The Indonesian Journal of Computer Science
www.ijcs.net
Volume 14, Issue 2, April 2025
https://doi.org/10.33022/ijcs.v14i2.4804

Investigation of Macrobending Losses in Single Mode Optical Fiber

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Article Information

Received : 19 Mar 2025
Revised : 6 Apr 2025
Accepted : 15 Apr 2025

Keywords

Macrobending losses, Single Mode fiber, OTDR measurement, Power Losses

Abstract

Microbending losses are initiated by bending the optical fiber and caused escaping the light from the cladding and core. Macrobending losses degrade the signal quality in long-haul data communication. In the proposed system, macrobending losses are measured by different bending diameters of patch cord single-mode fiber G.652 optical fiber cable by using an Optical Time Domain Reflectometer (OTDR) and an optical power meter to identify the bending losses. The investigation of macro-bending losses aims to analyze the signal power loss in single-mode fiber. The proposed system is investigated by measuring the optical power losses at different bending diameters ranging from 200 mm to 80 mm and the number of turns up to 5 turns and comparison of losses variation for wavelengths 1310 nm and 1550 nm, which are affected by macrobending. The results are compared with theoretical calculations and the practical measurements.

A. Introduction

The first low-loss optical fibers were established in 1970, with attenuation below 20 dB/km. Researchers discovered that losses of optical fibers caused additional losses due to light escaping from the core. Bending of optical fiber increases the attenuation of signal power by two mechanisms: macrobending and microbending. Macrobending of an optical fiber is the loss related to bending the optical fiber. Light escapes from the optical fiber cable when the optical fiber cable is bending; as the bends become more, light leaks out. The attenuation depends on the radius of the bend, the number of bends, and the wavelength of the signal [1]. The bending loss was measured by the optical spectrum analyzer of the turnable laser power over a wavelength range from 1500 nm to 1600 nm. Single mode fiber SMF 28 was used with the length of 1 to 2 m in the experiment. The bending losses were measured in the radius from 8.5 mm to 12 mm. For bend radii smaller than 8.5 mm, the optical fiber is easily broken. While for a bending radius larger than 12 mm, the bending loss is too low for reliable measurement [2]. Microbending loss of light energy in step index fiber depends on bend radius, which varies from 4 to 15 mm, and wrapping turns up to 40 turns in a wavelength of 1550 nm. The macrobending and wrapping turns losses were increased. When the bend radius and wrapping turn increased [3]. As the bend was sensitive to longer wavelengths, OTDR was used to test the fiber links. The wavelengths were commonly used for bending loss are 1310 nm and 1550 nm [4]. The diameter of bending was fixed when the number of bending turns (up to 14) was varied, and the number of bending turns was fixed when the diameter of bending was varied. The number of bending turns increases, the output voltage decreases, and thus the bending loss increases. The different bending loop diameters of 2.0 cm, 2.5 cm, and 3.0 cm were tested for the same optical fiber cable. The diameter of bending increases, the output voltage increases, and the bending loss decreases [5]. The bending loss was measured with the optical power meter to determine the output signal power. The bending losses of SMF 28 and G.652.D were measured at 1550 nm of wavelength for various bending diameter ranges from 20 mm to 3 mm. For an optical power of 0.5 W and the maximum safety bend is 7.8 mm, which is in agreement with the experimental data. The safety bending diameter of optical fiber increased with the power of 10 W and achieved 19.1 mm [6].

The proposed system analyzed the macro-bending losses in the different bending diameters and different numbers of turns up to 5 in the wavelengths of 1310 nm and 1550 nm. This paper is organized as follows. Next to the introduction, the rest of the paper is planned as section II explains research methodology. Section III includes results and discussion. Section IV concludes the work.

B. Research Method

Bending losses in optical fibers have an impact on long-distance communication and data centers. Bending losses in optical fibers happen when the optical fiber is bent, causing the attenuation of the guided light to leak out from the core. These bending losses of optical fiber are classified into macrobending and microbending losses. Macrobending loss occurs when the

https://doi.org/10.33022/ijcs.v14i2.4804

optical fiber is bent with a relatively large radius. If the bend radius is too small, light at certain angles will no longer be totally internally reflected and will escape into the cladding. Microbending loss is caused by small, irregular deformations along the fiber, often due to external forces like cable pressure, manufacturing defects, or temperature changes. These bends cause light scattering and leakage. The bending loss equation is utilized to calculate the bending losses that happen in an optical fiber when it is bent. When an optical fiber is bent, the light traveling through the fiber can escape from the core due to the bending, resulting in a loss of power. The macrobending loss becomes more significant when the radius of curvature is smaller.

$$\alpha_b = c_1 \, e^{-c_2 R} \tag{1}$$

Where,
α_b = bending loss
c_1 = The maximum bending loss constant that depends on the fiber and wavelength
R = radius of curvature
c_2 = The sensitivity of the bending loss to the bend radius

Radius of Curvature

The radius of curvature refers to the radius of a circle that closely fits the curve of an optical fiber when it is bent. It is essentially the distance from the center of the bend to the center of the fiber. In optical fiber, the radius of curvature is a critical factor because it influences bending losses. As the radius of curvature becomes smaller, the loss of light from the core of the fiber increases, leading to higher macrobending losses. [3][4]

$$R_c = 4\pi \underline{\qquad\quad} 3(nNA2\lambda)3 \tag{2}$$

Where,
R_c = radius of curvature
n_2 = refractive index of the clad
NA = numerial aperture
λ = wavelength

Numerical Aperture

The Numerical Aperture (NA) is a key parameter in optical fibers, describing the ability of the fiber to collect light and guide it through the core. It defines the range of angles over which the fiber can accept and transmit light.[3]

$$NA = \sqrt{(n_1^2 - n_2^2)} \tag{3}$$

Attenuation

Attenuation is the reduction or loss of optical power as light travels through an optical fiber. Signal attenuation is defined as the ratio of optical input power (P_i) to the optical output power (P_o), and it can be expressed in dB as:[3]

$$\alpha = 10 \log_{10}\left(\frac{P_i}{P_o}\right) \tag{4}$$

Where

α = the attenuation P_o = the output power

P_i = input power

The proposed system is evaluated for power losses by using the OTDR and power meter. OTDR (Optical Time-Domain Reflectometer) is a testing device used for fault detection, attenuation measurement, splice losses, and connector losses in optical fibers. It works to measure power losses, fiber breakage, macrobending losses, and splicing losses in an optical fiber and provides the results as a trace. An optical power meter (OPM) is a device used to measure the optical power (in dBm or mW) of a light signal in a fiber optic network. It helps ensure proper signal levels, detect power losses, and troubleshoot fiber optic links.The wavelengths are 1310 nm and 1510 nm. The input laser power is -4.34 dBm. The input laser power is received from the OTDR, and received power is measured with an optical power meter. The OTDR and optical power meter are connected with a patch cord single mode fiber G.652 optical cable. The patch cord single mode G.652 is bent in different bending diameter ranges from 200 mm to 80 mm, and the number of turns is up to 5 turns for each. Figure 1 shows the setup of hardware measuring instruments.

Figure 1. The setup of hardware measuring instruments

The input parameters are shown in Table 1. The parameters are used to analyze and calculate for theoretical calculations and evaluation of measurement values for macrobending losses.

Table 1. Input Parameter

No	Parameters	Specifications
1	*Refractive index of core , n_1*	*1.47*
2	*Refractive index of cladding, n_2*	*1.46*
3	*Outer diameter of the patch cord*	*20 mm*
4	*The maximum bending loss of SMF*	*0.046 dB/bend*
5	*The sensitivity of the bending loss*	0.11 m^{-1}

C. Result and Discussion

The results and discussion section analyzes the bending losses by theoretical calculations. The numerical aperture (NA) is calculated by equation 3 when the refractive index of the core and cladding are 1.47 and 1.46. The numerical aperture (NA) is received as 0.1711. And then, the radius of curvature (R_c) is calculated by equation 2 with each of the wavelengths. Firstly, in wavelength 1550nm, the radius of curvature (R_c) is 0.108 mm. The bending losses (α_b) are determined by equation 1 and input parameters. The theoretical determination of bending losses (α_b) is received as 0.046. The standard macrobending loss is $\leq$ 0.05 dB [7]. So, the theoretical calculation is matched with the recommendation of the macrobending loss. And, equation 4 is used to calculate the measuring optical power attenuation related to input optical power and output optical power.

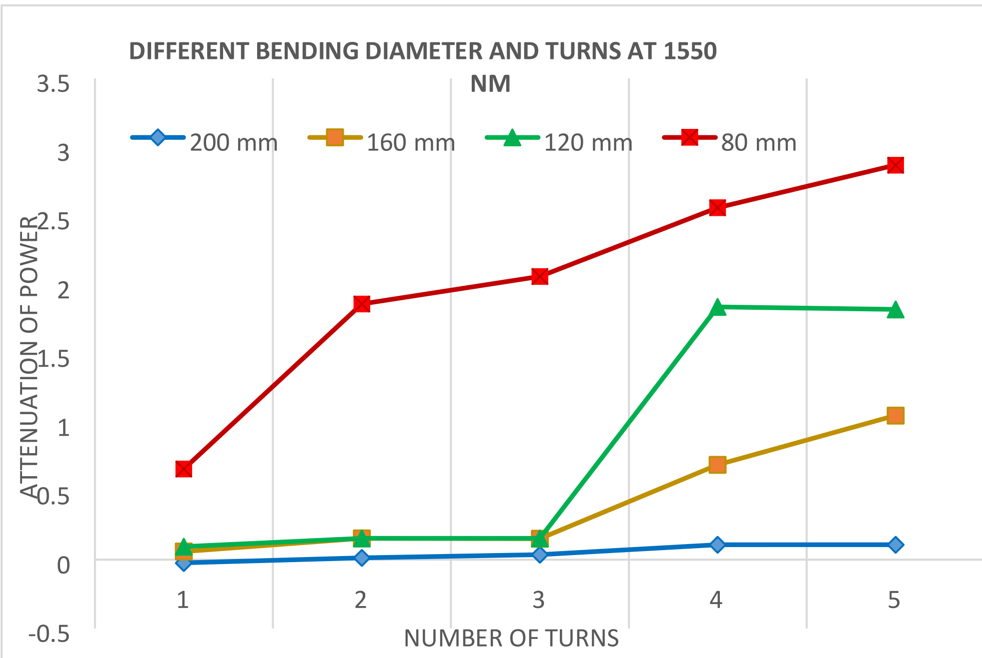

Figure 2. Attenuation of Different Bending Diameters and Turns at 1550 nm

Figure 2 shows the relationship between attenuation of optical power and the number of turns for different bending diameters at a wavelength of 1550 nm in an optical fiber. The x-axis represents the number of turns, ranging from 1 to 5, while the y-axis indicates the attenuation of power in dB. Four different bending diameters are compared with 200 mm, 160 mm, 120 mm, and 80 mm. The results show that the bending diameter decreases, and attenuation increases beyond three turns. The 80 mm diameter exhibits the highest power loss, with attenuation rising abruptly as the number of turns increases. The 120 mm and 160 mm diameters show moderate attenuation, with increases after three turns. The results are observed that a smaller bending diameter causes higher signal loss, and using larger bending diameters reduces attenuation in optical fiber systems.

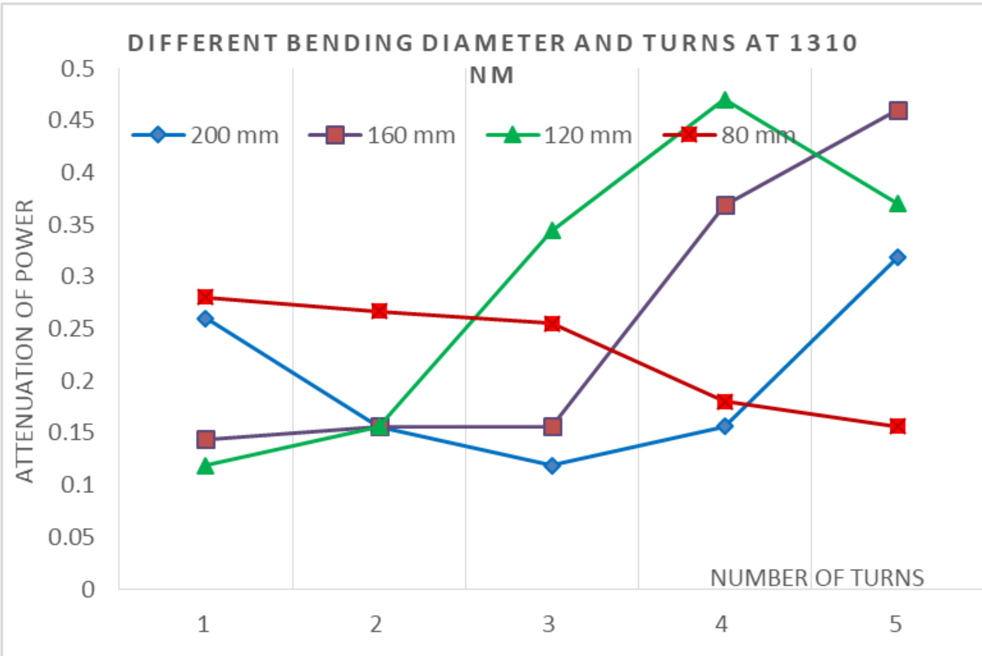

Figure 3. Attenuation of Different Bending Diameter and Turns at 1310 nm

Figure 3 represents the attenuation of power as a function of the number of turns for different bending diameters at a wavelength of 1310 nm in an optical fiber. Unlike at 1550 nm, the attenuation is varied. The 80 mm diameter starts with moderate attenuation, but attenuation decreases as the number of turns increases. The 120 mm diameter rise attenuation at four turns, then decreases. The 160 mm diameter increase attenuation after three turns. The 200 mm diameter, which has a low attenuation, starts increasing after the third turn. The variations are at 1310 nm; attenuation is a variation increasing pattern with smaller bending diameters. The results are indicated while bending losses are present; attenuation depends on the wavelength, fiber properties, and bending conditions. The theoretical calculation of bending loss is 0.045 dB. The measurement attenuation is nearly 0.156 dB.

Because the measurement attenuation includes macrobending losses and other additional losses such as connector losses.

D. Conclusion

The attenuation of power at 1310 nm varies with bending diameter and the number of turns, but unlike at 1550 nm, the graph is not increasing for all cases. While smaller bending diameters cause higher losses, the 80 mm diameter shows a decreasing attenuation after several turns. The 120 mm and 160 mm diameters exhibit a rise in attenuation beyond three turns, whereas the 200 mm diameter, which initially maintains low loss, starts increasing after the third turn. The variations of attenuation are received that bending loss at 1310 nm is more complex, likely influenced by fiber bending properties. To minimize losses, careful selection of bending diameter and an understanding of wavelength-dependent attenuation characteristics are essential for optical fiber installations.

E. Acknowledgment

I would like to thank supervisor, head of department and teachers from electronic engineering department in Mandalay Technological University for supplying the requirements, guidance for this study.

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