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Design Parameters of Fiber-Optic Bend for Sensing Applications

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ABSTRACT

The usefulness of losses in fiber optics depends on its application. Losses may be the worst scenario when they rocket up until zero power output. Attenuation in fiber optics can come from its attenuation coefficient, absorption, scattering, and extrinsic effects. Bending losses are extrinsic effects influencing the power loss in a single-mode step-index fiber. The loss of optical power in a single mode due to bending has been investigated at 1550 nm. The variations in macrobending loss have been measured in terms of the curvature radius and the number of turns. Results show that loss decreases as the bending radius increase and the number of turns decrease. This investigation may show the parameters of single-mode optical fiber and can be proposed for a fiber-optic bending sensor in the future.

Keywords: Sinusoidal Shape, Bending Loss, Single-Mode, Number Of Turns, Curvature Radius.

1. INTRODUCTION

Light loss can be correlated with the transmission, reflection, and attenuation mechanism [1]. The intrinsic attenuation loss comes from the substances present in the fiber, such as impurities and imperfection in the glass [2], whereas the extrinsic attenuation loss can be caused by external forces, such as macrobending or microbending [2]. The occurrence of power loss in an optical fiber is unsuitable for telecommunication applications. However, the loss phenomena can be useful for optical fiber sensors. Bending loss is in the form of macrobending, and microbending is the type suitable in fiber optics sensors. Recently, various fiber bending sensors have been proposed to measure different physical parameters, such as voltage, pressure, strain, and temperature. Currently, the bending loss mechanism is used in sensors for detection of respiration and heartbeat. Microbending loss is due to the microscopic fiber deformation in the core-cladding interface with a small radius of curvature [2, 3].

Macrobends are bends on a fiber, in which the radius of the curve is higher than the radius of the fiber. This phenomenon can be noted as r >> a, where a is the core radius, and r is the radius of the curvature. Commonly, macrobends can be characterized using bend angle and bend radius. When a fiber optics is bent, light is not confined and guided by the fiber core due to the failure of total internal reflection. Previous research has found that increasing the bending radius results in exponentially varying bending loss as shown in Figure 1 (a). Loss also increases when the 360° wrapping turn increases directly as shown in Figure 1(b)[2]. Several approaches have been described using different fiber bending configurations, including single loop, U-shape, sinusoidal shape, and figure-of-eight shapes [1]. In this article, the fundamental relationship among macrobending loss, bending radius, and number of turns (N) in step-index fiber is determined. The effects of different curvature radii and N on bending loss are investigated.

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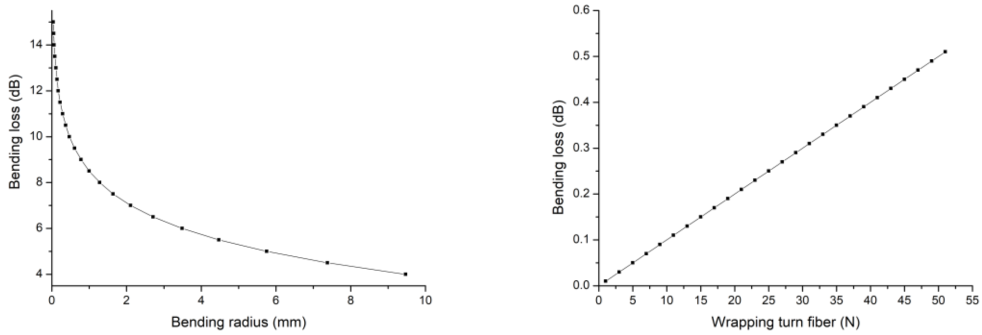

(a) (b)

Figure 1. Bending loss depends on the (a) bending radius and (b) wrapping turn of fiber.

2. MATERIAL AND METHODS

In this experiment, measurements were carried out using standard single-mode optical fiber (SMF-28) with core and cladding diameters of 9 and 125 μm, respectively. The length of the fiber used was 3 m from the source to the power meter at the wavelength of 1550 nm. For bending, the optical fiber in the sinusoidal shape of different vertices (1.0, 1.5, 2.0 and 2.5 cm) was made and used as shown in Table 1. The effect of N (up to 6 turns) was investigated. The schematic of the setup for measuring bending loss is shown in Figure 2.

Table 1 Parameter configuration of fiber optic design

Type of fiber optic	Wavelength (nm)	Tip vertex, a (cm)	Lateral vertex, b (cm)
Single mode 9 um	1550	0.75	1.0
	1550	0.75	1.5
	1550	0.75	2.0
	1550	0.75	2.5

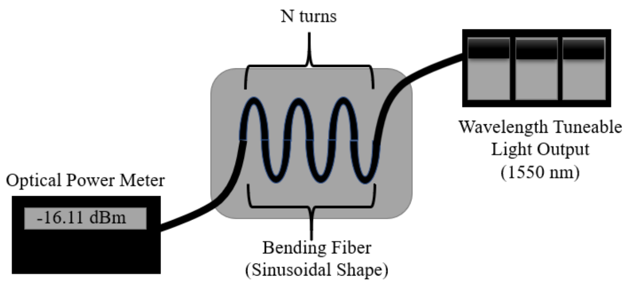

Figure 2. Schematic diagram of the optical set-up for measuring bending loss of fiber.

3. RESULTS AND DISCUSSION

For investigating the essential characterization of bending loss, the effect of bending radius (r) was studied and then the influence of turns number (N) on the loss was investigated.

3.1 Effect of Bending Radius

On the basis of the experimental setup, the bending radius is adjusted to observe the dependence of the bending radius and the bending loss. The bending losses are measured at 1550 nm. The measured results are depicted in Figure 3.

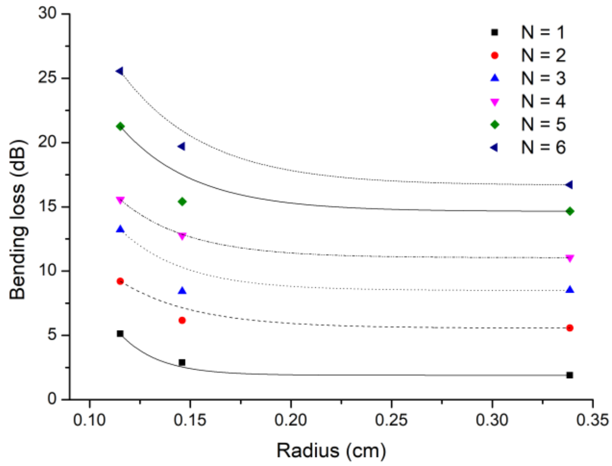

Figure 3. Relationship between bending radius and bending loss.

When the fiber is bent at 0.11 cm, the bending loss increases rapidly. Thus, a small bending radius induces a high bending loss. The variation seems exponential and satisfies the proposed relationship between losses and curvature radius through the equation [4, 10]:

$$L_r = A + \zeta_{r1}\exp\left(-\zeta_{r2}r\right) \tag{1}$$

where A and R are constants. The result is almost similar from those of previous research [5, 6, 7, 8, 9]. In this study, a sinusoidal pattern is chosen. Therefore, tip and lateral vertices affect the bending radius. The radius of the circle within the ellipse can be obtained according to the general formula of ellipse.

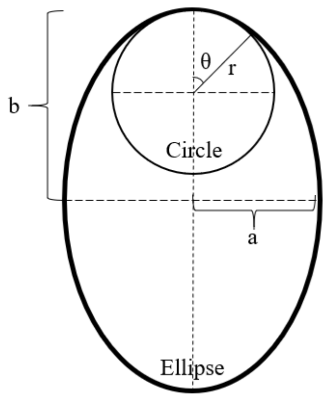

Figure 4. Circle with radius in an ellipse.

However, the bending loss experiment under different bending radii has achieved promising results due to the shape of macrobending. The bending loss increases exponentially with increasing radius of curvature, which is related to the semiaxes of the ellipse pattern, and is correlated with the sensitivity of the geometric structure.

3.2 Influence of Turns Number

The bending losses with 1 to 6 turns and various bending radii are measured at 1550 nm. From the experimental results (Figure 4), the relationship of bending loss, L_N, and N can be simplified. N is a linear equation and satisfies the proposed relationship between losses and N by using the equation [2, 4]:

$$L_N = A + BN \tag{2}$$

Where A and B are constant. By considering and making a comparison with the general single-mode bending loss [1, 3, 11], we determined that:

$$B = 8.686\alpha l \tag{3}$$

And l can be calculated using:

$$l = \frac{\pi\left[\left(3(a+b)\right) - \left(\sqrt{\left(3(a+b)\right)\times(a+3b)}\right)\right]}{2} \tag{4}$$

where a and b are tip vertex and lateral vertex of an ellipse, respectively.

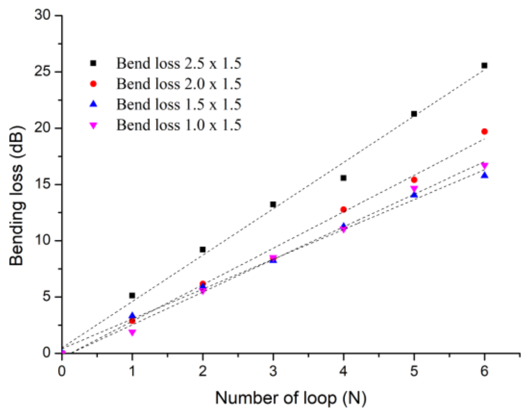

Figure 4. Variation of bending loss versus a number of turns.

The variations in L against N are plotted in Figure 4 to show that the lower bend loss happens when the tip vertex of the sinusoidal shape is 2.5 cm. The values of the semiaxes of the ellipse are essential to determine the sensitivity of fiber optics on the bend loss effect. Ellipse is considered in this situation because the changes in the amplitude and the period on the sinusoidal shape affect the geometry of the bend. The parameter of sensitivity, S, can be related as [12]:

$$S = \sqrt{\frac{b}{a}} \tag{5}$$

Figure 4 shows that the sensor with tip and lateral vertices of 0.75 and 2.5 cm, respectively, is the most sensitive. As shown in Table 1, the change in the tip vertex is inversely proportional with the change in the lateral vertex. The most sensitive sensor has a large sensor sensitivity.

Table 1 Sensitivity table according to change of lateral vertex

Tip vertex, a (cm)	Lateral vertax, b (cm)	Sensitivity, S
0.75	1.0	1.15
0.75	1.5	1.41
0.75	2.0	1.63
0.75	2.5	1.82

4. CONCLUSION

In conclusion, the bend loss in step fiber depends on the bending radius and turns number. Results show that loss reduction increases the curvature radius and decreases N. The relationship among bend loss, bending radius, and N has been analyzed, and results show that the single-mode optical fiber has potential applications in fiber-optic bending sensor due to its sensitivity to bend loss.

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