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Orbital Angular Momentum of Airy Gaussian Vortex beams

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Summary: A right triangular aperture irradiated by an Airy Gaussian vortex beam generates a fringe like pattern in the diffraction plane that establishes its Orbital Angular Momentum. In this paper, we, we unveil the angular momentum of such beams using the Helmholtz Hodge Decomposition approach. These beams offer tremendous applications in nanotechnology and also in optical trappers, rotators and biomedical science.
Keywords: Airy Gaussian beam, Optical vortex, Orbital Angular Momentum, Phase singularity

1. Introduction

Vortex embedded helical beams, Bessel and Airy beams are special types of light fields that carry angular momentum. This implies that these beams rotate as they propagate through space, a property that can be exploited for use in applications such as optical tweezers and spanners, quantum optics, nanotechnology, biotechnology and optical communications. In this paper, we generate an Airy Gaussian beam that carries an optical phase singularity lending an overall Orbital Angular Momentum to the beam. Such waves have been studied and have shown to exhibit a cosine wave trajectory as they propagate in a harmonic potential [1]. The state of the angular momentum has been demonstrated through the use of the Helmholtz Hodge Decomposition technique [2].

1. Orbital Angular Momentum of Airy Gaussian Vortex Beam

The Orbital Angular Momentum (OAM) of light depends upon the spatial variation of a light field. The simplest example of a light beam carrying OAM is a plane beam with an embedded phase singularity [3,4]. An Airy Gaussian vortex beam has an embedded vortex that lends it a finite OAM. The transverse phase profile is given as $\exp(im\phi)$ where ϕ is the angular coordinate and m is either positive or negative. The Poynting vector, which is at all times parallel to the surface normal to these phase fronts, has an azimuthal component around the beam and hence, an overall angular momentum along the beam axis. The z component of the OAM for a singular beam that is associated with a twisted wavefront is given by $m\hbar$ per photon, where m is the charge of the beam. At a radius r, the inclination of the phase front, and hence of the Poynting vector, with respect to the beam axis is simply $l\lambda/2\pi r$. This, in turn, sets the azimuthal component of the light, giving it an angular momentum of $l\hbar$ per photon. The concept of OAM led to a vigorous interest in optical tweezers and new manifestations of quantum entanglement. Phenomenologically the OAM basis set has naturally led to the recognition of rotational frequency shifts, angular uncertainty relations, and Poincare sphere equivalents for partial modes.

2. Helmholtz Hodge Decomposition

It has been shown that the Vector field decomposition method namely the Helmholtz Hodge Decomposition (HHD) can also be applied to analyze scalar optical fields that are ubiquitously present in interference and diffraction optics. A phase gradient field that depicts the propagation and Poynting vector directions can hence, be separated into solenoidal and irrotational components.

We first construct a phase gradient field $\nabla\phi$ from a scalar field by using the relation

$$\nabla\phi = \frac{\mathrm{Im}[\psi^{*}\nabla\psi]}{I}$$

where ψ is a scalar field resulting due to interference or diffraction and $I = \psi^{*}\psi$ is the intensity distribution.

$\nabla\phi$ directs in the direction of the local propagation vector which is normal to the phase contour surfaces. The phase gradient fields in a singular beam can be seen to have a non zero curl. Hence, the solenoidal part which is an explicit component of HHD carries the circulating internal energy of the field. The irrotational part is then devoid of singularities, and depicts the spreading of optical energy.

3. Results

3.1 Diffraction of Airy Gaussian vortex beam through a triangular aperture

The diffraction pattern from a right triangular aperture results in a fringe like pattern. This is attributed to the interference from the two edges of the aperture. This is very similar to the Young's double slit experiment but the number of fringes here change depending upon the OAM state of the beam. The higher order singularities in such beams upon diffraction, decompose into elementary singularities which are found to be present in the dark fringes of the diffraction pattern. These elementary singularities and hence, the number of dark fringess directly reveal the OAM of the incident Airy Gaussian beam.

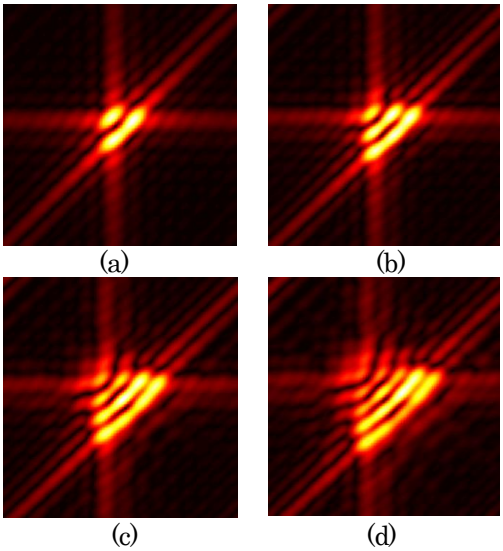


Fig. 1. Diffraction of Airy Gaussian beam through a right triangular aperture for OAM state 1 to 4.

3.2 Diffraction of Airy Gaussian vortex beam through a triangular aperture

The phase gradients of fields resulting from diffraction of Airy Gaussian vortex beam through a right triangular aperture are shown in fig. 2 (a) to (d) for various topological charges of the beam. It is clearly seen that the vortices show up as circulating energy centres in the dark fringes. The no of fringes reveal the OAM state of the beam.

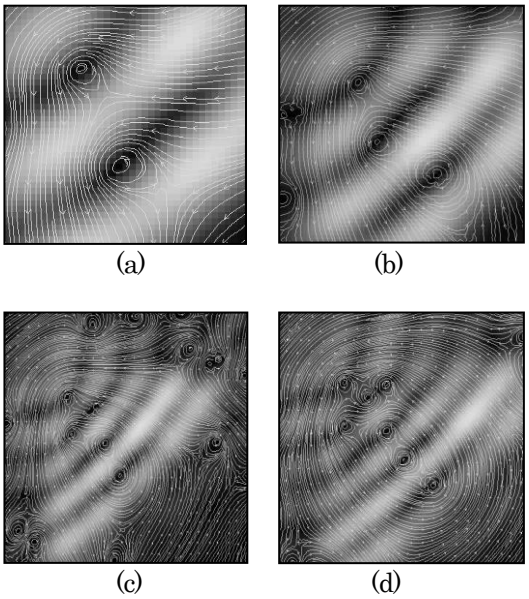


Fig. 2. Solenoidal component of the phase gradient fields of diffracted Airy Gaussian vortex beams of orders 1to 4, diffracted through a right triangular aperture.

4. Conclusions

It is seen that an Airy Gaussian vortex beam carries an Orbital angular momentum about its axis of propagation. This momentum offers it the ability to rotate and trap microparticles. The momentum splits upon diffraction through a triangular aperture, that reveals the OAM state of the beam. Such beams offer tremendous applications in nanotechnology and also in optical trappers, rotators and biomedical science.

References

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Professional Biography

Dr. Monika Bahl holds a Doctorate from Indian Institute of Technology Delhi in Physics. She also holds a dual Post Graduation degree (M Tech- Applied Optics, MSc. - Applied Physics) from Indian Institute of Technology Delhi. She has done her graduation from University of Delhi, Miranda house in Physics. She is an Assistant Professor in the Applied Sciences department in Amity University. She has published more than 7 papers in reputed journals and 11 proceedings in leading international conferences. She is a member of the Optical Society of America and the Australian Optical Society. She has won several awards and scholarships including the Best Oral paper presentation award at the ICOL'14 conference in IRDE, India. She has served both industry and academics including being a part of research teams at Wipro technologies and Moserbaer India Limited.



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