PSE605A (Photonics Lab Techniques)

Lab Report: Experiment 7

Fresnel and Fraunhofer Diffraction

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Fresnel and Fraunhofer Diffraction

1 Objectives

- To measure intensity distribution along the axis of the circular aperture and compare it with the calculated distribution using the concept of Fresnel zones.
- To measure irradiance in the far field Fraunhofer zone in the transverse plane, for a slit and compare it with theoretical results.
- To measure irradiance in the far field Fraunhofer zone in the transverse plane, for a circular aperture and compare it with theoretical results.

2 Equipments

1. He-Ne Laser (central wavelength at 632.8 nm), 2. Circular aperture, 3. Si pinhole photodetector, 4. Spatial filter, 5. Lenses (focal length – 7.5 & 2.5 cm), 6. Optical rail, 7. Digital multi-meter, 8. Travelling microscope, 9. Screen.

3 Procedure

3.1 For Fraunhofer

1. First of all, do the proper alignment of He-Ne laser mount so that laser beam has minimal drift in the lateral plane
2. Put the spatial filter assembly in place and try to get a smoothed out but enlarged beam at the output.
3. Put the collimating lens in place and get a properly collimated beam which is well aligned to the optical bench
4. Put the slit and lens in place and observe the Fraunhofer diffraction pattern on screen.

5. Now put the Si photodetector in place and before starting data collection once again make sure that all the optics is aligned properly so that the beam of the laser, having passed through the all the components, runs parallel to the optical bench.
6. Move the Si photodetector laterally in the steps of 0.1mm to record the intensity variation and collect the readings of photodetector output voltage.
7. Keep collecting the data until you cross at least two maxima and two minima.
8. From the collected data find the size of the diffracting aperture using Fraunhofer diffraction theory.
9. Also measure the size of diffracting aperture using a travelling microscope and compare the two results.
10. Record the diffraction pattern using camera.

3.2 For Fresnel

1. First of all, do the proper alignment of He-Ne laser mount so that laser beam has minimal drift in the lateral plane
2. Put the spatial filter assembly in place and try to get a smoothed out but enlarged beam at the output.
3. Put the collimating lens in place and get a properly collimated beam which is well aligned to the optical bench
4. Put the circular aperture and magnifying lens in place and observe the Fresnel diffraction pattern on screen. On changing the longitudinal distance, the pattern will change.
5. Now put the Si photodetector in place and start with a well-adjusted position of magnifying lens.
6. Before starting data collection once again make sure that all the optics is aligned properly so that the beam of the laser, having passed through the all the components, runs parallel to the optical bench.
7. Move the magnifying lens longitudinally in the steps of 1mm to get variation in the pattern at the detector and collect the readings
8. Keep taking readings until you enter in the far field region.
9. From the collected data find the size of the diffracting aperture using the Fresnel diffraction theory.
10. Also measure the aperture size from travelling microscope
11. Compare the two results and explain the error and plausible causes for it.

4 Observations

With the help of travelling microscope, the dimensions of the different apertures are determined as follows:

- The dimension of the rectangular slit which is: length=0.21 mm
- The diameter for large circular aperture which is used for Fraunhofer pattern is 0.34 mm.
- The diameter for small circular aperture which is used for Fresnel pattern is 1.12 mm.

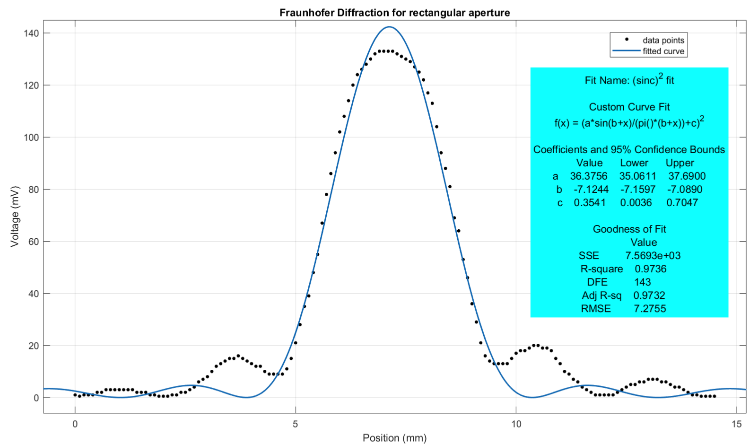

Figure 1: Fraunhofer diffraction for rectangular aperture

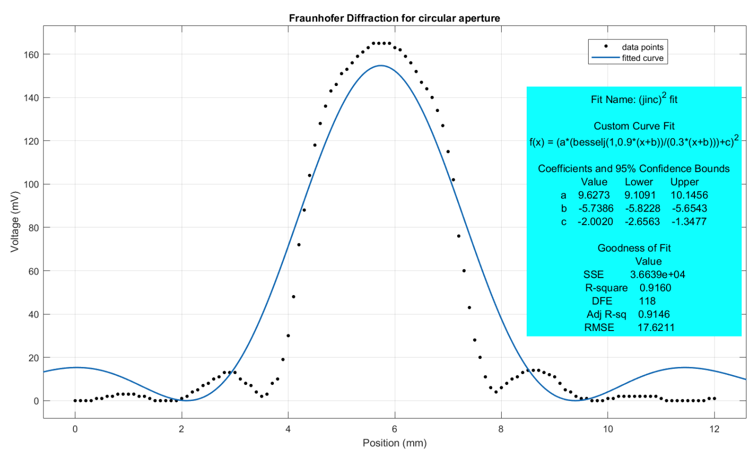

Figure 2: Fraunhofer diffraction for circular aperture

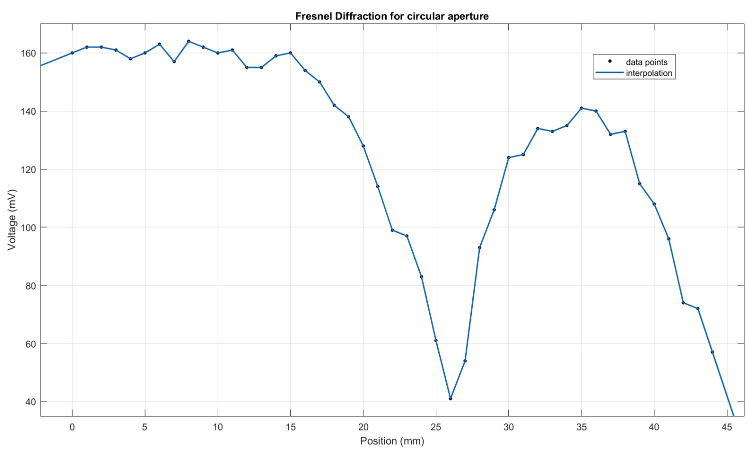

Figure 3: Fresnel diffraction for circular aperture

5 Calculation

5.1 Fraunhofer diffraction for circular aperture

The first angle at which the minimum occur is given by,

$$sin\theta = \frac{1.22\lambda}{d}$$

Where d = diameter of the aperture.
The distance between slit and the detector (from measurement) = 169.8 68.5 = 101.3 cm
Distance for 1st minima = (7.9 5.7)mm = 2.2mm
For small angle of $\theta, sin\theta = \theta$,

$$\theta = \frac{distance\ for\ 1st\ minimum\ from\ center}{The\ distance\ between\ slit\ and\ detector} = \frac{1.22\lambda}{d}$$

$$or,\ d = \frac{1.22 * 632.8 * 10{-}9}{.22/101.3} = 0.355 * 10{-}3\ m$$

Therefore, diameter for circular aperture =0.355 mm

5.2 Fraunhofer diffraction for rectangular aperture

The distance between slit and the detector (from measurement) = 169.8-92.5 = 77.3 cm. The aperture size can approximately calculated as

$$a = \frac{\lambda}{\theta} = 0.188\ mm$$

5.3 Fresnel diffraction for circular aperture

$$F = \frac{a^2}{L\lambda}$$

For Fresnel, $F \approx 1$,Where, a is the dimension of the diffracting element, λ is the wavelength of light and L is the minimum of distance between source to aperture and aperture to screen.
L (from measurement) = 169.8-69.9=99.9cm=0.999 m

$$a = \sqrt{L\lambda} = 0.795\ mm$$

6 Error Calculation

6.1 Fraunhofer diffraction for circular aperture

Diameter for circular aperture (experimental value) = 0.355 mm
Diameter for circular aperture (theoretical value) = 0.34 mm

$$Relative\ Error = \left|\frac{Theoretical\ Value - Experimental\ Value}{Theoretical\ Value}\right| * 100\% = 4.4\ \%$$

6.2 Fraunhofer diffraction for rectangular aperture

Width obtained (experimental value) = 0.188 mm Width obtained (theoretical value) = 0.21 mm

$$Relative\ Error = \left|\frac{Theoretical\ Value - Experimental\ Value}{Theoretical\ Value}\right| * 100\% = 10.48\ \%$$

6.3 Fresnel diffraction for circular aperture

Diameter for circular aperture (experimental value) = 0.795 mm
Diameter for circular aperture (theoretical value) = 1.12 mm

$$Relative\ Error = \left|\frac{Theoretical\ Value - Experimental\ Value}{Theoretical\ Value}\right| * 100\% = 29.02\ \%$$

7 Discussions & Conclusions

- Error in calculating the diameter of the circular aperture for Fraunhofer diffraction is very little.
- But the error in calculating the length of the rectangular aperture for Fraunhofer diffraction is not ignorable.
  It might be due to the imperfect shape of the aperture.
- For fresnel diffraction, the error in calculating circular aperture is quite high.
  Surely, misalignment is the reason for this.
- Measuring the diameter or length of the aperture has to be done carefully.
- Alignment is the most important thing. It can bring much better results.
- The Room has to be completely dark. Otherwise, it will add noise to the detector. In our case, We used a torch to see the output. I think it added the noise.

8 Appendix

8.1 Sources of Error

1. The sensitive surfaces of optical components necessitate handling them with care, avoiding direct contact with bare hands to prevent contamination or damage.
2. Misalignment of optical components can introduce significant errors in the experiment. Therefore, meticulous attention to alignment is essential to minimize potential sources of error.
3. External light sources can interfere with photodetector readings, leading to inaccuracies. Implementing measures to minimize ambient light, such as using light shields or conducting experiments in controlled environments, helps reduce this source of error.
4. The least count of the travelling microscope should be taken into account as it contributes to the overall measurement uncertainty. Understanding and accounting for this factor is crucial for accurate dimensional measurements in the experiment.

8.2 Precautions

1. Allow 15 minutes for the laser to stabilize after it is turned on before commencing the experiment.
2. Optical components must remain stationary throughout the experiment to avoid introducing misalignment.
3. Refrain from touching any surface of the optical components to prevent contamination or damage.
4. Always wear safety goggles during alignment procedures to avoid direct exposure to the laser beam and its reflections

8.3 Observation Table

8.3.1 Fraunhofer diffraction for circular aperture

Table 1: Fraunhofer Diffraction for circular aperture

Position (mm)	**Voltage (mV)**
0.000000	0.000000
0.100000	0.000000
0.200000	0.000000
0.300000	0.000000
0.400000	1.000000
0.500000	1.000000
0.600000	2.000000
0.700000	2.000000

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Table 1 – continued from previous page

Position (mm)	Voltage (mV)
0.800000	3.000000
0.900000	3.000000
1.000000	3.000000
1.100000	3.000000
1.200000	2.000000
1.300000	2.000000
1.400000	1.000000
1.500000	0.000000
1.600000	0.000000
1.700000	0.000000
1.800000	0.000000
1.900000	0.000000
2.000000	1.000000
2.100000	2.000000
2.200000	4.000000
2.300000	5.000000
2.400000	7.000000
2.500000	8.000000
2.600000	10.000000
2.700000	11.000000
2.800000	13.000000
2.900000	13.000000
3.000000	13.000000
3.100000	10.000000
3.200000	8.000000
3.300000	7.000000
3.400000	4.000000
3.500000	2.000000
3.600000	3.000000
3.700000	8.000000
3.800000	10.000000
3.900000	19.000000
4.000000	30.000000
4.100000	48.000000
4.200000	72.000000
4.300000	88.000000
4.400000	104.000000
4.500000	118.000000
4.600000	128.000000
4.700000	136.000000
4.800000	143.000000
4.900000	146.000000

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Table 1 – continued from previous page

Position (mm)	**Voltage (mV)**
5.000000	151.000000
5.100000	153.000000
5.200000	156.000000
5.300000	159.000000
5.400000	161.000000
5.500000	163.000000
5.600000	165.000000
5.700000	165.000000
5.800000	165.000000
5.900000	165.000000
6.000000	163.000000
6.100000	162.000000
6.200000	159.000000
6.300000	156.000000
6.400000	152.000000
6.500000	147.000000
6.600000	144.000000
6.700000	140.000000
6.800000	134.000000
6.900000	127.000000
7.000000	115.000000
7.100000	102.000000
7.200000	76.000000
7.300000	60.000000
7.400000	43.000000
7.500000	28.000000
7.600000	20.000000
7.700000	11.000000
7.800000	6.000000
7.900000	4.000000
8.000000	6.000000
8.100000	8.000000
8.200000	10.000000
8.300000	11.000000
8.400000	13.000000
8.500000	14.000000
8.600000	14.000000
8.700000	14.000000
8.800000	13.000000
8.900000	12.000000
9.000000	11.000000
9.100000	8.000000

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Table 1 – continued from previous page

Position (mm)	**Voltage (mV)**
9.200000	5.000000
9.300000	4.000000
9.400000	2.000000
9.500000	1.000000
9.600000	1.000000
9.700000	0.000000
9.800000	0.000000
9.900000	0.000000
10.000000	1.000000
10.100000	1.000000
10.200000	2.000000
10.300000	2.000000
10.400000	2.000000
10.500000	2.000000
10.600000	2.000000
10.700000	2.000000
10.800000	2.000000
10.900000	2.000000
11.000000	1.000000
11.100000	0.000000
11.200000	0.000000
11.300000	0.000000
11.400000	0.000000
11.500000	0.000000
11.600000	0.000000
11.700000	0.000000
11.800000	0.000000
11.900000	1.000000
12.000000	1.000000

8.3.2 Fraunhofer diffraction for rectangular aperture

Table 2: Fraunhofer Diffraction for rectangular aperture

Position (mm)	**Voltage (mV)**
0.000000	1
0.100000	0
0.200000	1
0.300000	1

Continued on next page

Table 2 – continued from previous page

Position (mm)	Voltage (mV)
0.400000	1
0.500000	2
0.600000	2
0.700000	3
0.800000	3
0.900000	3
1.000000	3
1.100000	3
1.200000	3
1.300000	3
1.400000	2
1.500000	2
1.600000	2
1.700000	1
1.800000	1
1.900000	0
2.000000	0
2.100000	0
2.200000	1
2.300000	1
2.400000	2
2.500000	2
2.600000	3
2.700000	4
2.800000	6
2.900000	7
3.000000	8
3.100000	10
3.200000	12
3.300000	13
3.400000	14
3.500000	15
3.600000	15
3.700000	16
3.800000	15
3.900000	14
4.000000	13
4.100000	12
4.200000	12
4.300000	10
4.400000	9
4.500000	9

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Table 2 – continued from previous page

Position (mm)	**Voltage (mV)**
4.600000	9
4.700000	9
4.800000	11
4.900000	15
5.000000	21
5.100000	28
5.200000	35
5.300000	39
5.400000	48
5.500000	55
5.600000	67
5.700000	78
5.800000	86
5.900000	94
6.000000	102
6.100000	108
6.200000	114
6.300000	120
6.400000	124
6.500000	126
6.600000	128
6.700000	130
6.800000	132
6.900000	133
7.000000	133
7.100000	133
7.200000	133
7.300000	132
7.400000	131
7.500000	130
7.600000	129
7.700000	127
7.800000	125
7.900000	122
8.000000	117
8.100000	113
8.200000	104
8.300000	94
8.400000	88
8.500000	81
8.600000	69
8.700000	64

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Table 2 – continued from previous page

Position (mm)	Voltage (mV)
8.800000	53
8.900000	46
9.000000	36
9.100000	29
9.200000	21
9.300000	16
9.400000	14
9.500000	13
9.600000	13
9.700000	13
9.800000	13
9.900000	15
10.000000	17
10.100000	18
10.200000	18
10.300000	19
10.400000	20
10.500000	20
10.600000	19
10.700000	19
10.800000	18
10.900000	15
11.000000	13
11.100000	10
11.200000	9
11.300000	7
11.400000	6
11.500000	4
11.600000	3
11.700000	2
11.800000	1
11.900000	1
12.000000	1
12.100000	1
12.200000	1
12.300000	2
12.400000	3
12.500000	4
12.600000	5
12.700000	5
12.800000	6
12.900000	6

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Table 2 – continued from previous page

Position (mm)	**Voltage (mV)**
13.000000	7
13.100000	7
13.200000	7
13.300000	6
13.400000	6
13.500000	5
13.600000	4
13.700000	4
13.800000	3
13.900000	2
14.000000	1
14.100000	1
14.200000	0
14.300000	0
14.400000	0
14.500000	0

8.3.3 Fresnel diffraction for circular aperture

Table 3: Fresnel Diffraction for circular aperture

Position (mm)	**Voltage (mV)**
0	160
1	162
2	162
3	161
4	158
5	160
6	163
7	157
8	164
9	162
10	160
11	161
12	155
13	155
14	159
15	160
16	154

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Table 3 – continued from previous page

Position (mm)	Voltage (mV)
17	150
18	142
19	138
20	128
21	114
22	99
23	97
24	83
25	61
26	41
27	54
28	93
29	106
30	124
31	125
32	134
33	133
34	135
35	141
36	140
37	132
38	133
39	115
40	108
41	96
42	74
43	72
44	57