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Measuring of Laser Beam Parameters

Laboratory Guide
to the Lab Work No 5

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The aim of the work:

Conduct measurements of the geometric parameters of the laser beam-beam divergence and its transverse dimensions. Understand the causes of the divergence of radiation.

Preliminary task

To study geometrical methods for measuring the parameters of a laser beam. Determine the diffraction divergence of the beam with a diameter of 1.5 mm for wavelengths $\lambda 1$ = 632.8 nm and $\lambda 2$ = 532 nm and diameter of the diffraction-limited beam at a distance of 25 m.

Theory

An important characteristic of a laser system is the radiation divergence, expressed in radians. The smaller the divergence, the smaller the diameter of the beam at a distance from the source will be different from the initial one. In addition, this parameter is responsible for the minimum volume in which laser radiation can be concentrated. It is known that the limiting size of the focusing spot is determined by diffraction phenomena and is approximately equal to the wavelength of the radiation. However, in real laser systems, the restriction on the degree of focusing occurs at an earlier stage because of the divergence of the beam. The limitations on the divergence in high-power laser installations arise due to many reasons, primarily as a result of the inhomogeneity of the active medium in large volumes and deviation from the ideal optical surfaces of prisms, lenses, mirrors and other elements used in amplifiers. Inhomogeneities of the active medium can arise due to imperfections in the technology of its production (for example, microimpurities, impregnations, defects in the crystal lattice, etc.). They can also appear during laser operation: thermal distortions due to uneven pumping and, consequently, uneven heating of the volume of the active medium, self-focusing facilitated by the presence of intensity inhomogeneities in the cross section of the laser beam, etc.

When determining the divergence of a laser beam, it is necessary to distinguish the structure of the radiation field in the near-field and far-field zones.

The incoherent component of the radiation (and this is always present in one or another way in the output beam), diffraction at the output aperture, scattering by inhomogeneities of the active medium and mirrors, etc., will give a mixture of plane and spherical waves in the near-field zone. This area is also called "Fresnel".

As can be seen from Fig. 1, at a distance

$$l_0 = \mathrm{D}^2 / \lambda . \qquad (1)$$

The incoherent component goes beyond the limits of the main "coherent" radiation beam. Then there remains a component with a plane wave front, which is usually described by the Fraunhofer approximation. Thus, when

$$l < l_0 = \mathrm{D}^2 / \lambda$$

we have a near-field (Fresnel) zone, and when

$$l > l_0 = \mathrm{D}^2 / \lambda$$

we have far-field (Fraunhoferov) zone.

For an He-Ne laser (λ = 632.8 nm) with a beam diameter of 4 mm, from formula (1) we obtain l_0 = 25 m.

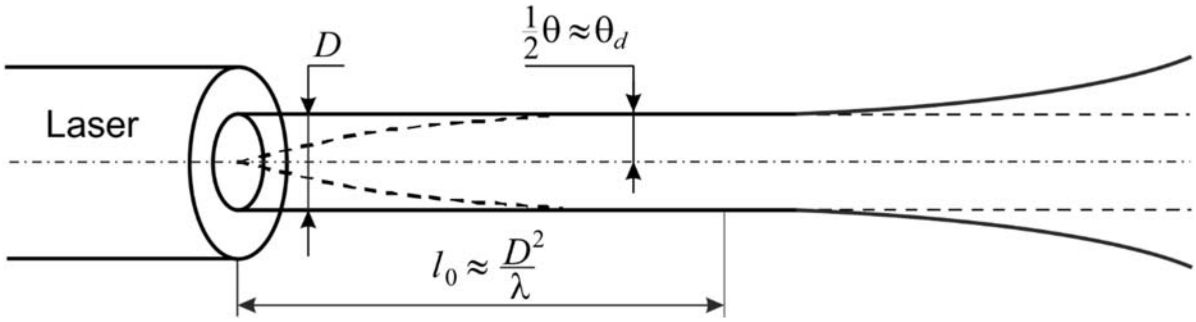


Fig. 1. Image formation in compound microscope

Consider a wave with total spatial coherence (ideal case). Even in this case, a beam with a finite aperture will inevitably diverge as a result of diffraction. In Fig. 2a shows a wave with a uniform transverse distribution of intensity and a plane wave front incident on a screen S with a circular hole of diameter D. According to the Huygens-Fresnel principle, the wavefront of the beam in some plane P behind the screen can be represented as The result of the superposition of elementary waves (wavelets) emitted from each point of the hole. It is seen that, because of the finiteness of the diameter of the hole D, the beam must have a finite divergence. The magnitude of the angle of diffraction divergence (relative to the beam axis) can be determined from the expression:

$$\theta_d = \beta\lambda / D \text{ , (2)}$$

where β is a numerical coefficient of the order of unity, the exact value of which depends on the shape of the hole and the type of distribution of the intensity of radiation in its plane. In the case of an infinite slit of width D, the coefficient β = 1. In the case of a uniformly illuminated circular hole, β = 1.22. A beam whose divergence angle can be expressed by the relation (3.2), in which β ~ 1, is called diffraction-limited. If the laser beam leaves the circular hole with a diameter D, the total divergence of the diffraction-limited beam will be determined as

$$\theta_{DL} = 2\theta_d = 2{,}44\lambda / D \text{ (3).}$$

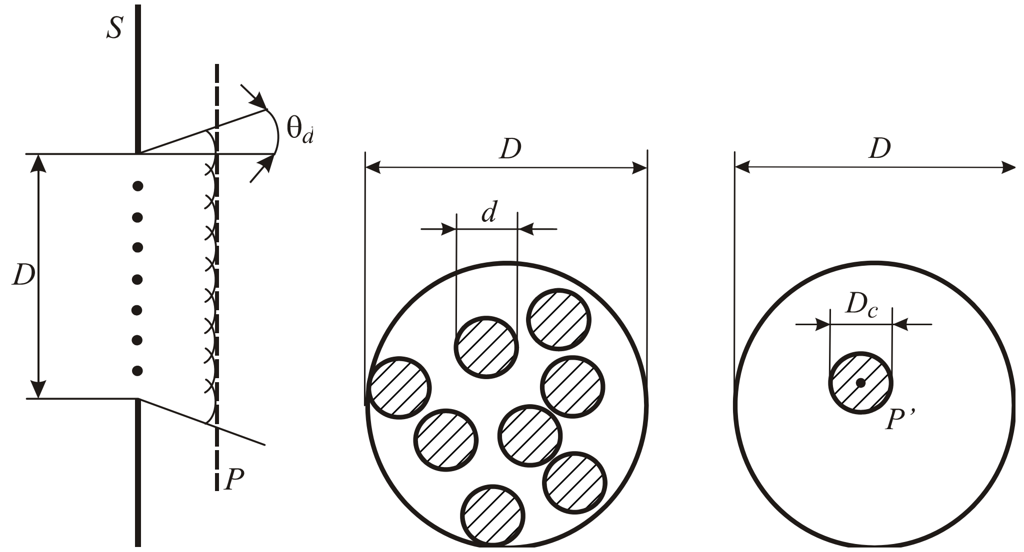
If the beam has only a partial spatial coherence, then its divergence will be greater than the minimum value due to diffraction. Indeed, for any point P' of the wave front, the Huygens-Fresnel principle can be applied only to points lying in the limits of the coherence area S_c near P'. Thus, the dimensions of the coherence region play the role of a limiting hole for coherent superposition of elementary waves. If the beam of diameter D consists of a set of uncorrelated beams of smaller diameter d (Fig. 2b), each of which is diffraction-limited (that is, spatially coherent), the divergence of the entire beam in the integral is θ_d = Bλ/d. If such beams were correlated-that is, their radiation would be synchronous, then the divergence would be θd = βλ/D. In the general case, when the beam has a predetermined distribution of diameter intensity and a coherence region of diameter Dc at a given point P (Figure 3.2, b), the divergence angle will be defined as

$$\theta_d = \beta\lambda / D_c . \qquad (3.4)$$

Thus, the concept of directivity is closely connected with the concept of spatial coherence.

Since the waves emitted from each coherence region are generally not coherent with each other, at large distances (in the far zone), it is necessary to summarize not the intensity but the intensities of the fields. Let the wave be two coherent beams from neighboring sources, with a diameter of the cross section Dc each (Fig.3.3), and these beams are not coherent with each other. We set Dc = 100 μm and λ = 0.5 μm. In accordance with (3.4), we have θd = 2 • 10-2 rad, so that at a distance, for example, L = 25 m, the diameter of the cross section of the beam emanating from the first coherence region will be equal to

$$D \approx D_c + 2\theta_d L \approx 2\theta_d L = 1 \text{ m} .$$



a) b)

Fig. 2. The divergence of a plane, spatially coherent, electromagnetic wave due to diffraction (a) and examples of beams with partial spatial coherence (b).

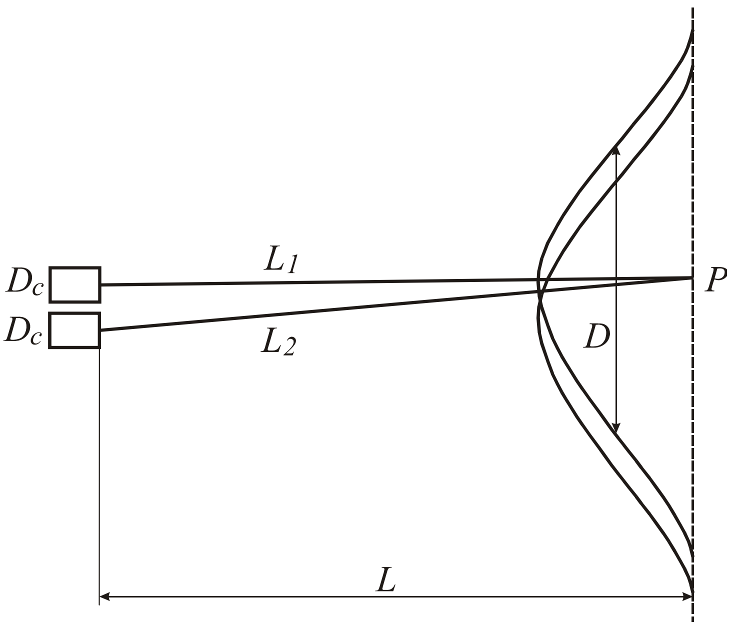


Fig. 3. Transverse radiation profiles from two coherent sources at a large distance

In the same plane, the diameter of the cross section of the beam originating from the second region of coherence will also be equal to D, and the cross sections will be shifted by a negligibly small value equal to D_c. Thus, at large distances the total beam will have the same transverse dimensions as the beam coming from one coherence zone.

So, we have

$$D = 2\theta_d L = 2(\beta\lambda / D_c)L . \qquad (5)$$

Consequently, the divergence angle of the beam is

$$\theta = D/2L = \beta\lambda / D_c. \qquad (6)$$

Measurement of radiation divergence

The divergence of the radiation of interest to us is determined, of course, by the field structure in the far field. One can measure the direction or divergence of a laser beam by two main ways.

1) By measuring the beam pattern at a large distance from the source. Let D1 be the diameter of the beam, measured at a very large distance L from the source (in the far zone). Then the half-angle of the beam pattern θ (Figure 3.4) can be obtained from the relation:

$$\theta = 2 \cdot \mathrm{arctg}(D_1/2L) \approx D_1/L. \quad (7).$$

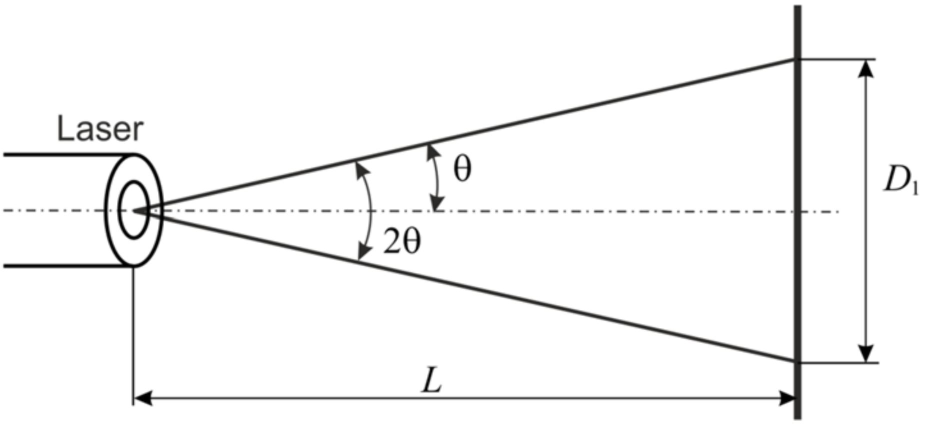


Fig. 3. Measuring the divergence of radiation in the far-field zone.

In laboratory measurements, measuring the characteristics of a laser beam directly in the far zone is sometimes problematic due to linear dimensions. As indicated above at D = 4 mm and λ = 632.8 nm, the length of the near zone is of the order of 25 m. Accordingly, measurements of divergence and transverse dimensions of the beam should be performed at distances greater than 25 m. Therefore, in laboratory practice for field measurement in the far-field zone, the method of focusing radiation is usually used.

2) The method of focusing radiation consists in measuring the radial distribution of the intensity I (r) of the beam, focused in the focal plane of the lens.

The lens (in the absence of aberrations) transforms the flat front of the wave into a spherical wave, i.e. Into a dot image in the focus of the optical lens. If the wave is not flat (that is, the ray diverges), then a circular image of the finite dimensions with a diameter d is obtained in the focal plane

$$d = \theta \cdot F, \quad (8)$$

where F is the focal length of the lens.

Thus, in order to measure the divergence of θ, i.e. At half the intensity, it is necessary to use an aberration-free object with a known focal length and aperture of a larger beam cross section, measure the value of d at the level $I_{max}/2$ and substitute θ in formula (8). The greater the focal length of the lens (lens), the more accurately the value of θ will be determined. The value of d can be determined by a photographic method - by placing the film in the focal plane, followed by photo-metering using standard techniques.

You can use the method of calibrated diaphragms. In this case, placing alternately the diaphragms with a known diameter d1 in the focal plane, measure the intensity (intensity) of the transmitted radiation (using a standard laser power meter or photomultiplier, followed by amplification of the signal if its value I_s small). Accordingly, for $d_1>d$, all radiation passes through the diaphragm, with $d_1<d$ - only a part. With the passage of half the intensity, $d_1=d$. Then determine θ.

Another simple variant of the definition of θ is possible, combining both previous methods, and more accurate. In the focal plane of the long-focus lens, a diaphragm with a diameter d1 is known to be much smaller than d. Then, by precisely moving the diaphragm across the beam axis, a radial beam intensity distribution is obtained; determine I_{max}, and d at the level $I_{max}/2$. As a radiation receiver, either a power meter or another standard instrument is used here.

More precise determination of the divergence of the laser beam is possible with the involvement of more complicated methods.

Measurement of transverse beam dimensions

The transverse dimensions of the beam can be easily determined for visible radiation of dimensions over several millimeters. The easiest way is visual. Here several options are possible. The first is simply by measuring the diameter of the beam (with the use of safety glasses!). The second is by passing an unfocused beam through a set of calibrated diaphragms (but of course, there is a much larger diameter d_2 than in the case of determining the divergence of the radiation). At d_2 = D, all radiation must pass through the diaphragm. This value is taken as the diameter of the beam. With transverse beam dimensions of about 1-2 mm and less, the techniques described give a big error. In this case, expanding the beam dimensions with an objective lens with a larger aperture than the beam cross section and the known focal length have the following picture (Fig. 5).

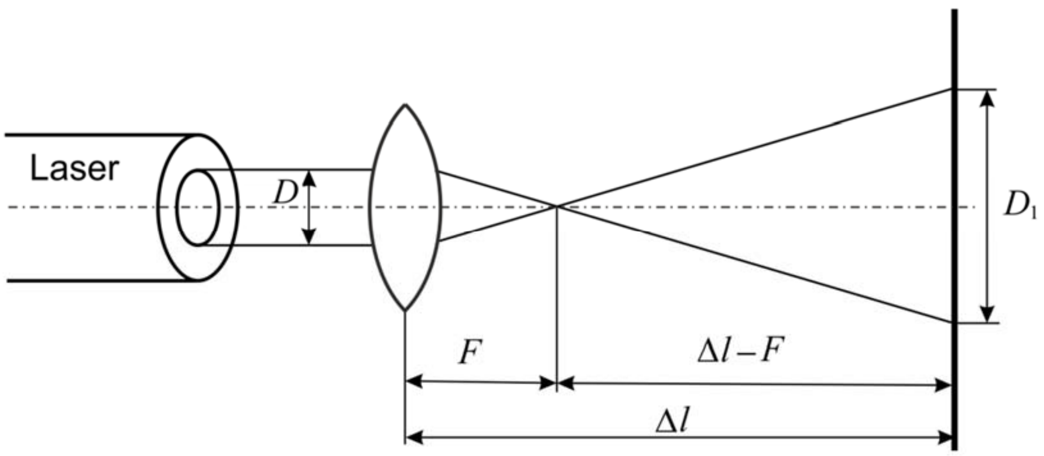


Fig. 5. Scheme for measuring the transverse dimensions of a laser beam

From geometric considerations, we have:

$$D = \frac{D_1 \cdot F}{\Delta l - F} \quad . \qquad (9)$$

With the definition of the transverse dimensions of the beam of radiation of the invisible spectral range, the situation is somewhat more complicated. Here it is necessary to use special radiation receivers (as, indeed, when measuring the divergence of radiation).

In-lab task

1. Measure the divergence of the emission of a helium-neon laser.
2. Measure the diameter of the helium-neon laser beam.
3. Measure the divergence of the solid-state laser radiation.
4. Measure the diameter of the solid-state laser beam.
5. Compare the results with the calculated data for the case of diffraction divergence.
6. Express your opinion about the accuracy of measurement of these quantities.

Control questions:

1. What is the divergence of laser radiation?
2. What determines the divergence of radiation?
3. What are the components of laser radiation?
4. How is the minimum divergence of the radiation beam limited?
5. How to reduce divergence? Can we make it null?
6. What methods of measuring divergence do you know?
7. Explain the concepts of Fresnel diffraction and Fraunhofer diffraction.
8. How does the diameter of the beam correlate with the diameter of the GRT?
9. How to choose the distance from the output window of the laser to the lens and from the lens to the screen when measuring divergence?
10. At what distance from the radiation source should be measured beam divergence?