ENSC 470/894
Optical Engineering and Laser Applications

Lab 3 – Measurement of Laser Gaussian Beam Profile

Group 12

Siyue Zhao 301207073

Xinwei Zhang 301215429

Lestley Gabo 301170055

1 Introduction

In this lab our goal is to measure the spot size and profile of the laser beams from an HeNe laser and laser pointer. We will then create a beam expander for the two laser beams. Our data then be calculated and analyzed understand the fundamental meaning of the Rayleigh Range of Gaussian beams, Z_R, and its relationship with a beam expander.

2 Methods

2.1 Setup

The first thing we have to do is to make sure that the HeNe laser has been on for at least one hour before being used. This allows the laser to be stabilized when measured for our data. On the other hand, the laser pointer does not need this treatment as it is already stable. We make sure that the laser beams of the HeNe laser and laser pointer are hitting the silicon detector. This power of the laser is shown on the FieldMaster power meter and we can tell the difference because when the laser is not hitting the silicon detector the power meter only shows the background power.

2.2 Power Measurement

A software called Laser Power is used to measure the power of the laser beams. A knife edge is placed on top of motor which is controlled by a motor control which is in turn controlled by the software Laser Power. The knife edge is then placed near the edge of the laser beam but not touching it. The Laser Power will control the motor which moves the knife edge to gradually block the laser beam, measuring the power each time the knife edge is moved. This process has a slit cut into a Gaussian beam shape which forms the integral of a Gaussian which is called an Error Function.

2.3 Manual Measurement

While the software Laser Power automatically measures the power, we also manually measure the spot size of both the lasers. This enables to compare our manually estimated spot size with the automated spot size.

2.4 Beam Expander

We then apply a beam expander made up of two lenses and then following the same procedures described above for the non-expanded beam. Also, we will be measuring the distances between the silicon detector, two lenses, and laser origin.

3 Equations

The Rayleigh Range formula, Z_R, is shown in equation (1) below. The λ is the wavelength of the laser (RED He-Ne laser; 632.8 nm), and the w_o is the waist size $(\frac{1}{e^2})$ of the laser.

$$Z_R = \frac{\pi w_0^2}{\lambda} \tag{1}$$

For the beam expander, equation 2 and 3 below shows the distance between the two lenses and the magnification of the waist size respectively.

$$d = f_1 + f_2 \tag{2}$$

$$w_{02} = m * w_{01} \tag{3}$$

The f1 and f2 in equation (2) are the focal points of the two lenses used. While the w_{01} in equation (3) is the initial laser beam waist and w_{02} is the beam expanded laser beam waist. The formula for the magnification is shown below in equation (4).

$$m = \frac{f_2}{f_1} \tag{4}$$

Also, the spot size is found using equation (5) below.

$$w(z) = w_0 \left[1 + \frac{z^2}{Z_R^2}\right]^{\frac{1}{2}} \tag{5}$$

4 Results

4.1 HeNe Laser Spot Size

The full power intensity of the system is

$$I = Full\ intensity\ of\ the\ laser - background\ intensity$$

$$I = 1.02 \times 10^{-3} - 4.68 \times 10^{-6}\ W$$

$$I = 1.02 \times 10^{-3}\ W$$

The peak intensity is found to be half of the full intensity.

$$I_{01peak} = \frac{I}{2} = 5.1 \times 10^{-4}\ W$$

We also know that the distance, *z*, is

$$z_{01} = \frac{(I_{peak}(z) - y_0)(x_1 - x_0)}{y_1 - y_0} - x_0$$

$$z_{01} = \frac{(5.1 \times 10^{-4} - 6.59 \times 10^{-4})(2.19991 - 1.99992)}{3.55 \times 10^{-4} - 6.59 \times 10^{-4}} - 1.99992 = -1.9019\ mm$$

Then we find the half value of the peak intensity.

$$I_{01peak\_half} = \frac{5.1 \times 10^{-4}}{2} = 2.55 \times 10^{-4}\ W$$

And thus, the corresponding z for the half value of the peak intensity is

$$z_{01half} = \frac{(2.55 \times 10^{-4} - 3.55 \times 10^{-4})(2.3999 - 2.19991)}{1.39 \times 10^{-4} - 3.55 \times 10^{-4}} - 2.19991 = -2.10732\ mm$$

The waist is then:

$$w_{01} = z_{01} - z_{01half} = 0.20542\ mm$$

We can use equation (1) to calculate for the Rayleigh Range, Z_R.

$$Z_{R01} = \frac{\pi(0.20542 \times 10^{-3})^2}{632.8 \times 10^{-9}} = 0.209493\ m = 209.50\ mm$$

Now that we have our w_{01}, z, and Z_{R01} we can calculate for the spot size $w(z)$.

$$w(z)_{01} = (0.20542\ mm)\left[1 + \frac{(-2.10732\ \ mm)^{\ 2}}{(209.50\ mm)^2}\right]^{\frac{1}{2}}$$

$$w(z)_{01} = 0.000205430\ m = 0.21\ mm$$

4.1.1 HeNe Curve Fit

Figure 1 is the fitted curve for the original HeNe laser beam.

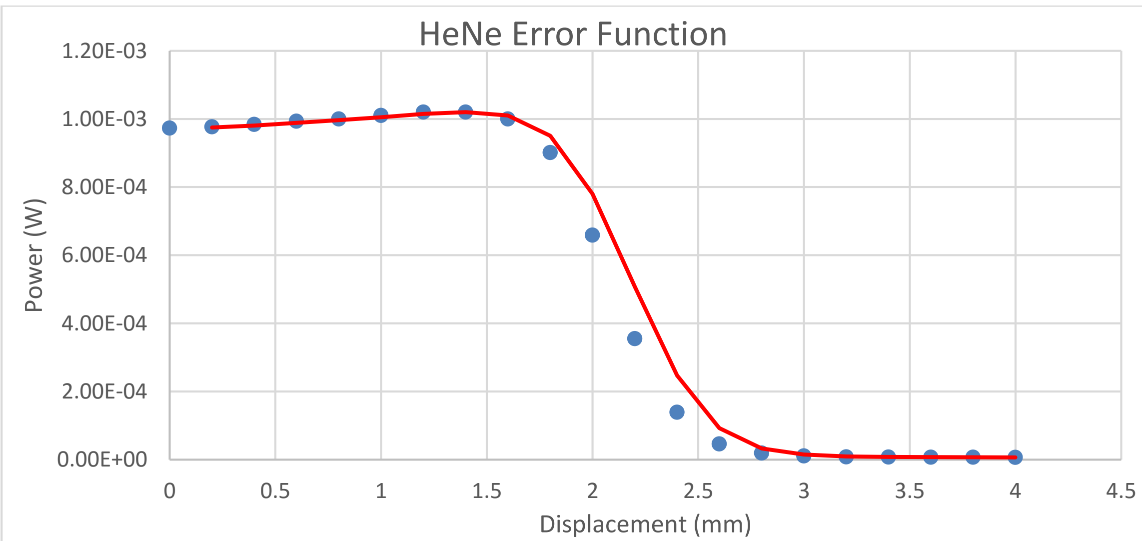

Figure 1 : HeNe laser power with curve fit data

4.2 Laser Pointer Spot Size

The laser pointer peak is $I_{pointerpeak}(z)$ is

$$I_{pointerpeak}(z) = \frac{(4.75\ x\ 10^{-4})}{2} = 2.38\ x\ 10^{-4}\ W$$

Therefore, the $I_{pointerpeak\_half}$ is

$$I_{pointerpeak\_half} = 1.19\ x\ 10^{-4}\ W$$

Our new distance $z_{pointer}$ is then

$$z_{pointer} = -1.4837\ mm$$

And the $z_{pointerhalf}$ value is

$$z_{pointerhalf} = -2.9799\ mm$$

The new waist size is found to be

$$w_{pointer} = (-1.4837\ ) - (-2.9799) = 1.496\ mm$$

Using the same method for calculating the Rayleigh Range, we found the Rayleigh Range for the laser pointer to be

$$Z_{Rpointer} = 13.1471\ m = \ 13,147\ mm$$

Note: We used this exact green laser pointer in Lab 2 therefore we know that this green laser pointer has the exact wavelength of $\lambda = \ 534.7917\ \pm\ 0.1386\ \mathrm{nm}$ which is what we used for the wavelength on the laser pointer Rayleigh Range above.

Lastly, the spot size of the expanded laser beam is then

$$w(z)_{pointer} = 0.001496\ m = 1.50\ mm$$

4.2.1 Laser Pointer Curve Fit

Figure 2 below is the fitted curve for the expanded HeNe laser beam.

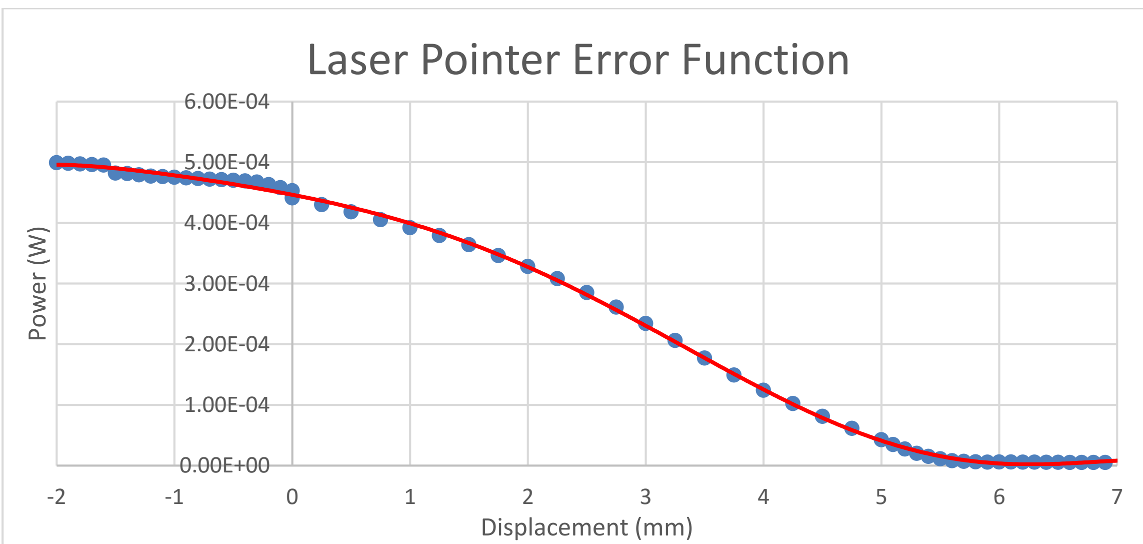

Figure 2: Green laser pointer laser power

4.3 HeNe After Beam Expander Laser Spot Size

From equation (4) we get the magnification. Negative means the image will be upside-down.

$$m = \frac{50}{-25} = \ -2$$

After passing the expander, the new $I_{02peak}(z)$ is

$$I_{02peak}(z) = \frac{(7.62\ x\ 10^{-4})}{2} = 3.82\ x\ 10^{-4}\ W$$

Therefore, the I_{02peak_half} is

$$I_{02peak\_half} = 1.92\ x\ 10^{-4}\ W$$

Our new distance z_{02} is then

$$z_{02} = -1.6983\ mm$$

And the z_{02half} value is

$$z_{02half} = -2.11522\ mm$$

The new waist size is found to be

$$w_{02} = (-1.6983) - (-2.3073) = 0.4169\ mm$$

Using the same method for calculating the Rayleigh Range, we found the Rayleigh Range for the HeNe laser after being beam expanded to be

$$Z_{R02} = 0.862981\ m = 862.98\ mm$$

Lastly, the spot size of the expanded laser beam is then

$$w(z)_{02} = 0.0004169 = 0.42\ mm$$

4.3.1 HeNe After Beam Expander Curve Fit

Figure 3 is the fitted curve for the expanded HeNe laser beam.

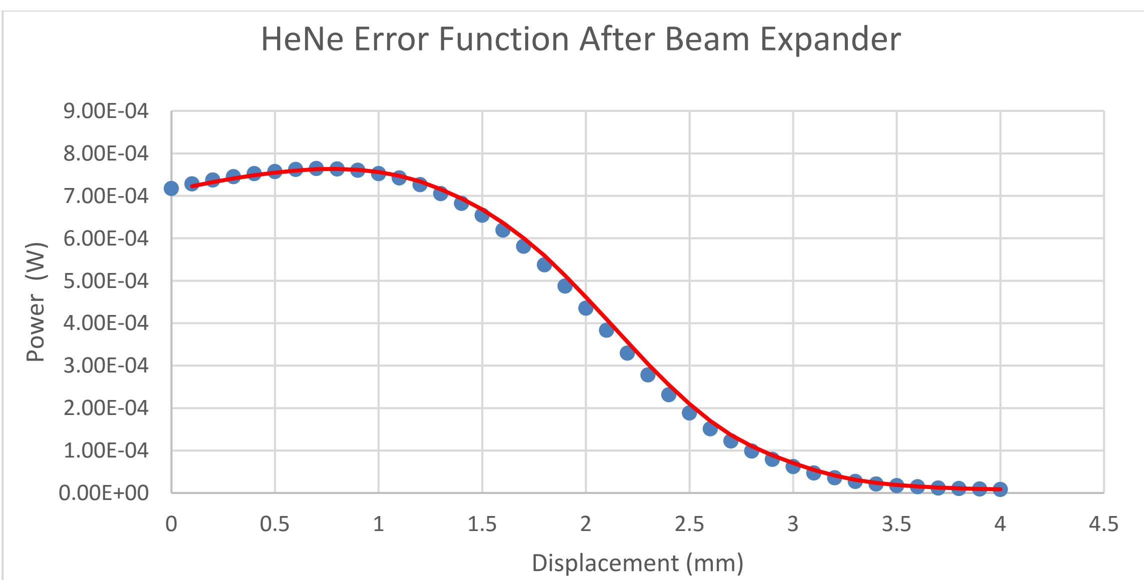

Figure 3: HeNe laser power after beam expander with curve fit data

5 Discussion

5.1 Spot Size

In the experiment, we measured the original HeNe laser beam using a ruler. The manually measured spot size was $2.1 \pm 0.02\ mm$. From our results in Section 4.1 we found that the actual automated spot size was $w(z)_{01} = 0.21\ mm$. Therefore, we know that the spot size we eyeballed was way bigger than the actual spot size of the laser beam. We know that the automated data spot size is the real spot size of the laser beam because it is measured from the Error Function of the laser Gaussian.

Our eyeballed measurement for the laser pointer spot size was $4.3 \pm 0.02\ mm$ and the actual spot size was $w(z)_{pointer} = 1.50\ mm$. We were very off on our eyeball measurement. One reason was that the beam was very bright and we had a hard time looking at the bright green laser when trying to measure it.

The expanded beam eyeballed spot size was $4.01 \pm 0.02\ mm$, while the calculated spot size from Section 4.3 is $w(z)_{02} = 0.42\ mm$. Unlike the original beam above, our eyeballed spot size measurement was very off compared to the real spot size of the expanded laser beam. We overshot our eyeballed manual measurement because it was hard to find the exact radius from which to start measuring the laser beam. There were different levels of intensities and we measured from the lowest intensity laser beam from one side to another. This method is proven to be a wrong way of measuring the spot size because the actual spot size is much smaller than what we see as the lowest intensity of the laser beam.

Looking at equation (5) it makes sense that the spot size for the expanded laser beam is bigger compared to the original laser beam. The spot size is heavily proportional to the waist size. In this case, for the expanded laser beam, the 2x more waist size means that the spot size is also going to be 2x more. Which is proven when comparing the original spot size $w(z)_{01} = 0.21\ mm$ with the expanded spot size $w(z)_{02} = 0.42\ mm$.

5.2 Magnification

The magnification of the spot size from both our eyeballed measurement and the actual spot size from both the original and beam expanded laser beams were consistently around 2x. This made sense because we used a concave lens with focal length of -25 mm and a convex lens with a focal length of 50 mm. Which should give us a magnification of 2 using equation (4) above. Since our eyeballed waist size and our actual waist size were consistent then we know that our beam expander was set up properly. This was further proven when we checked that the laser beam was consistent or collimated after being beam expanded.

5.3 Rayleigh Range

The value of the Rayleigh Range increased by a factor of 4x from the original beam to the expanded beam. This was to be expected because looking at equation (1) the Rayleigh Range value is a square of the waist. So if the waist is doubled (2x) by the beam expander then the Rayleigh Range should be quadrupled (4x) because of the squared waist in the formula. Our calculations prove this. The original beam was $Z_{R01} = 209.50\ mm$ then after the beam expander, the new Rayleigh Range became $Z_{R02} = 862.98\ \mathrm{mm}$.

6 Conclusion

In this lab we calculated and analyzed the waist, Rayleigh Range, and spot size for an HeNe and laser pointer laser beam. We found that our eyeballed measurements for the spot sizes for each beam was always too big compared to the actual sizes. This applied to all three spot sizes that we did eyeball measurements for. Which were for the original HeNe laser, expanded HeNe laser, and the laser pointer.

We can conclude that our beam expander was properly set up because the magnification of the spot sizes and Rayleigh Range were as expected from the formula. Also, when we checked the laser beam after being expanded we observed that it was consistent or collimated.

Looking at Figure 3 we can see that the Error Function is not very straight in the peak area. It has a slight curve. This was because when we did the lab the HeNe was just turned on for only about 30 minutes. This means the laser was not very stable when we did our collection, so our data may have some experimental errors because of that.

The Rayleigh Range for the expanded HeNe laser beam increased to be around 4x more than the original beam. While the spot size was 2x more than the original beam. This shows that our data collection was correct because those are the expected results in theory. This shows a relationship that the magnification of the waist is around the same magnification for the spot size while the magnification of the waist is a squared magnification value for the Rayleigh Range.

7 Appendix

7.1 Lab notes

15.)
16.) center power meter detector head in beam path
may need to reduce optical density

17.) Now measure beam expander spot size w/ Laser Power (steps 9-10)
(4mm, 40 steps)

18.) simple ruler measure spot size at
Knife edge and laser

Laser pointer
4.3 mm (ruler) spot size
± 0.02 mm

3.75 μW background power

He-Ne

4.68 μW background power
2.3 ± 0.02 mm (ruler) (spot size)
22 $\frac{1}{2}$ inches knife edge to laser
(57.15 cm)

Beam Expander f_1 = 50 mm f_2 = −25 mm

Laser didn't turn on long enough

before exp ⇒ 2.1 ± 0.02 mm spot size ruler
after exp ⇒ 4.01 ± 0.02 mm spot size ruler

Lens$_1$ f = 50 mm
Lens$_2$ f = −25 mm } 49.3 ± 0.02 mm
Lens 2 → laser } 6 $\frac{1}{2}$ inches
Knife edge → lens 1 ~~3~~ 13 inches

Distances

censor → knife edge
~~17.4~~ 79.5 ± 0.02 m