Gaussian beam measurement

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Abstract

The relative intensity of the HeNe passing through a polarizer was measured as a function of polarizer angle. This showed nonlinear behavior at high intensities as the photodiode saturates. In the subsequent experiments, a polarizer was placed at $45 \deg$, halving the intensity to a linear region on the photodiode.

The beam profile of the HeNe laser was measured using a knife edge on a translation stage. This was done by slowly incrementing the translation stage perpendicular to the beam, ranging from all light passing through to blocking the light fully. The data was plotted in Origin and a curve fit was applied using an erfc function. This resulted in a beam width of $0.399 \, \mathrm{mm} \pm 0.11 \, \mathrm{mm}$ at a location $21.9 \, \mathrm{cm}$ from the laser shutter.

The beam profile was additionally measured using the "70-30" technique. This was done by finding the relative maximum and minimum intensity, then calculating the 0.30 and 0.70 intensities. At several points along the beam axis, the translation distances was measured for these two intensities. The data was plotted in Origin and a curve fit was applied using a Gaussian width function.

The HeNe laser was profiled to have a beam waist $w_0 = 0.275 \, \mathrm{mm} \pm 16.1 \, \mu\mathrm{m}$, located at the focus $z_0 = -12.1 \, \mathrm{cm} \pm 12.0 \, \mathrm{cm}$ relative to the HeNe laser, i.e. located within the laser.

1 Description of Experiment

In this experiment, we will measure the beam profile of the HeNe laser using a knife edge. To begin, we will verify the powermeter gives a linear reading. This is accomplished by placing a polarizer between the laser and the powermeter wand, then profiling the intensity as a function of the polarizer angle. This data was plotted in Origin with a sinuosodial curve fit. As the powermeter saturates, the polarizer was later used to reduce the intensity to a linear region of the powermeter readings.

Next, a knife edge was mounted on a translation stage perpindicular to the laser beam. The stage was mounted $21.9\,\mathrm{cm}$ from the shutter of the laser. The translation stage was slowly adjusted from allowing the laser to pass to completely blocking the incident light to the powermeter. The corresponding intensity measurements were recorded and plotted in Origin as a function of the translation distance. The fit function used is given by

$$P = P_0 + \frac{P_{\max}}{2}\mathrm{erfc}\left(\frac{\sqrt{2}(x - x_0)}{w}\right) \tag{1}$$

where the measured voltage is proportional to the power P, and w is the waist radius at the distance chosen.

Then, the "70-30" technique was employed to measure the beam waist. This was done by using the maximum intensity of the light and multiplying by 0.30 and 0.70. At various points along the beam, the distance from the laser was recorded, as well as the translation distance at the two intensities. Mirrors were used to redirect the beam, keeping the beam within the optical breadboard. The data was recorded in Origin and a non-linear curve fit was applied using

$$w(z) = w_0\sqrt{1 + \frac{\lambda^2(z - z_0)^2}{\pi^2 w_0{}^2}} \tag{2}$$

From the curve fit, the beam waist w_0 and true origin of the beam z_0 was found.

2 Data and Analysis

With the laser blocked, the powermeter reading was $281.2\,\mathrm{mV}$ from the ambient light. The polarizer was then placed between the laser and powermeter. This data was recorded and plotted in Origin, shown in Figure 1. The resultant fit is poor, due to the nonlinearity of the power meter at high intensities. Because of this, the polarizer was kept at $45.0\,\mathrm{deg}$, resulting in a new minimum of $278.9\,\mathrm{mV}$ and maximum of $339.8\,\mathrm{mV}$.

Fixed point profile measurements

The profile was measured as a function of translation distance of the knife edge at a distance $z = 21.9\,\mathrm{cm} \pm 0.1\,\mathrm{cm}$ from the laser shutter. This data is shown in Figure 2, with the curve fit of form (1) applied. The curve fit results in a width $w = 0.399\,\mathrm{mm}$.

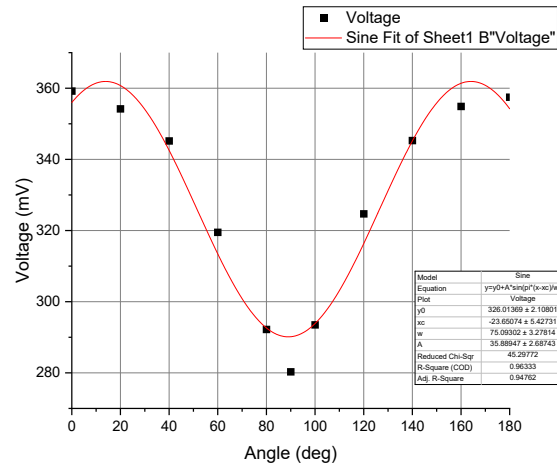| Model	Sine
Equation	y=y0+A*sin(pi*(x-xc)/w)
Plot	Voltage
y0	326.01369 ± 2.10801
xc	-23.65074 ± 5.42731
w	75.09302 ± 3.27814
A	35.88947 ± 2.68743
Reduced Chi-Sqr	45.29772
R-Square (COD)	0.96333
Adj. R-Square	0.94762

Figure 1: The relative intensity as a function of angle. The poor fit is likely due to clipping near the higher intensities caused by the photodiode saturating.
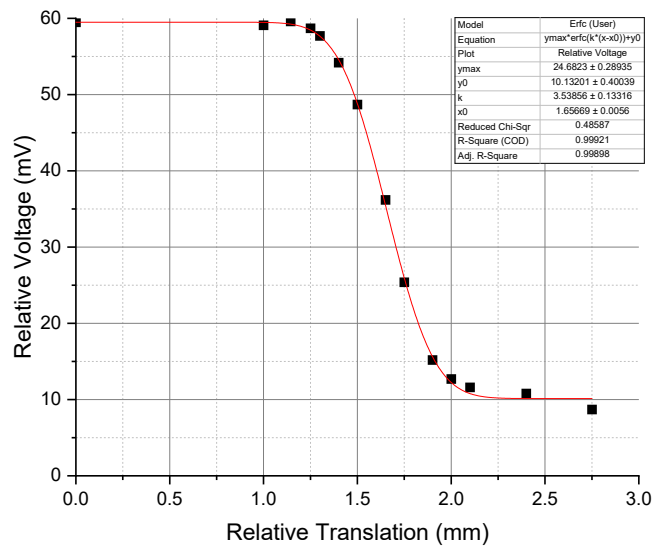

Model	Erfc (User)
Equation	ymax*erfc(k*(x-x0))+y0
Plot	Relative Voltage
ymax	24.6823 ± 0.28935
y0	10.13201 ± 0.40039
k	3.53856 ± 0.13316
x0	1.65669 ± 0.0056
Reduced Chi-Sqr	0.48587
R-Square (COD)	0.99921
Adj. R-Square	0.99898

Figure 2: The beam intensity profile as a function of translation distance.

Beam profile measurements using 30-70 technique

The distance z was measured with ± 1 inch (± 2.54 cm) accuracy using the optical breadboard grid, then using a ruler to measure the offsets relative to the threaded hole. This was plotted and shown in Figure 3. Applying (2), the beam waist $w_0 = 0.276$ mm ± 16.1 µm, with the focus at $z_0 = -12.1$ cm ± 12.0 cm. The uncertainty was calculated using the estimated standard deviation within Origin.

The expected value for the beam waist is roughly 0.33 mm[1], which creates an approximate error of 15.1%.

3 Results and Conclusion

The beam was found to have a beam waist of $w_0 = 0.276$ mm ± 16.1 µm with $z_0 = -12.1$ cm. The negative z_0 implies the laser cavity is confocal within the laser itself. Compared to the $1/e^2$ radius, there was roughly 15.1% error, but this error may be due to imprecise (± 1 in) measurements of the distance z and a poor curve fit.

Model	BeamWidth2 (User)
Equation	w0 * (1 + ((x - x0) / ((pi * w0^2) / lambda)^2)^(1/2))
Plot	Width
w0	2.75756E-4 ± 1.6142E-5
x0	-0.12073 ± 0.12024
Reduced Chi-Sqr	1.34151E-8
R-Square (COD)	0.97991
Adj. R-Square	0.97656
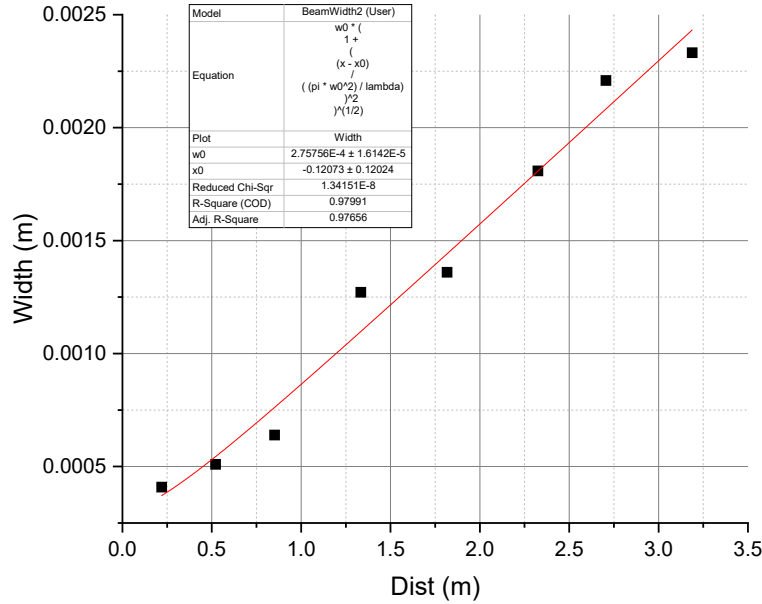
Figure 3: The beam waist as a function of distance along the beam axis.

[1]From the manufacturer website: `https://www.global-optosigma.com/en_jp/Catalogs/gno/?from=page&pnoname=05-LHP&ccode=W5002&dcode=&gnoname=05-LHP-991`

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Data tables

Table 1: Intensity as a function of polarizer angle

Angle (deg)	Voltage (mV)
0	359.2
20	354.2
40	345.2
60	319.5
80	292.2
90	280.3
100	293.5
120	324.7
140	345.3
160	354.9
180	357.5

Table 2: Intensity as a function of translation

Translation (mm)	Intensity (mV)
20	338.4
19	338.0
18.856	338.5
18.75	337.6
18.7	336.6
18.6	333.1
18.5	327.6
18.35	315.1
18.25	304.3
18.1	294.1
18	291.6
17.9	290.5
17.6	289.7
17.25	287.6

Table 3: Beam width as a function of distance from HeNe shutter

Distance (cm)	Beam width (mm)
21.9	0.409
52.07	0.51
85.09	0.64
133.35	1.272
181.61	1.36
232.41	1.809
270.51	2.209
318.77	2.332

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① Setup laser to power meter   1:10

$V_{no\ laser} = 281.2$ mV

Laser saturates, added polarizer #1 at 45°

New $V_{no\ laser} = 278.9$ mV   1:24

② plotted in origin, $z = 21.9$ cm   1:40

③ 30-70 rule

$V_{max} = 339.8$

$V_{max} - V_{min} = 60.9$ mV

$V_{min} + 0.3(60.9) = 297.17$

$V_{min} + 0.7(60.9) = 321.53$

using Step 2 data, position

321.5 mV	18.404 mm	W = 0.409 mm
297.1 mV	18.190 mm	
52.07 cm		

2:08
321.5 mV	17.454 mm	W = 0.510 mm
297.1 mV	17.187 mm	
85.09 cm		
321.5 mV	30.852 mm	W = 0.640 mm
297.1 mV	30.517 mm	
133.35 cm		
321.5	28.200 mm	W = 1.272 mm
297.1	27.534 mm	

181.61 cm

    321.5   21.664 $w = 1.360$

    297.1   20.952

232.41 cm

    321.5   20.684   9.5

    297.1   19.734 $w = 1.809$

217.17 cm

    321.5   27.842   2.248

    297   26.534

270.51

    321   21.250   2.209   13.5

    297   20.093

318.77

    321.5   20.208   2,332

          18.987