Laser Beam Characterization by using Rayleigh Scattering

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Abstract

It is proposed a new method based on Rayleigh scattering in which the M^2 parameter is estimated with a single view of the laser beam. In the device described here, the laser beam is focused into a scattering cell and the laterally scattered light is imaged on to a CCD camera allowing a complete view of the laser beam diameter evolution. Using this new technique to measure M^2 parameter of a single mode He-Ne beam laser we obtained M^2 = 1.2 that is close to the actual value M^2 = 1.1.

Introduction

There are many applications in which the accurate knowledge of the laser beam diameter and divergence is critical [1]. One of the most accepted ways of characterize the "quality" of the laser beam is by measuring the so called M^2 parameter, that indicates how many times the laser beam divergence exceeds the diffraction limit. The M^2 parameter is obtained by measuring the diameter of a focused laser beam in several positions of the beam path. The measuring of the beam diameter can be accomplished with a mechanical scanning device consisting of a rotating drum containing a knife-edge, slit, or pinhole that moves in front of a single element detector. More accurate and fast measurements of the laser beam width are obtained with a CCD camera that provides a direct and real time view of the laser beam profile. However, in all these methods a real time assessment of M^2 parameter is impeded since many measurements of the beam width through the laser beam pathway are necessary. To overcome this problem we proposed a new method based on Rayleigh scattering that allows estimating the laser beam quality (i.e., M^2 parameter) with only one measurement. The main idea of the method is that the light scattered by tiny randomly oriented molecules streams out in every direction (elastic scattering). Such incoherent luminous source can be easily imaged by an optical system, and in this way, we have a complete lateral view of the laser beam, where each point on image plane is proportional to the intensity of the actual laser beam at equivalent location on object plane.

Experimental Setup

Figure 1 shows a diagram of the experimental setup used at this work. The beam of a single-mode HeNe laser (M^2 = 1.1) is focused with lens L1 (f = 40 mm) into a scattering cell containing a very small quantity of aniline diluted on water. The lateral scattered light is imaged onto a digital camera (Kodak, KC120, 8-bits, 1260 x 980 pixel) connected to a computer. A cylindrical lens L2 (f = 80 mm) magnify 7 times the image of the laser beam only in one direction transversal to the optical axis of the cell.

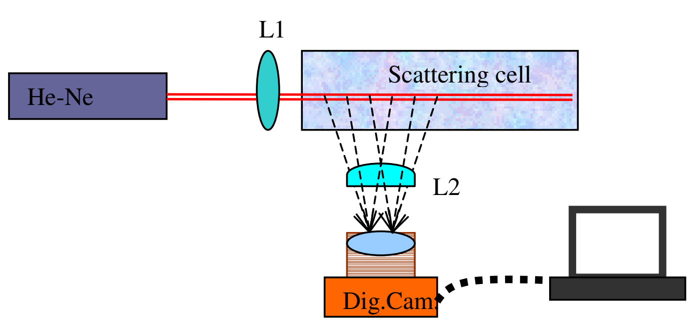

Figure 1: Experimental setup for laser beam characterization by using Rayleigh scattering.
(L1: spherical lens, f = 40 mm; L2: cylindrical lens, f = 80 mm)

A typical digital image (y:z = 32:880 pixels) of the laser beam scattered on the cell is shown in Figure 2. Taking into account the magnification of the image in the y-axis, each pixel represents a 11 µm × 80 µm rectangle, which corresponds on the image plane to the integrated intensity (on x direction) of the actual laser beam.

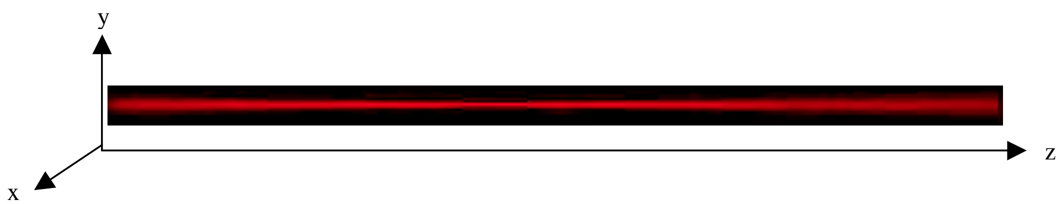

Figure 2: Digital image of the scattered laser beam (y: 32 pixel; z: 880 pixel).

Results and Discussions

The effective beam diameter can be defined in any of a number of ways [2]: the $1/e^2$ diameter of the intensity profile, the second moment of the intensity distribution, the 10-90 % power transmission diameter (knife-edge method), etc. In this work, taking into account that we have only an integrated lateral view of the laser beam, two methods are more suitable:

- fitting the experimental data to a Gaussian profile with the diameter $2W$ defined by $1/e^2$ level that work well only for symmetric Gaussian beams, that is our case;
- knife-edge method in which the laser beam diameter is defined by a clip width D_C of the beam between 10 % and 90 % (the clip levels) of the total power [3]; this method is suitable for multimode lasers.

According to Siegmann [3], the two definitions for the laser beam diameter are related by:

$$2 \cdot W = 1.561 \cdot D_C \tag{1}$$

Figure 3 shows the typical results for a laser beam measurement, where the experimental data for the laser intensity (each point is equivalent to one pixel of the image) is represented by boxes and the dots represents the curve fitting of the experimental points to a Gaussian function with beam radius W. In the same Figure, we plot the laser power $P(y)$ as a function of lateral dimension y. The clip levels at 10 and 90 % that define the clip width D_C are shown by the dashed lines.

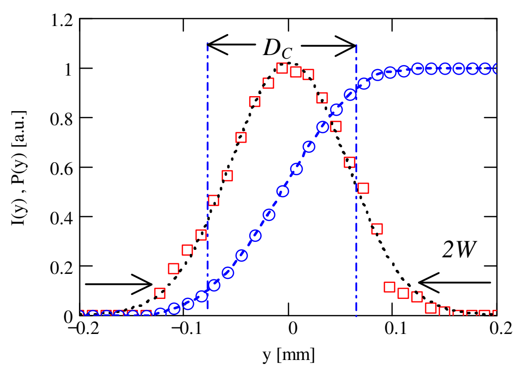

Figure 3: Measurement of beam diameter. (··· : I(y) Gauss. fit; □ : I(y) exp. ; -o- : P(y) exp.)

Figure 4 shows the evolution of the laser beam radius as a function of the propagation distance z, obtained applying the two methods in every column of the image shown on Figure 2. As it can be seen both methods agree very finely as it would be expected for a quasi-Gaussian beam. It should be stressed that it is not true for a multimode laser beam, in which the knife-edge method would be preferred.

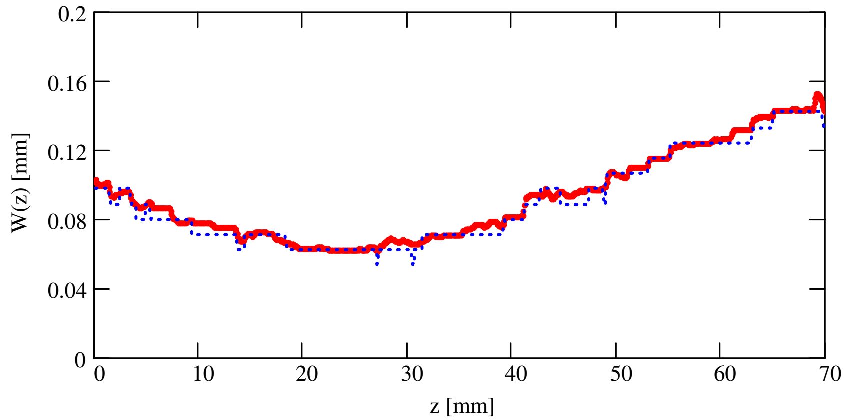

Figure 4: Beam radius versus propagation distance z. (——: Gaussian ; - - - -: Knife-edge)

The International Organization for Standardization (ISO; Geneva, Switzerland) [4] defines the method required to accurately measure the propagations factor M^2, which is based on a multiple-beam-width measurements made through the waist. All the propagation parameters of the laser beam are obtained by curve fitting the measured data with the expression [5]:

$$W^2(z) = W_0^2 + \theta^2 \cdot (z - z_0)^2 \quad (2)$$

where $W(z)$ represents the beam radius at axial distance z, W_0 is the waist radius located at axial distance z_0, $\theta = M^2 \cdot \lambda_n / (\pi \cdot W_0)$ is the laser beam divergence, and λ_n is the laser wavelength in the medium with refraction index n = 1.33 (water). The accuracy of the parameters depends on the number of measurements taken through the propagation distance z. The main advantage of the method proposed here is the great number of diameter measurements that are obtained taken only one picture of the laser beam (e.g., in the Figure 4, 880 measurements were taken). Fitting the experimental data shown on Figure 4 to the function defined by equation (2), as it shown on Figure 5, we obtained for the laser beam propagation factors:

$W_0 = 0.065 \pm 0.01$ mm; $z_0 = 23.3 \pm 0.2$ mm, $\theta = 2.9 \pm 0.1$ mrad, and $M^2 = 1.2 \pm 0.2$.

Taking into account the error caused by the pixel resolution the values obtained here agree reasonably with the actual parameters for this laser ($M^2 = 1.1$).

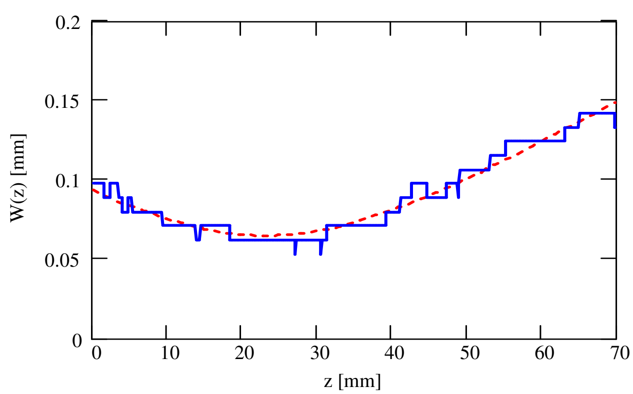

Figure 5: Curve fitting of the laser beam radius W(z) versus propagation distance z.
(- - - - : Fit Eq. (2) ; ——: experimental data)

Conclusions

The results obtained in this paper confirm that the method proposed here works very well to characterize a laser beam taking only one picture of the beam, and in this way it opens the possibility to measure also the beam parameters of pulsed lasers. It can be useful too in real time detecting of any fluctuations of the laser beam parameters.

Acknowledgements

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