APPLICATION NOTE

AXICONS

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1. INTRODUCTION

In 1954, J. H. McLeod introduces axicon word to describe optical element that images a point source into a line focus [1]. Best example mentioned by McLeod was the conical lens formed by a plane and a conical surface. Some papers on axicons uses and properties were published in the seventies [2,3].

In the late eighties, a paper on non-diffracting beams by Durnin and others enhance the interest into axicon lenses [4,5]. It has been showed that an axicon could generate a Bessel beam, so-called non-diffracting beams, which transverse distribution was constant along the propagation, theoretically.

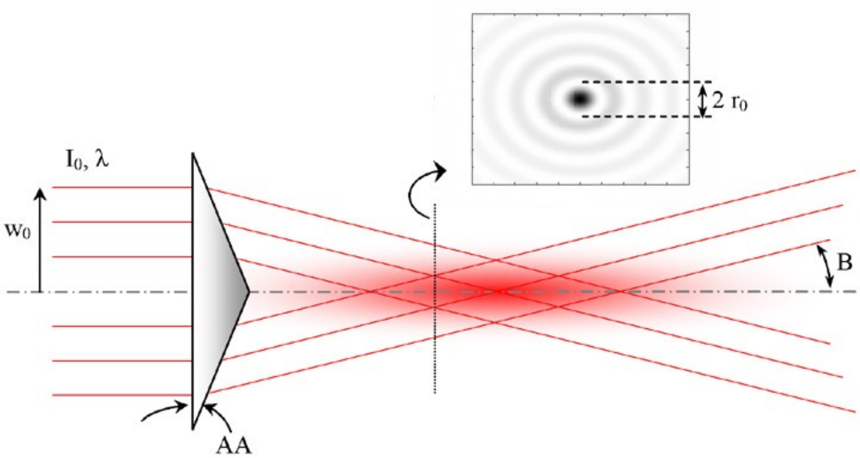

Figure 1. Axicon ray-trace

2. INTENSITY DISTRIBUTION

Transverse intensity distribution created by a uniform plane wave passing through a infinite dimension axicon is described by first order Bessel function, J0(kBr). This transverse intensity distribution is constant along the propagation, that's why they're called non-diffracting beams. The Bessel function J0(kBr) is characterized by a intense central part encircled by an infinity of rings of smaller intensity. In fact, each ring contain same amount of energy, so bigger the ring, smaller the intensity. The size of central lobe is given by :

$$r_0 = \frac{2.4048 \cdot \lambda}{2\pi \cdot B}$$

(Eq. 1)

The transverse intensity distribution at a specific position is created by constructive interference from a small annulus of rays of corresponding diameter incident on axicon. As propagation distance increase, as the annulus diameter that generate interference increase, consequently, the intensity of an ideal Bessel beam increase indefinitely with propagation.

In real world, we can't generate a uniform plane wave and and infinite dimension axicon, so Bessel beams are not realizable in practice. In fact, we can use a collimated Gaussian beam to illuminate a finite dimension axicon. The beams generated this way are called Bessel-Gauss beams. The intensity is no more increasing indefinitely with propagation, but is decreasing after a certain distance. The intensity distribution of Bessel-Gauss beams generated by an axicon can be calculated by resolving Fresnel diffraction integral with the stationary phase approximation [6]:

$$I_{B-G}(r,z) = I_0 \cdot \left(4\pi^2 B^2 \frac{z}{\lambda}\right) \cdot \exp\left[-\frac{2(Bz)^2}{w_0{}^2}\right] \cdot J_0{}^2(kBr)$$

(Eq. 2)

Where r,z are radial and longitudinal coordinates, I0 is incident on-axis intensity, w0 is the beam waist, λ is the wavelength, k is the wavenumber (k=2pi/λ) and B is beam deviation angle function of axicon angle (AA) and refractive index (n) by :

$$B = \arcsin(n \cdot \sin(AA)) - AA$$

(Eq. 3)

This result for the Fresnel integrals is only valid near optical axis. If we are focusing on the intensity on the optical axis only, we get :

$$I_{B-G}(0,z) = I_0 \cdot \left(4\pi^2 B^2 \frac{z}{\lambda}\right) \cdot \exp\left[-\frac{2(Bz)^2}{w_0{}^2}\right]$$

(Eq. 4)

From axicon and Gaussian beam properties, one can also find the position of the on-axis maximal intensity (Zmax) [7] :

$$z_{max} = \frac{w_0}{2B}$$

(Eq. 5)

And the value of this maximal intensity (Imax) :

$$I_{MAX} = \frac{2\pi^2}{\lambda} B w_0 \exp(-0.5) \cdot I_0$$

(Eq. 6)

Finally, if we define depth of field by the distance where on-axis beam intensity is greater than half the maximal intensity, we can approximate the depth of field by :

$$DOF \cong 0.8 \cdot \frac{w_0}{B}$$

(Eq. 7)

3. AXICON – SPHERICAL LENS COMBINATION

The idea to use the combination of a spherical lens with an axicon has been proposed by P.A. Bélanger and M. Rioux in a paper published in 1978 [3]. This combination creates an intense ring in the focal plane of the lens. This feature is of great interest in laser machining applications to drill holes. Within paraxial approximation, the radius of the ring in the focal plane can be computed with lens focal length (FL), axicon refractive index (n) and axicon angle (AA) by this simple relation :

rA = (n-1) x AA x FL (Eq. 8)

An elegant way to combine an axicon and a lens is to have a single element with first surface spherical and second surface axicon. This type of single element axicon lens is produced by Doric Lenses Inc. with possibility to choose different parameters of both surfaces.

4. APPLICATIONS

Initially, axicons have been used in precision alignment systems for large telescopes. Thereafter, some scanning optical system used axicon to take advantage of their large depth of field [8], example many supermarket code bar reader uses axicons. Like it has been mentioned before, the combination of an axicon with a lens is used in laser machining to drill holes [3].

Axicons are also largely used in different research project. In fundamental physics, axicons are used to generate an optical trap which guides atoms or molecules [9]. Reflective axicons are used with ultra-short laser pulses to generate and study X-pulses properties [10]. Axicons can also be used in medical applications; example a group from COPL from Quebec city have insert an axicon into a 2 photons absorption confocal microscope to analyze neurons activities [11].

Contact-us for any further questions about axicons for your applications, we will be pleased to answer your needs.

5. REFERENCES

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