

# The measurement of a transverse profile of laser beam by Knife Edge method

## 1. The theoretical part

### 1.1 The propagation of Gaussian beam

The Gaussian beam is fundamental solution of electromagnetic field in the optical resonator and is noticed as  $TEM_{00}$ . Transversal intensity distribution  $I$  of this mode is given by gauss function:

$$I \approx A_0 \exp\left(\frac{-2(x^2+y^2)}{w^2}\right) = A_0 \exp\left(\frac{-2r^2}{w^2}\right) \quad (1)$$

where  $A_0$  is a amplitude of the intensity,  $x$  and  $y$  are Cartesian coordinates,  $r$  is a radial coordinate and  $w$  is a beam radius. The beam radius  $w$  is defined as the spatial distance between the axis and the point, where the intensity decreases to 13.5% of its maximal value (see Fig. 2).

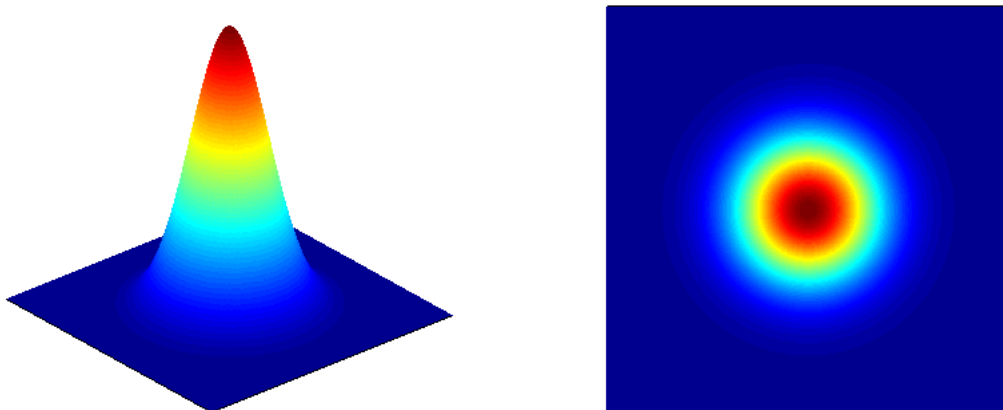


Fig. 1 The model of Gaussian beam

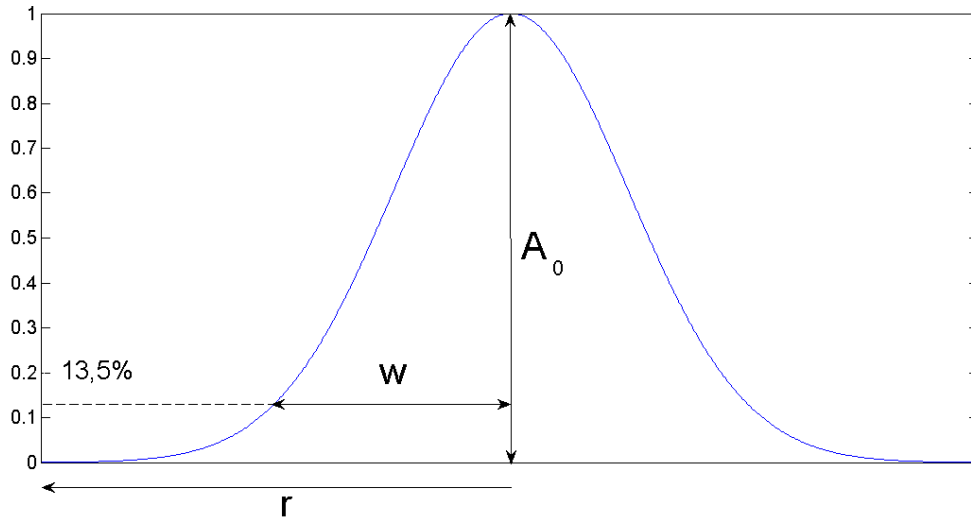


Fig. 2 The Gaussian beam with basic parameters

In the process of Gaussian beam propagation the beam radius is variable. The position with the smallest radius of beam is called waist and the corresponding radius is noticed as  $w_0$ . Due to the divergence the beam radius increases with the rising distance. The distance where the area of the beam (the spot) is twice bigger than the area in the waist is called Rayleigh's range and usually noticed as  $z_0$ . The dependence between the beam radius  $w$  and the distance  $z$  from waist  $z_1$  is defined by the formula:

$$w = w_0 \sqrt{1 + \left(\frac{z-z_1}{z_0}\right)^2} \quad (2)$$

In the Fig. 3 is shown the Gaussian beam propagation.

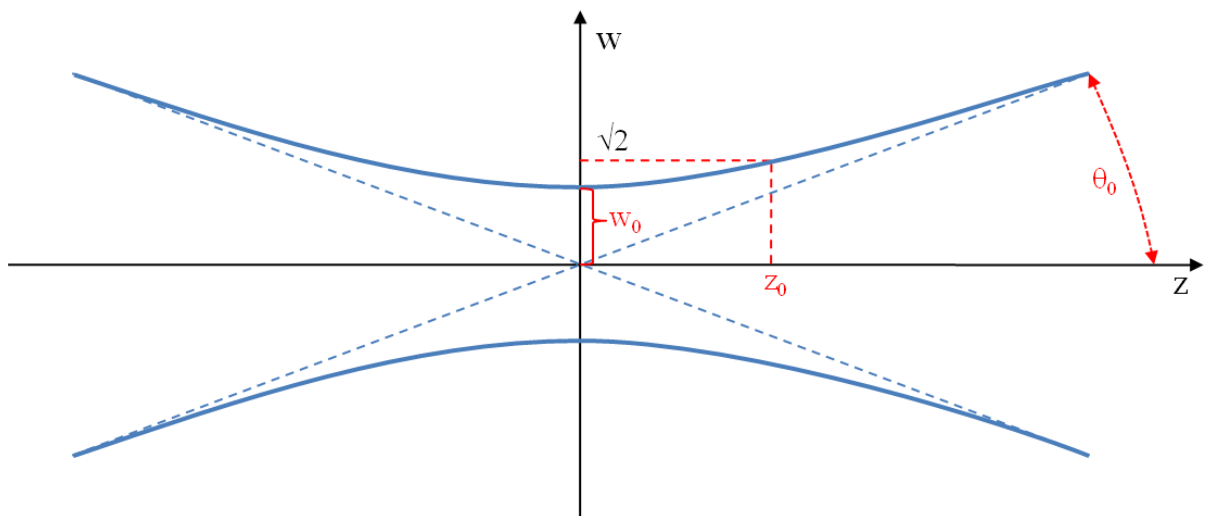


Fig. 3 Propagation of the Gaussian beam

For the propagation of the Gaussian beam the following invariant applies:

$$w_0 \theta_0 = \frac{w_0^2}{z_0} = \theta_0^2 z_0 = M^2 \frac{\lambda}{\pi} \quad (3)$$

where  $\theta_0$  is a beam divergence,  $\lambda$  is a radiation wavelength and  $M^2$  is a parameter corresponding to the laser radiation quality. Multiplication on the left side of the equation (3) is called *BPP* parameter (*beam product parameter*) and its minimal value is given by the diffraction limit. In the ideal case the  $M^2$  parameter equals to 1 and exactly represents the Gaussian beam. Due to the nonhomogeneity, diffraction losses, the laser type or laser power the  $M^2$  parameter is greater than 1 and corresponds to the laser beam having worse quality which is not exactly Gaussian.

## 1.2 Knife Edge method

For many laser applications the beam quality is cardinal because it defines the smallest possible beam area in the focal point. The determination of the  $M^2$  parameter belongs to fundamental measurement for the laser output characterization.

Several methods for the  $M^2$  parameter determination were developed and the knife edge method belongs to the widely used. Its main advantage is the simplicity and possibility to use for wide range of radiation wavelengths.

The measurement principle is as following: The beam is focused by a lens and in the focal point (not correspond with the focal point in the case geometrical optic) the beam waist is located. In the variable distance  $z$  from the position of the waist the beam is progressively covered by a knife edge (blade) and the transmitted power is measured.

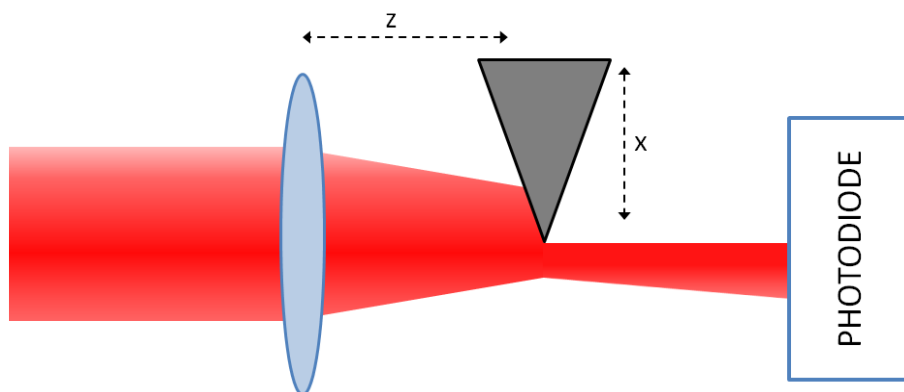


Fig. 4 The principle of Knife Edge method

In the case when the beam is not covered by the blade the measured power reaches its maximal value. On other side the measured power is minimal when the blade covers the whole laser beam. We obtain a similar dependence as is shown in the Fig. 5 by progressively covering of the beam.

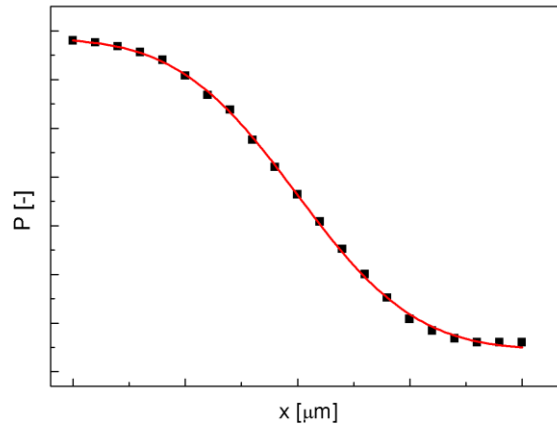


Fig. 5 The typically curve obtained during the measurement by the Knife Edge method

The measured datas we can fit by the equation:

$$P = P_0 + \frac{P_{max}}{2} \left( 1 - \operatorname{erf} \left( \frac{\sqrt{2}(x-x_0)}{w} \right) \right) \quad (4)$$

where  $P_0$  is a background power,  $P_{max}$  is a maximal power,  $x_0$  is a position of shift with the half of real power, and  $\operatorname{erf}$  is a standard error function; we obtain a value of the beam radius  $w$ . We repeat this procedure in the next distance  $z$  also for similar dependence acquirement. All obtained values of the beam radius  $w$  with respect to distance  $z$  we can fit by formula (2) for calculation of the waist, Rayleigh's parameter and the divergence or the  $M^2$  parameter by the formula (3).

## 2. The measurement goals

1. Move the blade to the position it doesn't covers the beam of He-Ne laser.
2. Remove carefully filters from a photodiode and check the incidence of beam on the active area of the photodiode with the dimensions of 10 x 10 mm. Put the filters back.
3. Switch on the oscilloscope.
4. Switch on the photodiode - the switcher is on the bottom side of the photodiode. Check the connection between the photodiode and the oscilloscope (channel 1) using a BNC cable.
5. Set the automatic triggering mode of the oscilloscope using the menu "Trigger", item "Mode" and select ("Auto" or "Untriggered roll").

6. Move the blade to the position where it covers the whole laser beam. On the oscilloscope check the background level with the maximal value up to 60 mV. This background level should be without significant fluctuations. In the case of necessity dim the laboratory light.
7. Move the blade to the position where it doesn't cover the beam. Check the voltage on the oscilloscope (acceptable value is in the range from 300 to 1000 mV). In the case of smaller or higher value consult the situation with the lecturer.
8. Check up the range of shift in z - axis direction and propose the step of measurement for at least of 10 measurements of the transverse profile of the focused beam.
9. The measurement in each point on the z - axis is performed in the following way:  
  
Check up the shift of blade in the x - axis from the position where it fully blocks the laser beam to the position where the beam is not blocked and therefore it fully incidents on photodiode. Calculate the measurement step in order to perform approximately 20 measurements. Afterwards measure the voltage change on the photodiode with the calculated step. The obtained transversal profile of the laser beam should be similar as the curve shown in the Fig. 5. It is important to determine the maximal and minimal value of the curve (points on the wings of the curve). More point on the wings of curve is useful and helpful for the fitting using formula (4).

### 3. The processing goals

1. The data processing perform in a computer program which has the possibility for definition of new function and for curve fitting. A suitable software (freeware) is SciDAVis (download on the link <http://ftp.jaist.ac.jp/pub/sourceforge/s/project/sc/scidavis/SciDAVis/0.2.4/> or <http://download2.polytechnic.edu.na/pub4/sourceforge/s/sc/scidavis/SciDAVis/0.2.4/>). Next possible programs are Origin, Matlab etc. The following description is valid for SciDAVis, in Origin the functions are similar. In the case of necessity is possible change of language in the software (Edit -> Preferences -> General -> Language).
2. In the new table assign dates from one measured transverse profile of beam profile : the voltage on the photodiode (column Y) depending on the blade position (column X).
3. Plot the measured points (scatter plot).
4. In the menu *Analysis* choose the item *Fit wizard* (Ctrl+Y).
5. Choose a new function in category *user defined* and in the dialog window (bottom) insert the right side of the function (4). In the box *Parameters* define the variable names and save this new function.
6. Press button *Fit >>* for display dialog window in which the initial variables values can be estimated.
7. Insert initial guess and press button *Fit*.

8. If the software finds the solutions and variables values, the red fitted curve will be shown in the graph. The fitted curve should be similar as a curve shown in Fig.5. If the fitting is not successful, you should try to insert different initial values.
9. The optimal variables values will be displayed in the top window. Find the value of the beam radius and note it in the new table ( preferably in a new document) together with the corresponding z-axis position.
10. Repeat the procedure for all measured transverse beam profiles (at different positions on the z-axis).
11. Values beam radius  $w$  depending on the position  $z$  fit by equation (2) and determinate beam waist  $w_0$  and Rayleigh's range  $z_0$ .
12. According to these parameters calculate the  $M^2$  parameter and divergence  $\theta_0$  using by the equation (3). The He-Ne laser wavelength is 632.8 nm.

#### 4. The required results

1. The report should contain at least 5 curves with the transverse laser beam profile together with the optimal fitting.
2. Include the graph of the beam radius depending on the distance with the calculated optimal parameters - the beam waist, Rayleigh's range, divergence and  $M^2$  parameter.
3. Try to explain why the calculated  $M^2$  parameter is higher than 1.

#### 5. References

- [1] Koechner, W. *Solid-State Laser Engineering*. New York, USA : Springer, 2006. 742 s. ISBN 0-387-29094-X.
- [2] Vrbová, M., Jelínková, H., Gavrilov, P. *Úvod do laserové techniky*. Praha : Vydavatelství ČVUT, 1998. 209 s.