

Laser

Beam Profile, Spot size and Beam Divergence

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Aim

As the title suggests, we try to measure the Beam Spot size and Beam Divergence of a Laser beam using a detector in various ways. We also try and see that the beam profile is Gaussian.

1 Theory

1.1 Definitions

- **Beam Spot Size:** Beam Diameter is defined as the distance across the center of the beam for which the irradiance(I) equals $\frac{1}{e^2}$ of the maximum irradiance. The spot size of the beam is the radial distance from the center of maximum irradiance to the $\frac{1}{e^2}$ points.
- **Beam Divergence:** The beam divergence of an electromagnetic beam is an angular measure of the increase in beam diameter with distance from the optical aperture from which the electromagnetic beam emerges. It is given by

$$\theta = \frac{w_1 - w_2}{d}$$

where w_1 and w_2 are the beam spot sizes of a laser beam mounted at two points separated by a distance d .

1.2 Few Details

Having, setup the definitions, let us try and look at the implications of both the quantities that we aim to measure. A Gaussian beam is a beam of electromagnetic radiation whose transverse electric field and intensity (irradiance) distributions are described by Gaussian functions. Many lasers emit beams with a Gaussian profile, in which case the laser is said to be operating on the fundamental transverse mode, or TEM_{00} mode of the laser's optical resonator. When refracted by a lens, a Gaussian beam is transformed into another Gaussian beam (characterized by a different set of parameters), which explains why it is a convenient, widespread model in laser optics. This is the reason why the dispersed beam which we get by using a disperser has a Gaussian Profile too. The Electric Field Amplitude of a Gaussian beam can be given by

$$E(r, z) = E_0 \frac{w_0}{w(z)} \exp \left\{ \frac{-r^2}{w^2(z)} \right\} \exp \left\{ -ikz - ik \frac{r^2}{2R(z)} + i\zeta(z) \right\}$$

where r is the radial distance from the center axis of the beam
 z is the axial distance from the beam's narrowest point (the waist)

$k = \frac{2\pi}{\lambda}$ is the wave number (in radians per meter)

$w(z)$ is the radius at which the field amplitude and intensity drop to $1/e$ and $1/e^2$ of their axial values respectively

w_0 is the waist size.

From this the intensity or the irradiance can be calculated as follows

$$I(r, z) = \frac{|E(r, z)|^2}{2\eta} = I_0 \left\{ \frac{w_0}{w(z)} \right\}^2 \exp \left\{ \frac{-2r^2}{w^2(z)} \right\}$$

where η is the characteristic impedance of the medium in which beam is propagating. For free space it is nearly 377Ω . Let's now see Beam Divergence. The divergence of a beam can be

calculated if one knows the beam diameter at two separate points (w_1, w_2), and the distance (d) between these points. The beam divergence is given by

$$\theta = 2 \arctan \frac{w_2 - w_1}{2d}$$

For the laser we observe that the divergence is very less. So, we can approximate $\tan \theta$ to θ . Hence giving

$$\theta = \frac{w_2 - w_1}{d}$$

The divergence of a laser beam is proportional to its wavelength and inversely proportional to the diameter of the beam at its narrowest point.

2 Procedure

The laser that we are working with is a rectangular one. So, any measurement done should have two primary orientations taken into consideration and the results should be given for both the orientations separately.

The setup is very simple. We have a laser and a detector (for measuring the intensity) set on an optical breadboard. We have few attachments like a disperser and a small aperture cap which can be fixed on the detector. Firstly, we start with the alignment of the laser beam. We can do this by slowly adjusting the laser in its support while checking the intensity pattern along two virtual horizontal lines at different heights on the beam cross-section. After this is done, we fix a distance for the detector and take intensity measurements of the beam along a horizontal line passing the point with the maximum intensity. This can be repeated with variants like with disperser alone, with cap alone, with disperser and cap. Similar readings can be taken for the vertical orientation of the laser beam too. But, I did these variants only for the horizontal orientation.

For calculating the beam divergence, we calculate the maximum intensity of the beam, which helps in calculating the beam spot size, at different distances from the laser with the help of the optical bread board. These can also be tabulated and the resulting calculations lead to the necessary results.

3 Observations and Results

P.S. : MOST OF THE DATA IS ATTACHED SEPARATELY.

The only tabulated data here is the maximum irradiance versus the distance from the laser data.

S.No	Dist from laser(l) cm	Max Intensity	Spot size (w)
1	42.5	40.6	3.8
1	55.0	40.6	3.8
2	67.5	40.5	3.8
3	80.0	40.4	3.8
4	92.5	40.2	3.7

- Spot size for collimated beam in horizontal orientation = $3.8cm$
- Spot size of beam with the cap and disperser in horizontal orientation = $8.6cm$
- Spot size for the beam with the disperser in horizontal orientation = $9.4cm$
- Spot size for the beam with detector with a cap in horizontal orientation = $2.7cm$
- Spot size of the collimated beam in vertical orientation = $1.9cm$
- Beam Divergence is observed to be $=0.002rad$ in $50cm$.

Few Observations

- When we used the small aperture cap, there were regions where the beam intensity did not fall or atleast the change is not apparent. This can be attributed to the diffraction due to the presence of this small aperture which though gives a better profile does not help the cause completely.
- The Horizontal and Vertical Orientation profile of the beam is plotted and is observed that the Laser beam is gaussian extended in horizontal direction.
- We can see from the beam divergence that the laser is very well collimated.