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Laser beam formation in special ophtalmological instruments*

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A new laser system for operational treatment of the glaucomia of the front part of the eye is proposed, in which an axicon has been used to expand the beam. The results of aberration calculations of the optical system including the axicon are presented. The calculations of both the optical transfer function and the intensity distributions in the vicinity of the focus for different input beams have been performed. The results of experimental examinations of the axicon and the whole optical track are presented.

1. Introduction

The application of laser techniques in ophtalmology offered new possibilities in treatment of many diverse diseases [1]. Clinic practice in operational treatment of glaucomia of the frontal part of the eye indicates the necessity of constructing special laser devices. In the case of iris perforation very high power densities should be led to the operation point, while the damage of the frontal eye chamber is expected to be minimized. Besides a coaxial viewing of the operation field also the possibility of precise pointing of the working beam onto the place of perforation should be assured. Different types of optical systems satisfying these requirements are discussed in [2]. As a result a special laser device with a suitable beam forming system has been proposed. Below, a short description of this system has been given followed by a numerical examination of its optical quality and a preliminary examination of the selected elements.

2. Description of the system

The system of performing an eye iris perforation shown in Fig. 1 is composed of: working YAG laser, auxiliary He-Ne laser, axicon, focusing system. To produce the working beam a YAG laser with a shortened pulse duration $\tau = 10$ ns has

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been applied. The assumed range of changes in pulse energy is 1–100 mJ. The perforation of the tissue in this region appears due to interaction of the plasma produced in the focus of the optical system, while both the thermal effects and the photocoagulation outside the operation point are avoided. The He-Ne LM200

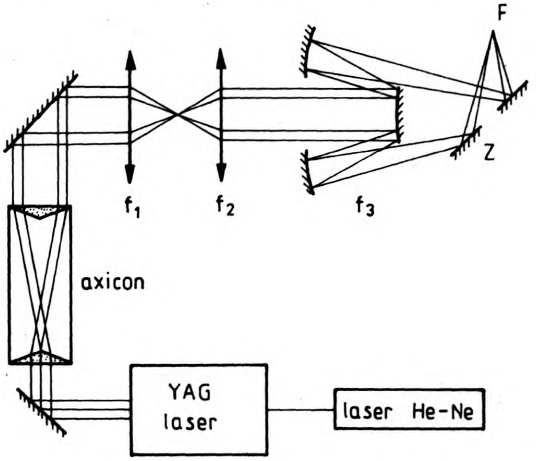

Fig. 1. Scheme of the optical path

laser beam located coaxially in front of the YAG laser resonator enables a precise pointing of the working beam onto the operation point.

After emerging from the laser resonator the laser beam of an intensity distribution close to that of the Gaussian type is transformed by an axicon to a beam of annular cross-section being next transformed by the lenses f_1 and f_2 and a mirror objective f_3 to be finally focused at the point F. The total aperture angle of the beam amounts to 16°. The mirror Z reflecting the convergent beam has a hole enabling the viewing of the operational field.

3. Numerical examinations of the optical system

The focusing system together with the axicon has been designed in the Institute of Physical Chemistry, Polish Academy of Sciences (Fig. 2). The spherical aberration

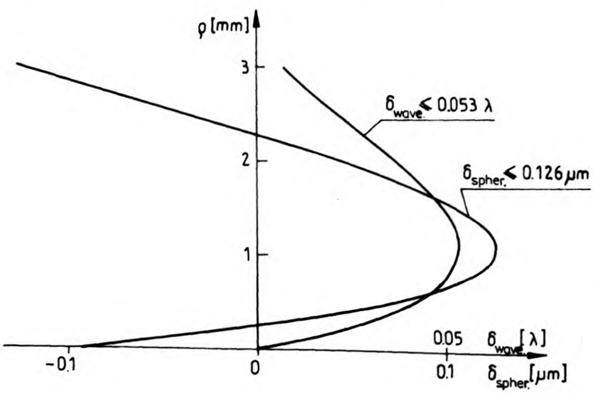

Fig. 2. Aberrations of the optical track with an axicon δ as a function of the radius ϱ defined in the output plane of the axicon

has been corrected numerically for the beam of annular cross-section. The value of this aberration is reduced to less than 0.126 μm, while the wave aberration is less than 0.053 λ for $\lambda = 1.06$ μm. Therefore it can be assumed that the optical system is diffraction-limited.

Due to untypical distribution of intensity in the pupil of the optical system the calculations of modulation transfer function (MTF) have been performed at the Institute of Optoelectronics, Military Technical Academy, Warsaw, for the intensity distributions shown in Fig. 3. In order to perform these calculations a computer

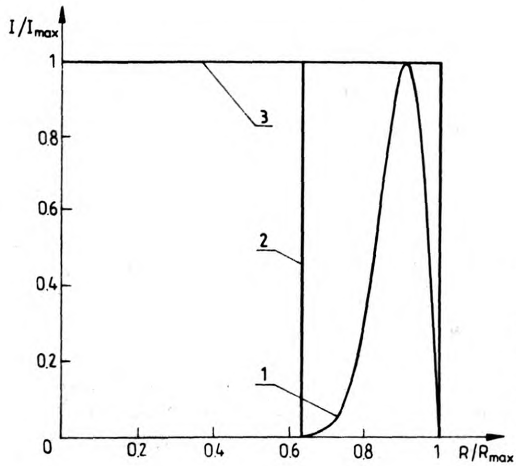

Fig. 3. Distributions of relative intensity I/I_{max} of the analysed beams in the objective pupil as a function of generalized radius R/R_{max}. 1 – Gaussian beam of radius $w_{1/e^2} = 1$ mm transformed by an axicon into an annular beam, 2 – beam corresponding to the system transmittivity region, 3 – uniform beam

programme has been elaborated starting from the autocorrelation formula [3]. This programme enables to take into account the arbitrary axially symmetric distributions of both amplitude and phase within the pupil (Fig. 4). In the

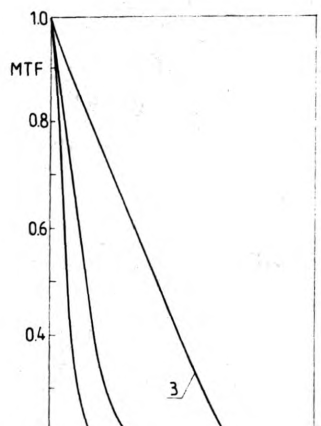

Fig. 4. Modulation Transfer Function vs the generalized spatial frequencies ν

calculations, the wave aberration of the system shown in Fig. 2 has been taken into consideration, however, for such small aberrations only the intensity distribution in pupil decided about the course of MTF. As can be seen in Fig. 4 the MTF of a Gaussian beam after its passage through the axicone (curve 1) is worse than that of uniform beam (curve 3) of an analogical cross-section.

Using the calculational apparatus reported in [4] the light intensity distributions in the vicinity of the focus for different input beams has been analysed. The case of focusing beam no. 1 (i.e., such as is expected in our system) is of a particular interest. An important characteristic of the system from the user's viewpoint is the course of intensity maximum across a given cross-section as a function of the distance from the focus.

For comparison, this relation has been also shown for the case of Gaussian beam of parameters analogical to those of the beam incident to the axicon (Fig. 5).

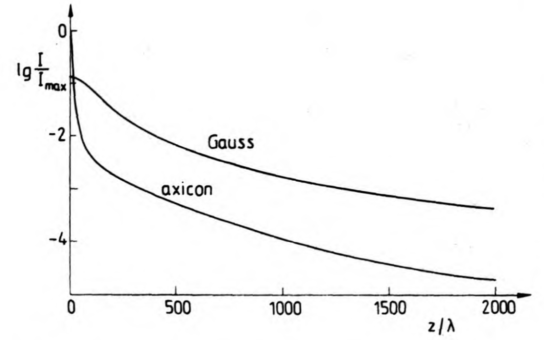

Fig. 5. Distribution of maximal intensity I/I_{max} at its given cross-section as a function of the distance from the focus z/λ expressed in the wavelength units referred to maximal intensity I_{max} at the focus (axicon – for the input beam of intensity distribution illustrated by curves 1 in Fig. 3, Gauss – for the input Gaussian beam of parameters analogical to those of the beam entering the axicon)

It can be seen that the application of the axicon results in an almost tenfold gain of intensity in the focus, while starting from the distance 80λ from the focus, the maximal Gaussian beam intensity exceeds considerably the intensity of the beam expanded by the axicon.

When compared to the classical beam expander the application of the axicon renders somewhat worse results. However, it should be taken into account that the fundamental advantage of applying the axicon is the possibility of an immediate coaxial viewing of the operation field.

4. Experimental examination of selected elements of the system

A deciding element in the quality of the whole optical system is the axicon. Errors in the surface processing, especially in the vicinity of the cone vertex, may considerably worsen the focus and consequently what is gained by applying the method of beam expansion may be lost due to these errors. Therefore, the influence of the axicon on the laser beam divergence has been examined. For this purpose, the intensity distribution has been measured by scanning the beam with a detector of 0.1 mm width at the plane of best focus of an aberration-free objective of long focal length.

As can be seen in Fig. 6, the half-widths of the curves **b** and **c** are slightly greater than that of the curve **a**, which indicates a high optical quality of the axicon.

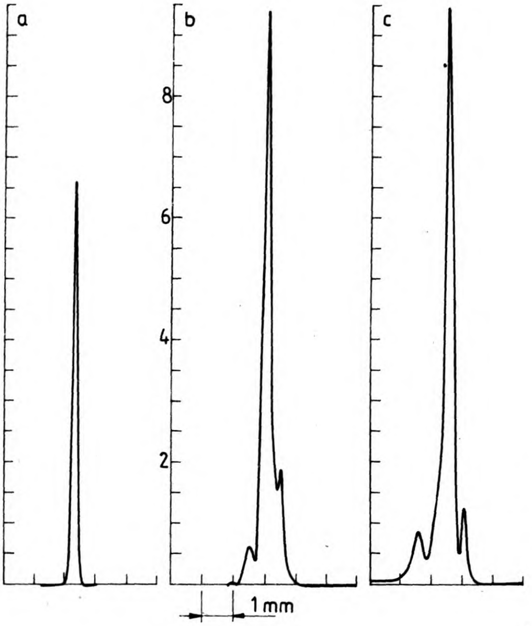

Fig. 6. Intensity parameters at the best focus plane for the aberration-free system of local length $f = 600$ mm of the laser beam of divergence $\Theta \cong 0.2$ mrad (**a** – without axicon, **b** – with axicon, horizontal direction of scanning, **c** – with axicon, vertical direction of scanning)

After having adjusted the optical track (Fig. 7), a series of pictures of intensity distribution in the convergent beam have been taken by using the He-Ne laser pointing beam (Figs. 8-10). Both the adjustment and the optical system quality

Fig. 7. Optical tracks of the system adjusted in laboratory conditions

seem to be correct which follows from the stated symmetry of the annular beam and the small sizes of the focus. The preliminary estimation of these magnitudes confirms the high quality of the optical track.

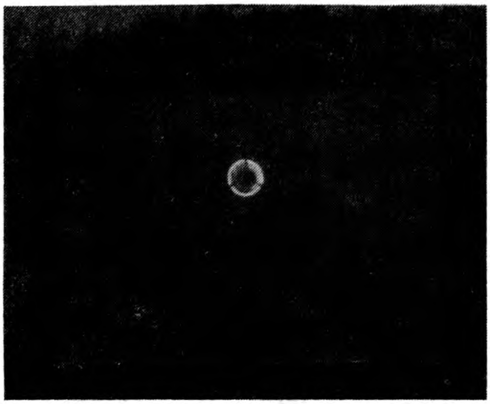

Fig. 8. Convergent beam at different cross-sections in the vicinity of the focus, magnification 0.55 ×

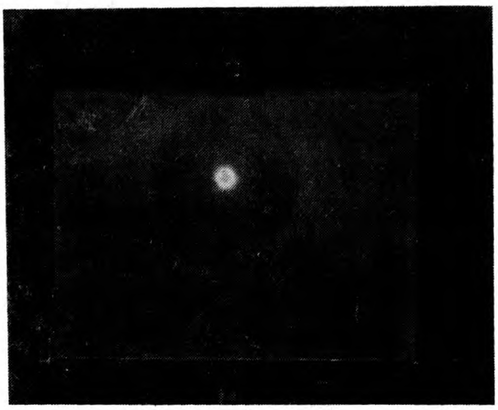

Fig. 9. The same as in Fig. 8

Fig. 10. The same as in Fig. 8

5. Final remarks

The presented results of both the numerical and experimental examinations allow to state that the system satisfies the needed requirements. The intensity distribution at the focus is determined by the parameter of the working beam from the YAG pulse laser. For the complete estimation of the system utility an analysis of light propagation at the borders of the media as well as inside the front eye chamber seems to be necessary.

References

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Формирование лазерного излучения в специальных офтальмологических приборах

В статье представлена новая лазерная система для офтальмологических операций глаукомы передней части глаза. Определены волновые аберрации всей системы вместе с аксиконом. Представлены результаты расчетов распределения интенсивности вблизи фокуса, кроме того расчитаны передаточные функции для разных пучков. Полученные экспериментальные результаты исследований аксикона и всей оптической системы подтверждают их высокое качество.