Физика

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INVESTIGATION OF THE DIFFRACTION OF A FOCUSED GAUSSIAN BEAM BY A HALF-PLANE NEAR THE BEAM WAIST

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Diffraction of a focused Gaussian beam in the vicinity of the waist region at the edge of the screen is considered on the basis of numerical simulation and experimental investigation. The Gaussian beam propagation has been simulated on the basis of the Helmholtz equation solution by the spectral method. The diffraction of coherent laser radiation (wavelength of 0,63 μm) at the edge of a rectangular screen overlapping half the beam in the transverse direction has been analyzed experimentally. The laser beam is focused by the lens of focal length of 4 cm. A dependence of the diffraction pattern on the screen position relative to the focal waist position is observed. It is found that if the screen is located at distances less than the focal length, then the diffraction pattern is observed in the dark region and represents a semicircle with diffraction fringes. If the screen is placed in the waist region, then the diffraction pattern becomes symmetrical with respect to the screen edge, and if the screen is located at a distance greater than the focal length, then the diffraction pattern is observed in bright area with the diffraction fringes appearing on the other side. The results can be used for the accurate determination of the focused Gaussian beams waist position.

Keywords: Gaussian beam; the beam waist; the focal plane; light diffraction.

Introduction

The focusing of structured light beams gives rise to new effects in the focal plane [1]. Changing of the sign of circular polarization of asymmetric light beams causes the transverse displacement of beam waist [2–6]. Transverse focal displacement is also observable in beams with vortices. The value of this displacement from the geometric focus depends on the topological charge of the vortices, the vortices initial position in the beam, and the beam aperture [7, 8].

Besides the transverse displacement, the longitudinal focal shift from the geometric focus is observable. This focal shift is directed toward the beam aperture and depends on a Fresnel number [9, 10]. For the focused Laguerre-Gaussian beams the longitudinal focal shift increases with the increasing of the focal distance and decreases with the increasing of the waist region diameter [11].

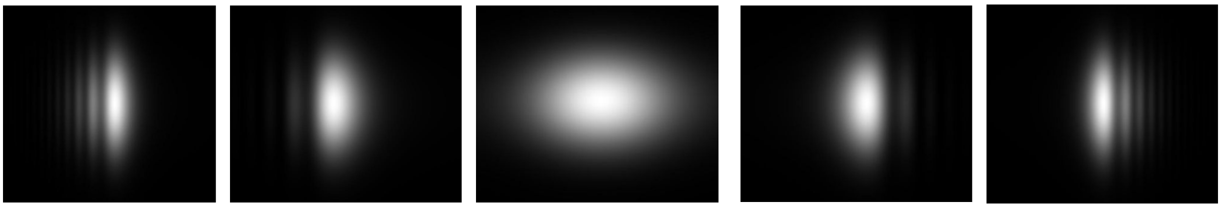
The diffraction by the screen with the straight edge (half plane) has been investigated for several decades and revealed new properties of optical waves [12]. It was found that the diffraction of a beam with a zero topological charge gives rise to optical vortices (wavefront dislocations) [13]. Half plane edge diffraction allowed researchers to determine the dependence of diffraction pattern on the sign of circular polarization and to demonstrate the vortex character of the longitudinal field component of the circularly polarized beams [14]. The diffraction of the Gaussian vortex beam by the edge of the screen resulted in the formation of polarization singularities, which appear from the transverse and longitudinal components of the diffracted beam electric field [15]. Moreover, half plane and slit diffraction of beams made possible the determination of the energy flow direction in beams with wavefront dislocations [16, 17].

The diffraction of focused beams by a screen will allow us to research the properties of light in the waist region. In this paper we present the results of numerical simulation and experimental investigation of the half plane diffraction of a focused Gaussian beam at the beam waist.

Half plane diffraction of a focused Gaussian beam: simulation

To obtain the diffraction pattern of the Gaussian beam cross section after the diffraction of the beam by the edge of the screen we solved Helmholtz equation using a spectral method. We calculated the far-field intensity distribution. The screen was located at different distances from the focal waist in such way, that it always overlapped the right half of the beam.

The results of the intensity distribution calculations are shown in Fig. 1. We can see that the diffraction pattern changes with the screen move along the beam propagation axis. If the screen is located in the waist region, the intensity distribution is symmetric with respect to the screen edge and forms an ellipse, the major ellipse axis is perpendicular to the screen edge (Fig. 1, *c*). If the screen is before or after the beam waist region, the intensity distribution has an evident diffraction nature and forms a semicircle with diffraction fringes. If the screen is far from the beam waist, the diffraction pattern is more evident, and the diffraction pattern image depends on the screen location (before or after the waist region). If the screen is located before the beam waist, the diffraction fringes are to the left of the screen edge (Fig. 1 *a*, *b*). If the screen is located after the beam waist, the diffraction fringes are to the right of the screen edge (Fig. 1 *d*, *f*).



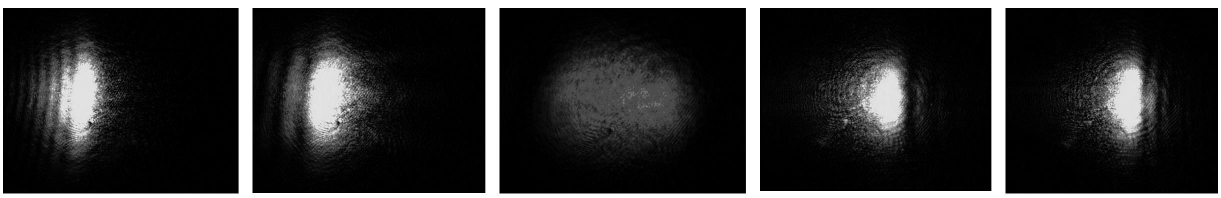
a) *b*) *c*) *d*) *f*)

Fig. 1. Calculated far-field intensity distributions.
The screen is between the lens and the focal plane (*a*, *b*); at focal plane (*c*); after the focal plane (*d*, *f*)

Half plane diffraction of a focused Gaussian beam: experiment

For experimental investigation we used the radiation of a He-Ne laser generated on the main transverse mode at the wavelength $\lambda = 632{,}8$ nm. The laser beam was focused by a lens with the focal distance of 4 cm. The opaque screen with the vertical edge was mounted on a two-coordinate micro-motion stage. We can smoothly insert the screen into a beam, overlapping the right half of the beam, and move the screen along the beam propagation. The changes in the far-field intensity distribution on the change of the screen location relative to the focal waist were recorded by a CCD-camera (Fig. 2). At some screen locations we detected clear vertical fringes (Fig. 2, *a*, *b*), which were observable under any beam cross-section overlapping (by half or not). At some point the light spot formed an ellipse, the major ellipse axis was perpendicular to the screen edge (Fig. 2, *c*). A further move of the screen along the beam propagation axis led to the appearance of vertical diffraction fringes at the other side of the intensity distribution (Fig. 2 *d*, *f*).

The comparison of Fig. 1 and Fig. 2 demonstrates that the symmetric diffraction pattern corresponds to the screen location at the focal plane. This fact allows us to assume that the focal plane position can be determined from the diffraction pattern form. We showed that the symmetry of the diffraction pattern is broken under the screen displacement by 20 µm from the focal plane. Therefore, using a lens with the focal distance of 4 cm, we could determine the focal plane position with an accuracy of 20 µm.



a) *b*) *c*) *d*) *f*)

Fig. 2. Experimental far-field intensity distributions. The screen is located *a*) at 1,5 mm before the focal plane; *b*) at 75 µm before the focal plane; *c*) at the focal plane; *d*) at 75 µm after the focal plane; *f*) at 1,5 mm after the focal plane

Conclusion

We investigated experimentally and theoretically half plane diffraction of the focused Gaussian beam in the vicinity of the waist region. We found that if the screen is located at distances less than the focal length, the diffraction pattern appears in the dark region. If the screen is placed in the waist region, the diffraction pattern becomes symmetrical with respect to the screen edge. And if the screen is located at a distance greater than the focal length, the diffraction pattern appears in the bright area. The results can be used for the accurate determination of the focused Gauss beams waist position.

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ИССЛЕДОВАНИЕ ДИФРАКЦИИ СФОКУСИРОВАННОГО ПУЧКА ГАУССА НА ПОЛУПЛОСКОСТИ В ОБЛАСТИ ПЕРЕТЯЖКИ

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На основе численного моделирования и экспериментального исследования рассмотрена дифракция на краю экрана сфокусированного пучка Гаусса в окрестности области перетяжки. Моделирование распространения пучка Гаусса проводилось на основе решения уравнения Гельмгольца спектральным методом. Экспериментально исследовалась дифракция когерентного лазерного излучения на длине волны 0,63 мкм на краю прямоугольного экрана, перекрывающего половину пучка в поперечном направлении. Фокальная перетяжка формировалась с помощью линзы с фокусным расстоянием 4 см. Была обнаружена зависимость картины дифракции от положения экрана относительно положения фокальной перетяжки. Оказалось, что если экран расположен на расстояниях меньше фокусного, то дифракционная картина наблюдается в области тени и представляет собой полукруг с дифракционными полосами. Если экран помещен в область перетяжки, то дифракционная картина становится симметричной относительно края экрана. А если экран расположен на расстоянии большем фокусного расстояния, то дифракционная картина наблюдается в светлой области, при этом дифракционные полосы появляются уже с другой стороны. Полученные результаты могут быть использованы для точного определения положения перетяжки сфокусированных пучков Гаусса.

Ключевые слова: пучок Гаусса; перетяжка пучка; фокальная плоскость; дифракция света.

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