Experiment Number 5
The laser beam parameters
EP3290

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1 Aim

To determine the various parameters of a laser beam. Beam Divergence (θ_o), and Beam spot size.

2 Objectives

a. To understand the concept of laser.

b. To explore application areas of laser.

c. To calculate the divergence and spot size of the given laser beam.

3 Apparatus

a. He-Ne gas laser

b. Light detector with power output

c. Constant Power supply

d. Meter scale

4 Theory

4.1 Laser

The term LASER is the acronym for Light Amplification by Stimulated Emission of Radiation. It is a mechanism for emitting electromagnetic radiation via the process of stimulated emission. The laser was the first device capable of amplifying light waves themselves. The emitted laser light is a spatially coherent, narrow low-divergence beam. When the waves(or photons) of a beam of light have the same frequency, phase and direction, it is said to be coherent . There are lasers that emit a broad spectrum of light, or emit different wavelengths of light simultaneously. According to the encyclopedia of laser physics and technology, beam divergence of a laser beam is a measure for how fast the beam expands far from the beam waist. A laser beam with a narrow beam divergence is greatly used to make laser pointer devices. Generally, the beam divergence of laser beam is measured using beam profiler. Divergence means “Departure from norm or Deviation”. The beam divergence of laser beam is the measure of increase of diameter or radius. A laser beam consists of very nearly parallel light rays, the beam diameter increases far more slowly with distance from the light source as compare to the light beam from a other light sources.

4.2 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 if the radial distance from the center of maximum irradiance to the $\frac{1}{e^2}$ points.

4.3 Beam Divergence

The beam divergence of an electromagnetic beam is an angular mea- sure of the increase in beam diameter with distance from the optical aperture from which the electromagnetic beam emerges.

4.4 Irradiance distribution I(x,y) and Power transmitted

The irradiance distribution I(x,y) as a function of the Cartesian coordinates (x,y) measured from the beam center perpendicular to the direction of propagation is given by

$$I(x,y) = \frac{2P_o}{\pi\omega_o^2}\exp[-2\frac{x^2+y^2}{\omega_o^2}] \tag{1}$$

Power transmitted past a knife-edge blocking off all points for which x ≤a is, therefore, given by,

$$P = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(x,y)dxdy = \frac{P_o}{2}erfc(\frac{a\sqrt{2}}{\omega_o}) \tag{2}$$

It is easy to show that the points with 25 % and 75 % of relative powers are located at distances equal to the probable error e_p ($e_p \approx 0.6745\omega'$) on either side of the gaussian distribution, maximum Hence, ω' can be obtained from the relative power of knife-edge position curve and beam spot size ($2\omega_o = 4\omega'$) can be calculated.
Divergence: $\theta_o = \frac{1}{\sqrt{2D}}(\omega_3^2 - 2\omega_2^2 + \omega_1^2)^{\frac{1}{2}}$

Spot Size $= \frac{\lambda}{\pi\theta_o}$
Location of Beam Radius: z $= \frac{\omega_1^2 - \omega_0^2}{\theta_o}$

5 Observations

5.1 Measurements with z = 150 mm

(To determine ω_1):

S.No	Position of Knife(mm)	Power Meter Reading(mW)	Noramlized Power meter reading
1	15.00	5.000	1.0000
2	14.75	5.000	1.0000
3	14.50	5.000	1.0000
4	14.25	4.960	0.9920
5	14.00	4.280	0.8560
6	13.75	2.180	0.4360
7	13.50	0.454	0.0908
8	13.25	0.042	0.0084
9	13.00	0.011	0.0022
10	12.75	0.011	0.0022
11	12.50	0.011	0.0022
12	12.25	0.011	0.0022
13	12.00	0.008	0.0016
14	11.75	0.008	0.0016
15	11.50	0.007	0.0014
16	11.00	0.007	0.0014

Figure 1: Experimental Data 1

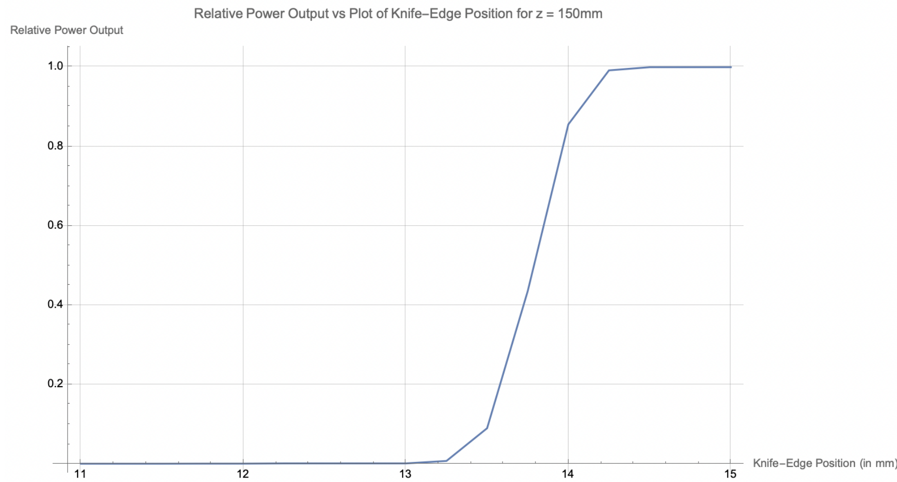

Figure 2: Graph 1

5.2 Measurements with z = 300 mm

To determine ω_2 :

S.No	Position of Knife(mm)	Power Meter Reading(mW)	Noramlized Power meter reading
1	11.0	6.470	1.000000
2	10.9	6.450	0.996909
3	10.8	6.370	0.984544
4	10.7	6.200	0.958269
5	10.6	5.840	0.902628
6	10.5	5.330	0.823802
7	10.4	4.470	0.690881
8	10.3	3.390	0.523957
9	10.2	2.300	0.355487
10	10.1	1.380	0.213292
11	10.0	0.784	0.121175
12	9.9	0.351	0.054250
13	9.8	0.135	0.020866
14	9.7	0.052	0.008037
15	9.6	0.029	0.004482
16	9.5	0.015	0.002318
17	9.4	0.012	0.001855
18	9.3	0.010	0.001546
19	9.2	0.010	0.001546
20	9.1	0.010	0.001546
21	9.0	0.010	0.001546

Figure 3: Experimental Data 2

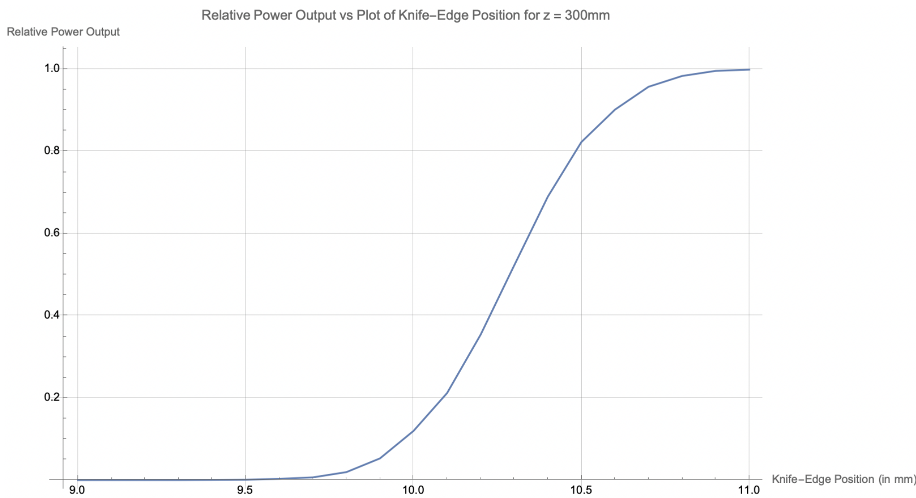

Figure 4: Graph 2

5.3 Measurements with z = 450 mm

To determine ω_3

S.No	Position of Knife(mm)	Power Meter Reading(mW)	Noramlized Power meter reading
1	16.0	5.010	1.000000
2	15.9	5.000	0.998004
3	15.8	5.000	0.998004
4	15.7	4.990	0.996008
5	15.6	4.970	0.992016
6	15.5	4.890	0.976048
7	15.4	4.710	0.940120
8	15.3	4.370	0.872255
9	15.2	3.780	0.754491
10	15.1	3.000	0.598802
11	15.0	2.160	0.431138
12	14.9	1.380	0.275449
13	14.8	0.740	0.147705
14	14.7	0.318	0.063473
15	14.6	0.123	0.024551
16	14.5	0.045	0.008982
17	14.4	0.018	0.003593
18	14.3	0.008	0.001597
19	14.2	0.005	0.000998
20	14.1	0.003	0.000599
21	14.0	0.003	0.000599
22	13.9	0.002	0.000399
23	13.8	0.001	0.000200
24	13.7	0.001	0.000200
25	13.6	0.001	0.000200
26	13.5	0.001	0.000200

Figure 5: Experimental Data 3

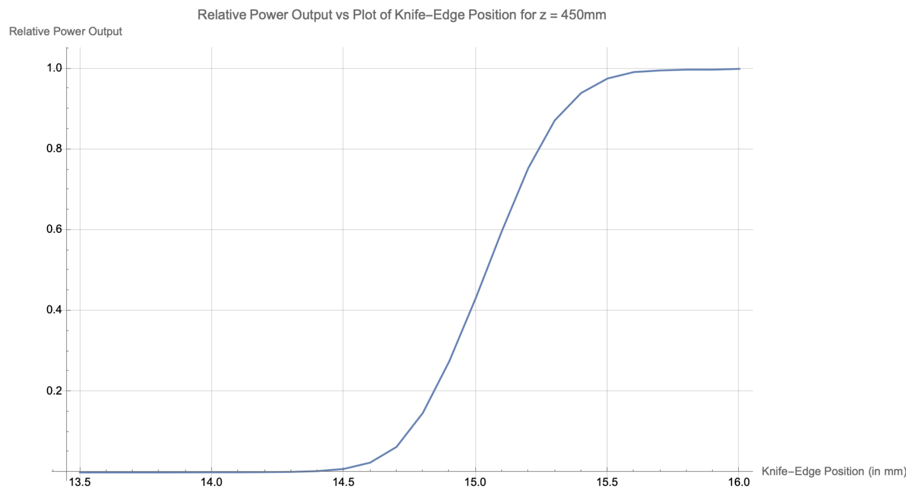

Figure 6: Graph 3

6 Calculations

6.1 For z = 150 mm

75% power at x_{75} = 14.1mm 25% power at x_{25} = 13.65mm

$$2 \times error = |x_{75} - x_{25}| \implies error \frac{0.45}{2} \approx 0.225mm$$

$$\omega_1 = \frac{0.225}{0.6745} /approx 0.333mm$$

6.2 For z = 300 mm

75% power at x_{75} = 10.45mm 25% power at x_{25} = 10.10mm

$$2 \times error = |x_{75} - x_{25}| \implies error \frac{0.35}{2} \approx 0.175mm$$

$$\omega_2 = \frac{0.175}{0.6745} /approx 0.259mm$$

6.3 For z = 450 mm

75% power at x_{75} = 15.2mm 25% power at x_{25} = 14.9mm

$$2 \times error = |x_{75} - x_{25}| \implies error \frac{0.3}{2} \approx 0.15mm$$

$$\omega_3 = \frac{0.15}{0.6745} /approx 0.222mm$$

6.4 Divergence

$$\theta_o = \frac{1}{\sqrt{2}D}(\omega_3^2 - 2\omega_2^2 + \omega_1^2)^{\frac{1}{2}}$$

$$\theta_o = \frac{1}{\sqrt{2}150}(0.222^2 - 2(0.259)^2 + (0.333)^2)^{\frac{1}{2}} \approx 0.76 \times 10^{-3}$$

6.5 Spot size

$$\omega_o = \frac{\lambda}{\pi\theta_o}$$

$$\omega_o = \frac{632.8nm}{\pi \times 0.76 \times 10^{-3}} = 265\mu m$$

6.6 Location of Beam Radius

$$z_o = \frac{(\omega_1^2 - \omega_o^2)^{\frac{1}{2}}}{\theta_o} = \frac{(0.333^2 - 0.265^2)^{\frac{1}{2}}}{0.76 \times 10^{-3}} = 265.3mm$$

7 Error Analysis

We measure ω_1, ω_2 , ω_3 with the help of position of knife edge with L.C = 0.02 mm and Power-meter readings with Lc = 0.001mW.

7.1 Error in measuring ω_i

$$0.6745 \times \omega \times 2 = |x_{75} - x_{25}|$$

$$2 \times 0.6745 \times \omega = 2dx \implies d\omega = \frac{dx}{0.6745}$$

$$\frac{d\omega}{\omega} = \frac{0.02mm}{0.6745 \times \omega}$$

$$\frac{d\omega_1}{\omega_1} = \frac{0.02}{0.6745 \times 0.333} = 0.089$$

$$\frac{d\omega_2}{\omega_2} = \frac{0.02}{0.6745 \times 0.259} = 0.114$$

$$\frac{d\omega_3}{\omega_3} = \frac{0.02}{0.6745 \times 0.222} = 0.134$$

7.2 Error in measuring θ_o

$$\frac{d\theta_o}{\theta_o} = \frac{1}{\omega_1^2 - 2\omega_2^2 + \omega_3^2} \times (\omega_1 \times d\omega_1 + 2 \times \omega_2 \times d\omega_2 + \omega_3 \times d\omega_3)$$

$$\frac{d\theta_o}{\theta_o} = \frac{1}{0.333^2 - 2 \times 0.259^2 + 0.222^2} \times \left(0.333^2 \times 0.089 + 2 \times 0.259^2 \times 0.114 + 0.222^2 \times 0.134\right)$$

$$\frac{d\theta_o}{\theta_o} = 1.22\%$$

7.3 Error in Measurement in Beam Radius ω_o

$$\frac{d\omega_o}{\omega_o} = \frac{1}{\pi}\frac{d\theta_o}{\theta_o} = 0.388\%$$

7.4 Distance of Beam Radii z_o

$$\frac{dz_o}{z_o} = \frac{1}{z_o} d(\frac{1}{\theta_o}.\sqrt{\omega_1^2 - \omega_2^2})$$

$$\frac{dz_o}{z_o} = \frac{1}{z_o} \times \left(\frac{1}{\theta_o^2} d\theta_o \sqrt{\omega_1^2 - \omega_0^2} + \frac{1}{\theta_o} \frac{1}{2\sqrt{\omega_1^2 - \omega_o^2}} 2(\omega_1 d\omega_1 + \omega_o d\omega_o) \right)$$

$$\frac{dz_o}{z_o} = \frac{1}{265.3} \times \Bigg(\frac{1}{0.76 \times 10^{-3}} \times 1.22\sqrt{0.333^2 - 0.265^2} + \frac{1}{0.76 \times 10^{-3}} \times \frac{1}{2\sqrt{0.333^2 - 0.265^2}} \times 2(0.333^2 \times 0.089 + 0$$

$$\frac{dz_o}{z_o} = 2.12\%$$

8 Conclusion

a. Divergence, $\theta_o = 0.76 \times 10^{-3} \pm 1.22\%$

b. Spot size, $\omega_o = 265\mu m \pm 0.38\%$

c. Location of Beam Radius, $z_o = 265.3mm \pm 2.12\%$

9 Sources of Error and Precautions

a. Massive error is propagated due fo ω_1,ω_2 and ω_3 . Ensure that the Power vs knife-edge distance graphs qre sufficiently accurate.

b. Ensure that the laser, knife-edge, and detecter are perfectly with respect to one another so that they form a straight line.

c. Care should be taken to ensure that the laser beam, after reflection off of the detector does not enter into the laser apparatus or human eyes.