spot radius increases with the increase of transmission distance, the number of side lobes increases with the increase of topological load, and the vortex direction also varies with the positive and negative of topological load.Meanwhile, the node-line distribution in the wavefront phase cross section also increases with the topological load, and the number and direction of torsion are also related to the topological load.It is concluded that there is a profound relationship between the transmission characteristics of vortex light and its topological load, and it is also the most important parameter to study the characteristics of vortex light.

Acknowledgements

Fund: National Natural Science Foundation of China, project number 11304271

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