PHY307 LABORATORY REPORT

EXPERIMENT-2

OPTICAL FIBER EXPERIMENT

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Abstract

Optical fibers are integral components of modern communication systems, facilitating the transmission of data over long distances with minimal signal loss. In this experimental study, we investigate key optical fiber characteristics, namely bending losses, splice losses, and numerical aperture, to enhance our understanding of their performance in real-world applications.

Bending losses refer to the attenuation of light signals as they traverse curved paths within optical fibers. Our experiment involves subjecting optical fibers to various bending radii and angles to quantify the impact of bending on signal integrity. The results provide valuable insights into the minimum bend radius required to maintain acceptable signal quality, which is crucial for the design of fiber optic networks.

Splice losses arise when optical fibers are joined together, and understanding these losses is essential for efficient network deployment and maintenance. We analyze the impact of different splice techniques on signal continuity and attenuation, aiming to identify the most effective methods for minimizing splice losses.

Numerical aperture (NA) is a fundamental optical parameter that characterizes the light-gathering ability of an optical fiber. We measure and calculate the numerical aperture of various optical fibers to assess their performance in terms of light-capturing efficiency. Understanding the NA is vital for optimizing fiber optic systems for specific applications, such as telecommunications and medical devices.

Our experimental setup employs state-of-the-art equipment and precise measurement techniques to ensure accurate results. The findings from this study will aid in the development of more robust and efficient optical fiber communication systems, paving the way for advancements in high-speed data transmission, telemedicine, and various other optical fiber-based technologies.

1 Theory

1.1 Optical Fibre

Optical fiber, a remarkable technology in modern telecommunications and data transmission, is a slender, flexible, and transparent strand made of ultra-pure glass or plastic. At its core, optical fiber operates on the principles of physics, primarily utilizing total internal reflection. When light, typically in the form of laser or LED-generated pulses, enters the fiber at a certain angle within the core, it is continually reflected off the inner walls due to the higher refractive index of the core compared to the surrounding cladding. This mechanism traps the light within the core, allowing it to travel great distances with minimal signal loss. The physics behind optical fibers enable them to transmit data at nearly the speed of light, making them an essential component in the modern world of high-speed internet, telecommunications, and data networking.

1.2 Experiments

1.2.1 Bending Loss Experiment

In a bending loss experiment on optical fiber, the objective is to understand how the curvature of the fiber affects the transmission of light signals. Optical fibers are designed to efficiently transmit light in straight paths, but when they are bent, some of the light can escape due to bending-induced micro bending or macro bending. This experiment typically involves subjecting the optical fiber to various bending radii and angles while measuring the attenuation of the transmitted light. By quantifying the bending losses, researchers gain insights into the fiber's resilience to bending and the minimum bend radius that can be tolerated before signal quality significantly deteriorates. This knowledge is crucial for optimizing fiber optic network layouts and ensuring reliable data transmission, especially in scenarios where bending of optical fibers cannot be avoided.

Here, in this experiment we took a bending loss apparatus consisting of rings of different di-

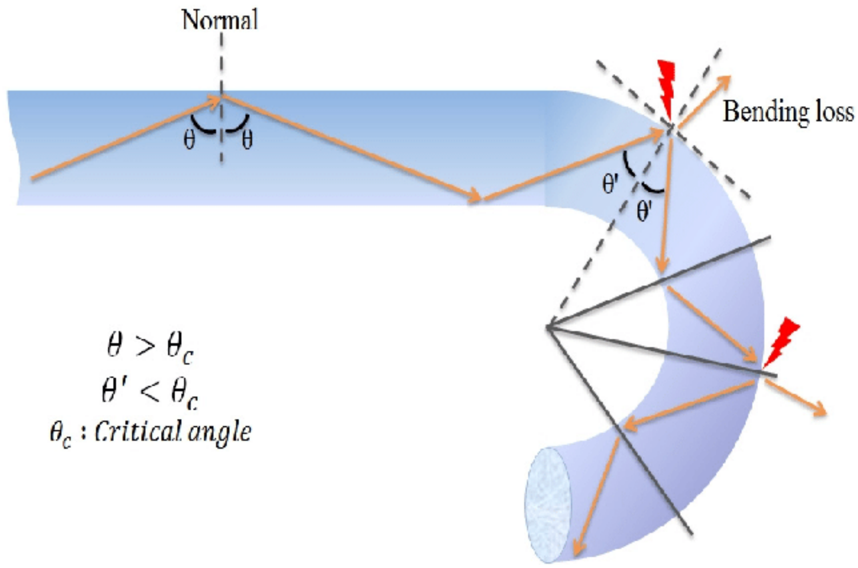

Figure 1.1. Bending Loss in a Optical Fiber

ameters(35 mm, 45 mm, 55 mm, 65 mm) and took turn(s) of the optical fibre to measure the attenuation of laser passing through it and which was detected at the photo diode detector end.

1.2.2 Calculation of Numerical Aperature

A single-mode optical fiber will only propagate light that enters the fiber within a certain Cone, known as the acceptance cone of the fiber. The half-angle of this cone is called the acceptance angle (θ_a)
So, the Acceptance angle is defined by

$$\theta_a = \tan^{-1}\frac{D}{Z}$$

and the Numerical Aperture is defined by,

$$NA = \sin\theta_a$$

The numerical aperture (NA) of an optical fiber is a key parameter that characterizes its ability to gather and transmit light. It is calculated using the formula NA = n * sin(θ), where "n" is the refractive index of the core of the fiber, and ”θ” is the half-angle of the maximum cone of light that can enter or exit the fiber while undergoing total internal reflection. The numerical aperture provides critical information about the fiber’s light-capturing and light-gathering capabilities. A higher NA indicates a fiber’s ability to collect light from a wider range of angles,

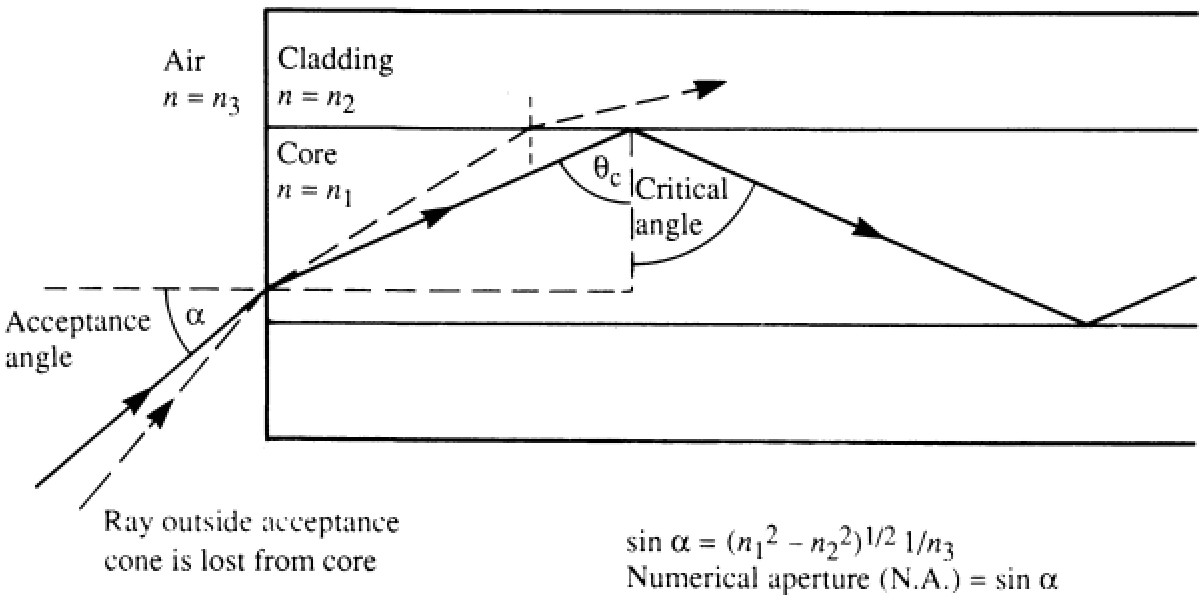

Figure 1.2. Numerical Aperature Calculation of Optical Fiber

making it more suitable for applications where efficient light transmission and coupling are essential, such as in high-speed data communication or medical imaging systems. Calculating the numerical aperture is fundamental in designing and selecting optical fibers tailored to specific optical systems and applications.

1.2.3 Splicing Loss Experiment

In a splice loss experiment on optical fiber, the objective is to quantify the attenuation or signal loss that occurs when two optical fibers are joined or spliced together. This experiment typically involves aligning the ends of two fiber segments with high precision and using specialized fusion splicing equipment. The key mathematical calculations involve measuring the power of the transmitted light before and after the splice. By comparing these power levels, researchers can determine the splice loss, expressed in decibels (dB), which represents the reduction in signal strength due to the splice. Understanding splice losses is crucial for optimizing the efficiency and reliability of fiber optic networks, as it helps in selecting appropriate splicing techniques and minimizing signal degradation during the connection of optical fibers.

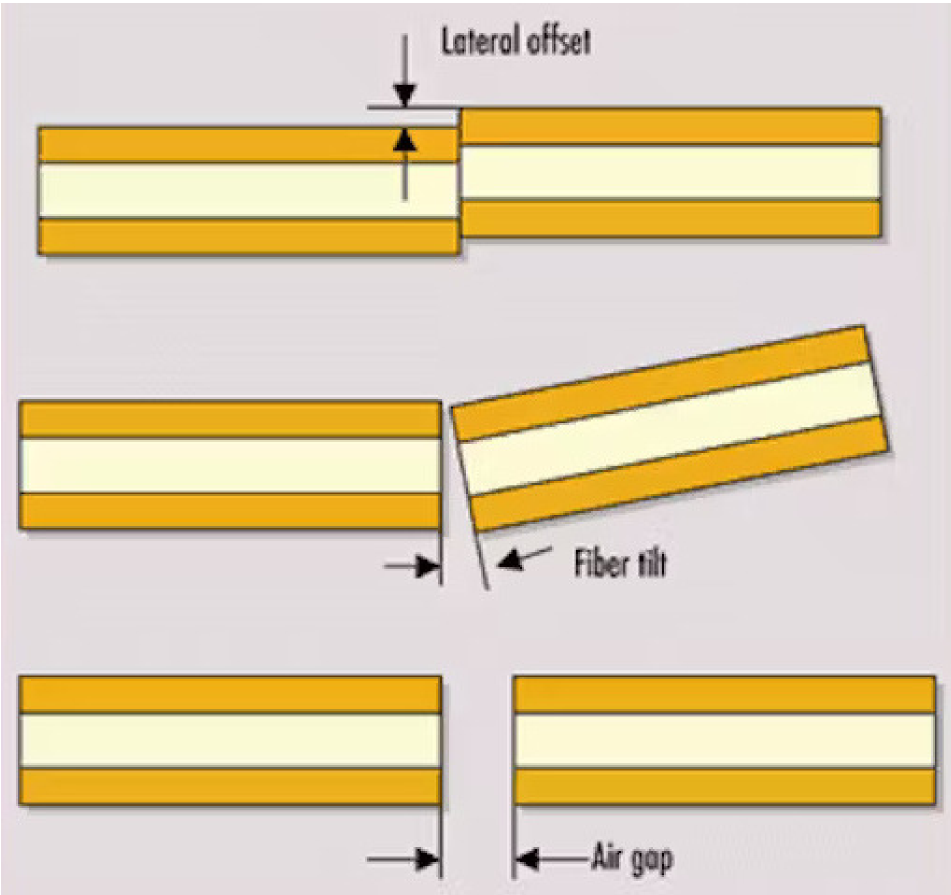

Figure 1.3. Splice Loss in Optical Fiber

2 RESULTS

2.1 Bending Loss Experiment

2.1.1 Experimental Data

Diameter (mm)	**Number of Turns**	**Current (mA)**
35	5	1.2
35	4	1.4
35	3	1.5
35	2	1.6
35	1	1.9
45	5	1.7
45	4	1.7
45	3	1.8
45	2	1.8
45	1	2.0
55	1	2.5
55	2	2.2
55	3	2.4
55	4	2.3
55	5	2.3
65	1	2.7
65	2	2.6
65	3	2.5
65	4	2.4
65	5	2.4

Table 2.1. Data of Bending Loss Expt.

Diameter (mm)	Weighted Mean Current (mA)
35	1.41
45	1.75
55	2.29
65	2.46

Table 2.2. Weighted Mean for each Diameter

2.1.2 Plots

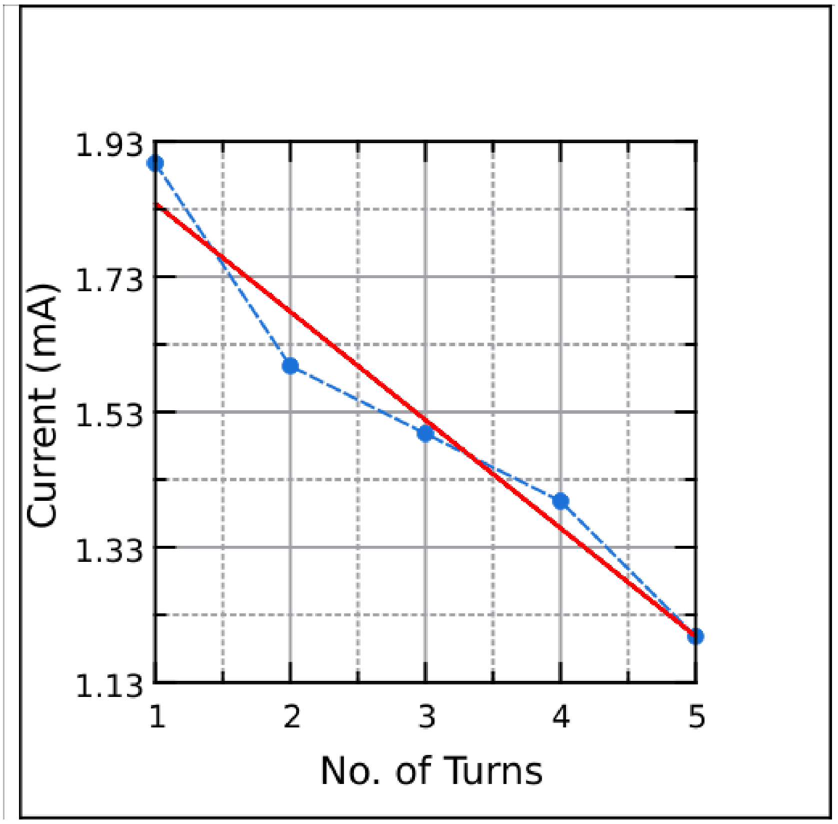

Figure 2.1. Bending the Fiber on 35 mm Diameter Circle(Red Line represents linear fitting)

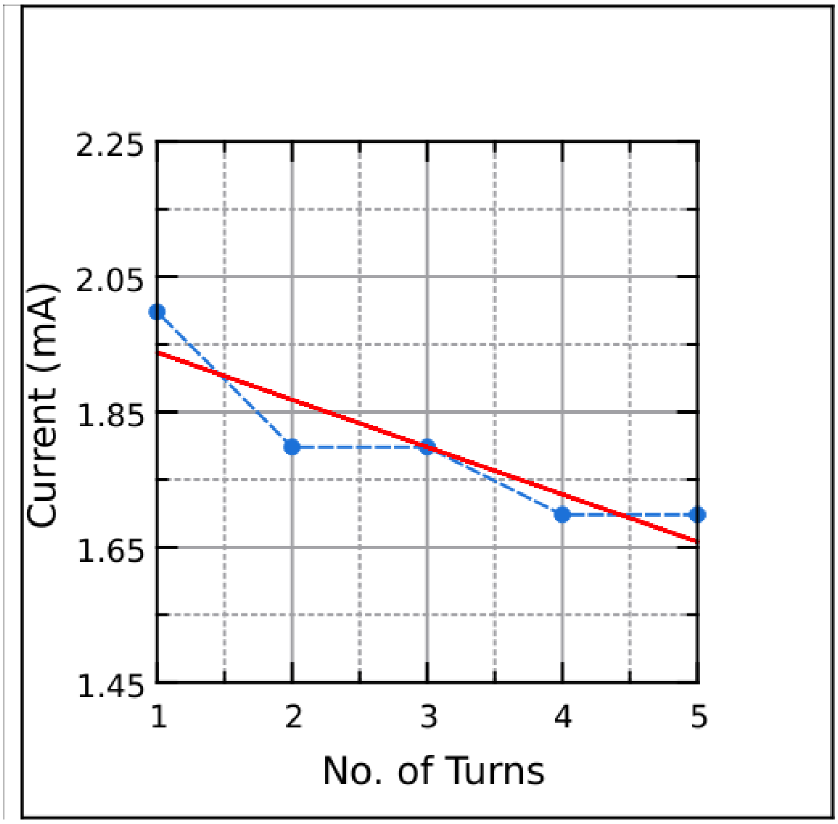

Figure 2.2. Bending the Fiber on 45 mm Diameter Circle

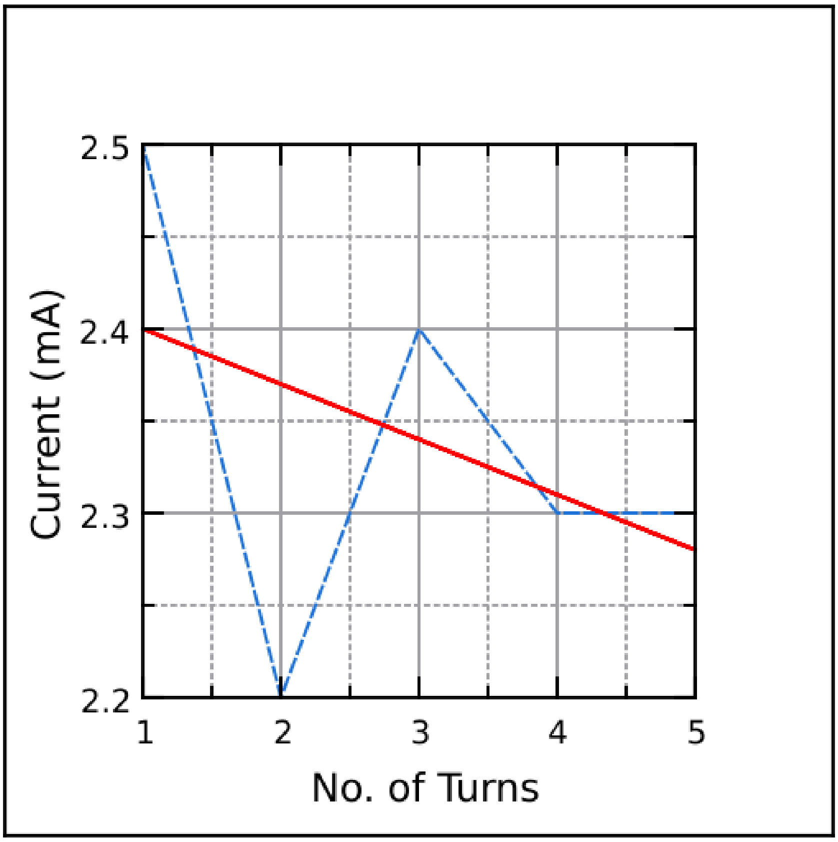

Figure 2.3. Bending the Fiber on 55 mm Diameter Circle

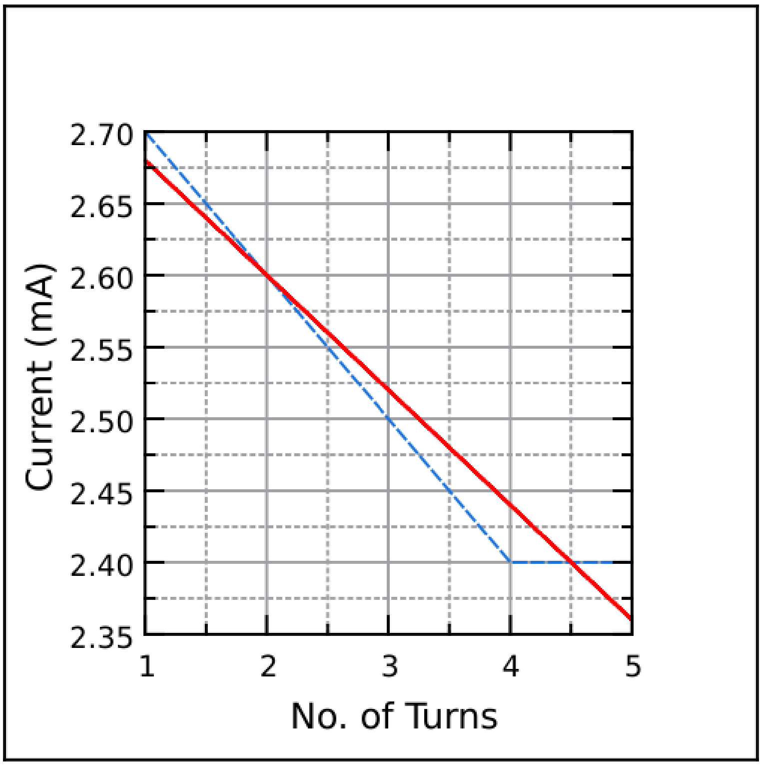

Figure 2.4. Bending the Fiber on 65 mm Diameter Circle

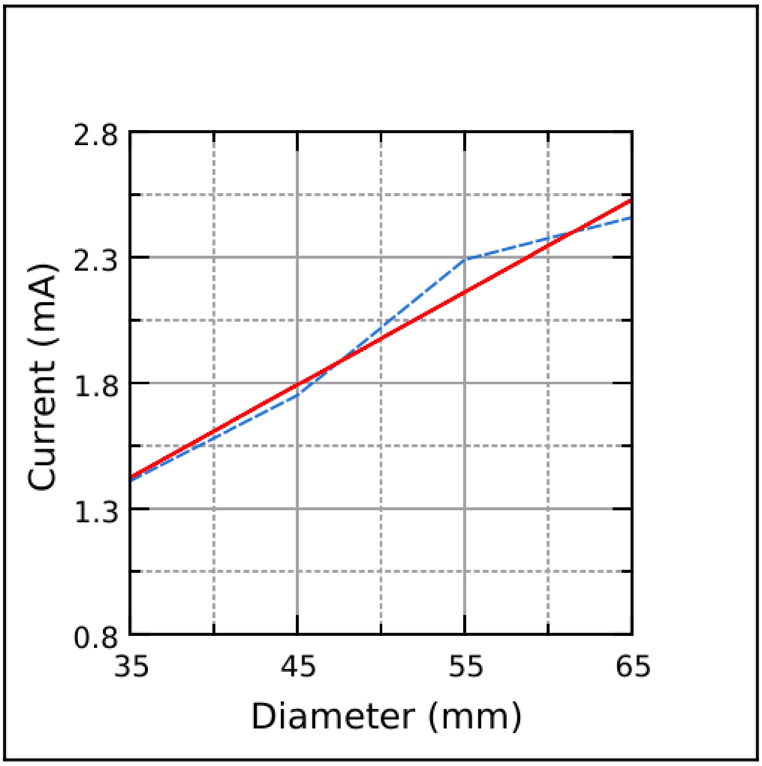

Figure 2.5. Bending the Fiber on various Diameters(Weighted Mean)

2.2 Calculation of Numerical Aperature

2.2.1 Experimental Data

Displacement (mm)	Current (mm)
9	0
9.1	0
9.2	0
9.3	0.1
9.4	0.2
9.5	0.3
9.6	0.6
9.7	0.8
9.8	1.1
9.9	1.4
10	1.8
10.1	2.1
10.2	2.4
10.3	2.7
10.3	2.7
10.4	3
10.5	3.3
10.6	3.5
10.7	3.6
10.8	3.5
10.9	3.3
11	3
11.1	2.7
11.2	2.3
11.3	2
11.4	1.7
11.5	1.4
11.6	1
11.7	0.7
11.8	0.5
11.9	0.3
12	0.1
12.1	0

Table 2.3. Table for Numerical Aperature

2.2.2 Plots

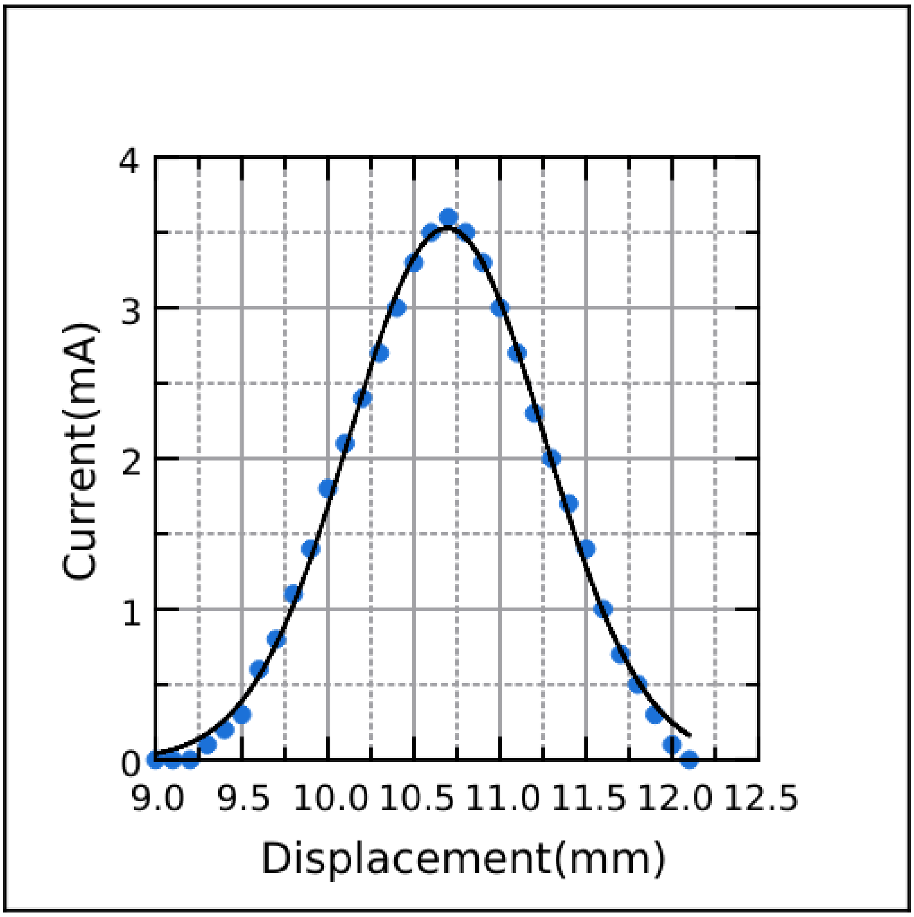

Figure 2.6. Numerical Aperture Measurement(**Black Line**represents Gaussian fitting)

2.2.3 Calculations

From the theory we have, So, the Acceptance angle is defined by

$$\theta_a = \tan^{-1}\frac{D}{Z}$$

Diameter of far field intensity at 5 percent intensity Micrometer reading (mm) level of the maximum attainable intensity (Mode Field Diameter)

$$D = (10.7 - 9.3)mm = 1.4mm$$

Here, the Acceptance angle is given by,

$$\theta_a = \tan^{-1}\left(\frac{1.4}{5.00}\right)$$

$$\theta_a = 15.64^o$$

So, the Numerical Aperture is given by,

$$NA = \sin\theta_a$$

$$NA = \sin(15.64^o)$$

$$NA = 0.26$$

- **Error Calculation:**

$$\theta_a = \tan^{-1}\frac{D}{Z} \implies \tan\theta_a = \frac{D}{Z}$$

Now, differentiating this term, we get,

$$\sec^2(\theta_a)\Delta\theta_a = \frac{\Delta D}{z} - \frac{D\Delta Z}{Z^2}$$

$$\Delta\theta_a = \frac{1}{\sec^2(\theta_a)}\left(\frac{\Delta D}{z} - \frac{D\Delta Z}{Z^2}\right)$$

$$\Delta\theta_a = \frac{1}{\sec^2(15.64)}\left(\frac{0.01}{5} - \frac{1.4 \times 0.01}{5^2}\right)$$

$$\Delta\theta_a = \frac{1}{\sec^2(15.64)} \times 0.001^o$$

$$\Delta\theta_a = 1.08 \times 0.001^o$$

$$\Delta\theta_a = 0.001^o$$

While calculating the Numerical Aperture, we get,

$$NA = \sin(\theta_a)$$

$$\Delta(NA) = \cos(\theta_a) \times \Delta\theta_a$$

$$\Delta(NA) = \cos(15.64^o) \times 0.001^o$$

$$\Delta(NA) \approx 0.001^o$$

- **Final Results**
  Mode Field Diameter (D) = (1.4 ± 0.01) mm
  Acceptance Angle (θ_a) = $15.64^o \pm 0.001^o$
  Numerical Aperture (NA) = $10.17^o \pm 0.001^o$

2.3 Splice Loss Experiment

2.3.1 Experimental Data

- **Variation due to Tilt**

Angle (Degree)	**Current (mA)**
-8	0
-7	0.1
-6	0.2
-5	0.2
-4	0.4
-3	0.4
-2	0.6
-1	0.7
0	0.7
1	0.7
2	0.6
3	0.5
4	0.4
5	0.3
6	0.1
7	0

Table 2.4. Variation of Light Intensity with the angle between two fibers

- **Variation due to Lateral Offset**

Displacement (mm)	**Current (mA)**
5.0	0
5.1	0.1
5.2	0.2
5.3	0.3
5.4	0.3
5.5	0.4
5.6	0.4
5.7	0.5
5.8	0.5
5.9	0.6
6.0	0.6
6.1	0.6
6.2	0.5
6.3	0.5
6.4	0.4
6.5	0.4
6.6	0.3
6.7	0.3
6.8	0.2
6.9	0.1
7.0	0

Table 2.5. Variation of Light Intensity with Lateral Offset between Two Fibers

- **Variation of Light Intensity with End Separation(Air Gap)**

End Separation (mm)	Current (mA)
0	9.7
0.1	9.6
0.2	9.4
0.3	9.1
0.4	8.7
0.5	8.2
0.6	7.6
0.7	7
0.8	6.5
0.9	6
1	5.5
1.1	5
1.2	4.6
1.3	4.2
1.4	3.9
1.5	3.5
1.6	3.2
1.7	2.9
1.8	2.7
1.9	2.5
2	2.3
2.1	2.1
2.2	2
2.3	1.9
2.4	1.8
2.5	1.6
2.6	1.5
2.7	1.4
2.8	1.3
2.9	1.2
3	1.1

Table 2.6. Variation of Light Intensity with Lateral Offset between Two Fibers

2.3.2 Plots

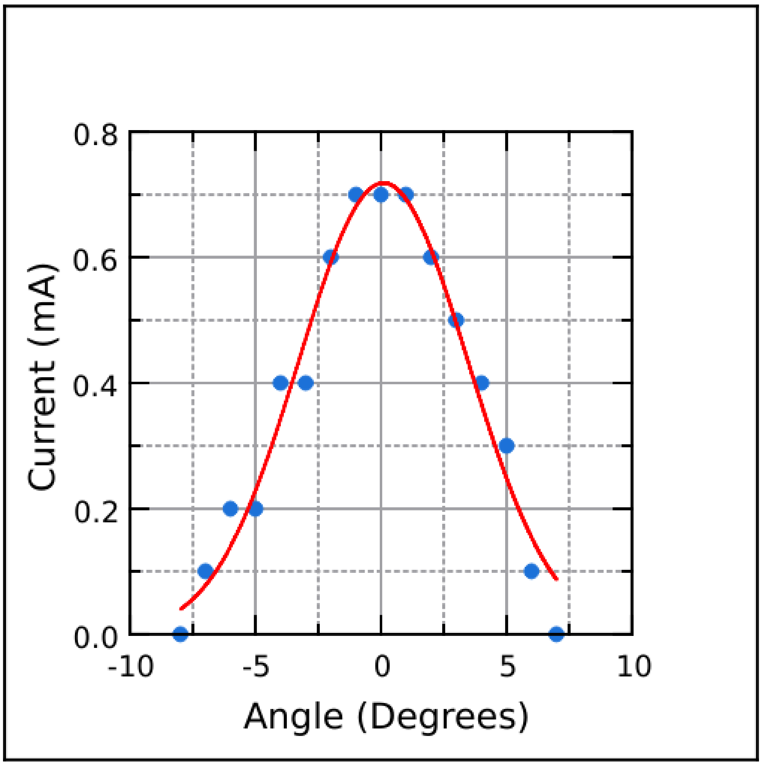

Figure 2.7. Variation due to Tilt(Red Line represents gaussian fitting)

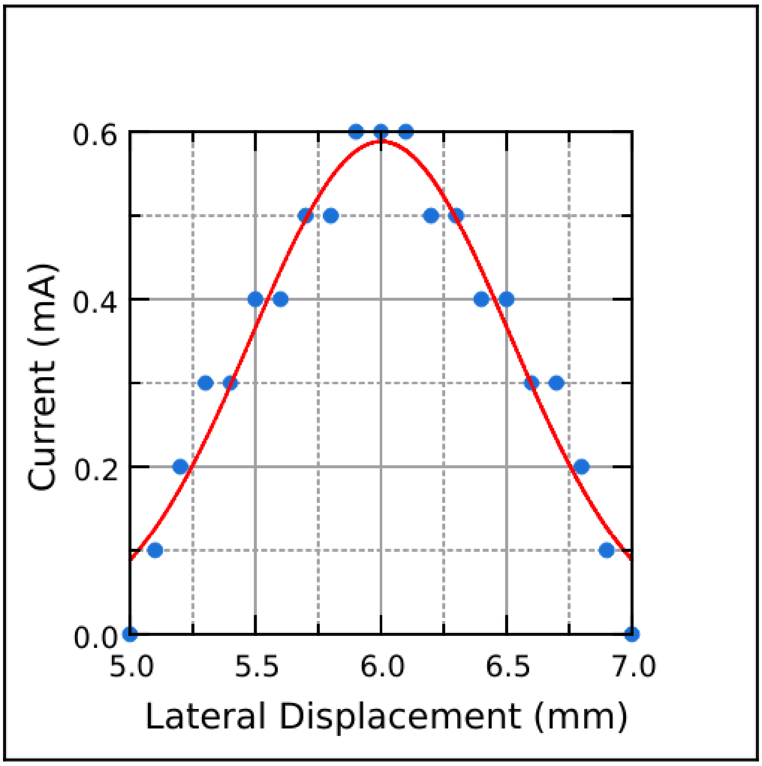

Figure 2.8. Variation due to Lateral Offset

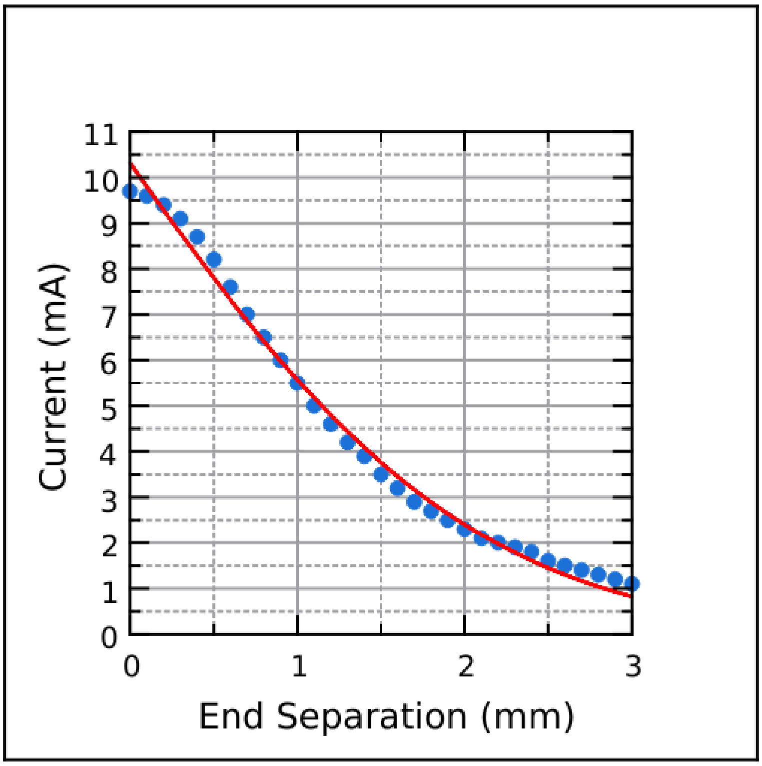

Figure 2.9. Variation due to End Separation

3 Discussion and Conclusions

- **Bending Loss Experiment** Macro-bending losses, on the other hand, occur in larger-radius bends and are primarily governed by geometric optics. When the incident angle of light exceeds the critical angle, it escapes the core and enters the cladding, resulting in losses. Our experiment demonstrated that the magnitude of macro-bending losses is influenced by factors such as the bend radius, core size, and the refractive indices of the core and cladding. As expected, smaller bend radii and larger core sizes led to increased losses.

  Moreover, we observed that as the bend radius decreased beyond a certain threshold, there was a sharp increase in bending losses. This critical bend radius is a crucial parameter to consider in practical applications, as it defines the fiber's flexibility limits while maintaining acceptable signal quality.

- **Calculation of Numerical Aperture** The NA is a fundamental parameter for characterizing optical fibers and plays a pivotal role in various optical systems, including telecommunications, medical imaging, and sensing applications.

  In our experiment, we determined the NA using the formula NA $=$ n * $\sin\theta$, where "n" represents the refractive index of the core material, and "θ" is the half-angle of the maximum cone of light that can enter or exit the fiber while undergoing total internal reflection. We ensured precise measurements of "n" and "" to obtain accurate NA values, we got NA $= 10.17^o \pm 0.001^o$.

  One notable finding is the direct correlation between the NA and the light-gathering ability of the optical fiber. Fibers with higher NAs can capture light from a wider range of angles, enabling them to transmit more light and information efficiently.

- **Splice Loss Experiment**

  1. **Loss Due to Tilt:** Tilt-induced splice loss occurs when the optical fibers are not perfectly aligned axially during the splicing process. Even a small angular misalignment can cause significant power loss due to light scattering at the splice interface.

The experimental results show that splice loss due to tilt is directly proportional to the angle of tilt. This underscores the importance of precise alignment techniques during splicing. To minimize tilt-induced loss, it's essential to use specialized fusion splicing equipment with automated alignment capabilities or to carefully align the fibers manually.

2. **Loss Due to Lateral Offset:** Lateral offset refers to the displacement of the fiber cores horizontally during the splicing process. Experimental data indicates that lateral offset leads to a notable splice loss, which increases with the magnitude of the offset. This effect is mainly caused by the mismatch between the fiber cores, resulting in imperfect coupling of light. To mitigate lateral offset-induced loss, precise fiber core alignment is crucial. Automated splicing machines or visual alignment aids can be employed to minimize lateral offset and enhance splice efficiency.
3. **Loss Due to End Separation:** End separation, the axial gap between the fiber ends during splicing, is a critical factor contributing to splice loss. Experimental findings reveal that as the end separation increases, splice loss becomes more pronounced. This is attributed to the reduction in the overlap between the fiber cores, leading to inefficient light coupling. It is evident that maintaining minimal end separation is vital for reducing splice loss. Splicing equipment with precise end-face detection and adjustment mechanisms can help ensure optimal end separation and minimize signal attenuation.

In this comprehensive experimental study, we delved into various critical aspects of optical fiber performance, encompassing bending losses, numerical aperture calculation, and splice losses attributed to tilt, lateral offset, and end separation. Our endeavor provided invaluable insights into the fundamental principles and practical implications governing optical fiber behavior.

Firstly, our investigation of bending losses elucidated the profound impact of curvature on signal transmission within optical fibers. We observed that both microbending and macrobending losses contribute significantly to signal attenuation. Microbending losses, caused by microscopic imperfections in the fiber core-cladding interface, underscored the importance of meticulous fiber handling during installation and maintenance. Meanwhile, macrobending losses, predominantly influenced by geometric optics, highlighted the relationship between bend radius, core size, and refractive indices. The identification of a critical bend radius served as a pivotal parameter for real-world applications, ensuring signal quality while accommodating bending requirements.

Secondly, our examination of numerical aperture (NA) calculations emphasized the NA's pivotal role in characterizing an optical fiber's light-gathering capacity. By applying the formula NA = n * sin(θ), we determined that NA is contingent on both the refractive index (n) of the core and the maximum angle (θ) at which light can enter or exit the fiber while undergoing total internal reflection. This knowledge is indispensable for tailoring optical fibers to specific applications, such as data communication and medical imaging, where efficient light transmission and coupling are paramount.

Lastly, our analysis of splice losses due to tilt, lateral offset, and end separation underscored the significance of precise alignment during the splicing process. These losses occur when light cannot efficiently transition from one fiber to another due to misalignment. Our experiments revealed the substantial impact of even slight misalignments on signal attenuation. These findings underscore the importance of meticulous alignment procedures and high-quality splicing techniques to minimize signal degradation during the connection of optical fibers.

In summary, this multifaceted experiment has enriched our understanding of optical fiber physics and practical considerations. It equips us with the knowledge necessary for optimizing optical fiber networks, ensuring reliable and efficient data transmission across various applications. As we advance in the era of high-speed communication and data-intensive technologies, the insights gained from this study will continue to play a pivotal role in shaping the development and deployment of optical fiber systems.

4 Precautions

1. Eye Protection: Always wear appropriate eye protection when working with optical fibers to prevent potential eye damage from laser or high-intensity light sources.

2. Fiber Handling: Treat optical fibers with extreme care to avoid microbending or damage. Minimize bending and twisting of fibers during setup and measurements.

3. Laser Safety: If lasers are used, adhere to laser safety protocols, including laser hazard assessments and the use of laser safety goggles where necessary.

4. Alignment: Ensure precise alignment of optical components, such as lenses, fiber connectors, and splice devices, to minimize signal losses due to misalignment.

5. Clean Environment: Work in a clean and dust-free environment to prevent contaminants from adhering to the fiber's surface, which can cause signal losses.