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ARTICLE

Single-mode Optical Fiber: An Investigation for the Bending Loss at Wavelength 650 nm

Anu Dhupar[a], **Suresh Kumar**[b,c], **Kajal Mittal**[c], **Anu**[d], **Sanjay K. Sharma**[e], **Vandana Sharma**[b] and **Jatinder K. Sharma**[b]

[a] *Department of Physics, Chandigarh University, Gharaun, Mohali – 140413, Punjab, India.*

[b] *Department of Physics, MMEC, Maharishi Markandeshwar (Deemed to be University), Mullana – 133207, Haryana, India.*

[c] *Department of Physics, Maharishi Markandeshwar University, Sadopur, Ambala – 134007, Haryana, India.*

[d] *School of Physics and Materials Science, Thapar University, Patiala – 147004, Punjab, India.*

[e] *School of ICT, Gautam Buddha University, Greater Noida – 201308, Uttar Pradesh, India.*

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Abstract: In modern time, the optical fiber communication has revolutionized the data transmission process and contributed vitally to the development of qualitative and speedy telecommunication systems. The arteries of this system are optical fibers which carry information as light signals and as fast as speed of light. But these light signals suffer energy losses during their propagation through the optical fibers. For the effective functioning of an optical fiber communication, it is necessary to know and prevent the prevailing energy losses (especially external bending losses) of the optical fibers. In this paper, the external bending loss of optical power while propagating through a single-mode optical fiber has been investigated. Further, the effects of wrapping turns (1 to 6 turns) and bending diameters (2 cm ≤ D ≤ 12 cm) on the power loss of laser at a wavelength of 650 nm have been studied.

Keywords: Single-mode optical fiber, Bending loss, Attenuation coefficient, Wrapping turns, Bending diameter.

PACs: 42.81.-I, 78.67.Pt, 42.25.Bs.

Introduction

Optical fibers are transparent and flexible strands which possess thicknesses of few microns and are fabricated from materials like glass, plastic … etc., [1]. They are spherical dielectric waveguides that efficiently transport optical energy and information in the form of light signals. They are especially designed to transmit signals over larger distances and at higher bandwidths than conventional electrical wires or cables. These fibers have many advantages over conventional wires and cables, such as less signal attenuation, less power loss, electrical isolation, high volume capacity, being free from electromagnetic interference of signals … etc. Specially designed optical fibers are also used in a variety of applications, including communication, optical sensors, fiber lasers, power transmission … etc. [2]. An optical fiber consists of typically three regions; namely, core,

Corresponding Author: Suresh Kumar **Email**: sureshlakhanpal@gmail.com

cladding and outer material. A core material having a high refractive index is surrounded by a transparent cladding material having a low refractive index and an outer polymer material which acts as protection jacket for inner materials and provides mechanical strength to the fiber. Light propagates through the core obeying the total internal reflection phenomenon which turns the fiber into an optical waveguide [3]. Optical fibers that uphold numerous propagation paths are called multimode fibers, while those that maintain only a single path are called single-mode fibers. In general, multi-mode fibers have a wider core diameter and are more suitable in short-distance communication links, high power transmission … etc. [4]. Single-mode optical fibers having smaller core diameters are mostly preferred for communication links longer than 1,000 meters [5]. The light gathering ability of an optical fiber, also known as numerical aperture, is more for multimode fibers than that of single-mode fibers. However, the information transmission ability of single-mode optical fibers is much larger than that of multimode cables [6, 7]. There are many factors responsible for high transmission ability of single-mode fibers, but the most important property is the comparatively low signal attenuation [8, 9]. Attenuation is the reduction in signal strength when it propagates through the channel medium. It has proved to be one of the important factors for the widespread acceptance of optical fibers in communication systems. It is affected by various mechanisms: absorption, scattering, bending, dispersion, misalignment … etc. However, the bending losses are particularly important in single-mode fibers, because they work internally and externally [6, 9]. In optical fibers, two types of bending occur: macro–bending (large-scale bending occurs externally) and micro–bending (small-scale bending exists in the core cladding interface). The macro–bending or external bending may occur during installation of optical cables, while the localized micro–bending can develop during manufacturing of the fiber [10-14]. Optical fibers are critically designed for the development of high-quality and high-speed networks [11 - 14], but external bending affects their functioning badly if not handled properly.

Hence, in this work, the authors try to investigate the consequence of external bending on the optical power transmission through single-mode fibers of different lengths (1 m, 1.4 m, 1.8 m and 2.2 m). The effects of wrapping turns (1 to 6 turns) and bending diameters (2 cm, 4 cm, 6 cm, 8 cm, 10 cm and 12 cm) on the power loss of laser light of wavelength 650 nm have been studied.

Experimental Work

The experimental work was carried out using different instruments with specifications such as a laser diode of wavelength (λ) 650 nm (red color), output power between 3 and 5 mW, operated at voltage 220 V ± 10% having frequency = 50 Hz, single-mode optical fiber (with plastic core and plastic cladding design) of variable lengths (1 m, 1.4 m, 1.8 m and 2.2 m), a light lens (45×), V grooves and post stands. For bending the optical fiber, aluminum mandrels of different diameters (2 to 12 cm) were used. A composite silicon laser detector acts as a digital micrometer used to measure the output optical power. The single-mode optical fiber was carefully aligned to the laser source and positioned to achieve maximum light intensity. A reference loss that was presented without any bending was recorded and subtracted from the loss obtained after bending of fiber. All the components and instruments are arranged as shown in Fig. 1. The experiment was performed in a dark-room environment to avoid interference of external light with experimental conditions.

Results and Discussion

The output optical power [11] of single-mode optical fiber is given by $P_o(L) = P_i \times \exp^{-\alpha L/10}$ dB, where P_i is input power, P_o is output power, α_{dB} is the signal attenuation per unit length in decibels and L is the length of the optical fiber. The attenuation of light (α_{dB}) while propagating through the fiber is expressed in decibels per unit length (*i.e., dB/m*) which is given by the relation, $\alpha_{dB}L=10\times\log(P_i/P_o)$ [4]. In terms of current, the bending loss in *dB* is given as, $dB = 20\times\log(I/I_o)$ for all values of current corresponding to different bending loop diameters. The values of optical output of laser diode (emitting red light of wavelength, λ = 650 nm) when propagating through single-mode fiber under different experimental investigations, such as different bending diameters (2 cm to 12 cm), different numbers of turns (1 to 6) and different optical fiber lengths; *i.e.*, 1 m, 1.4 m, 1.8 m and 2.2 m are listed in Tables 1 to 4.

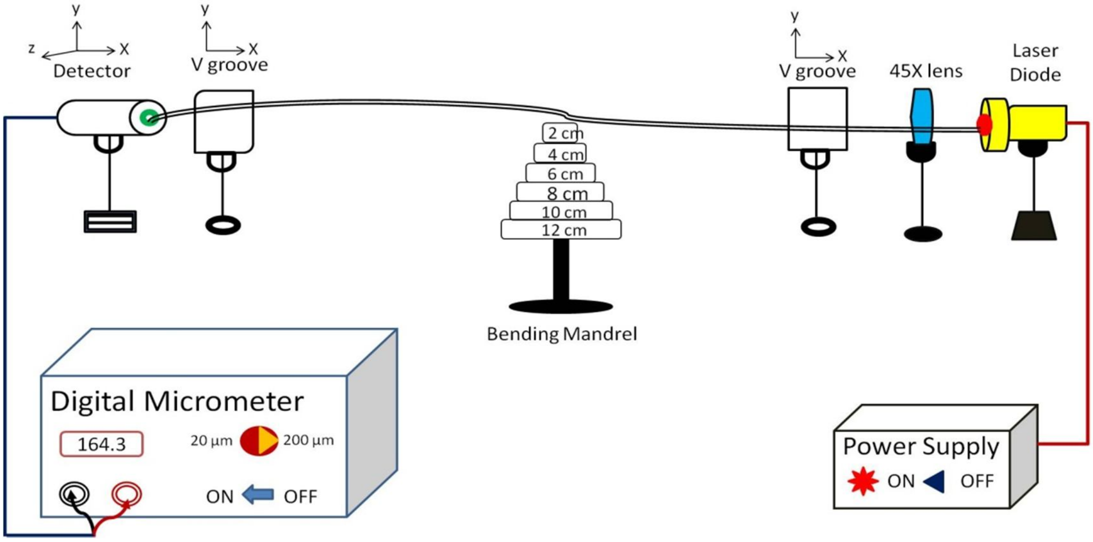

FIG. 1. The experimental setup for measuring optical loss due to macro–bending.

TABLE 1. The effect of number of wrapping turns on the output current of laser source at different bending diameters for single-mode optical fiber of length 1 m.

Sr.	Wrapping turns (N)	Output current ($\times10^{-6}$ A) Bending diameter (D) 2 cm	4 cm	6 cm	8 cm	10 cm	12 cm
1	0	190	190	190	190	190	190
2	1	164	167	169	172	175	179
3	2	147	150	153	156	160	164
4	3	128	131	137	139	144	147
5	4	108	114	117	121	127	133
6	5	94	98	102	105	111	118
7	6	73	81	86	90	96	102

TABLE 2. The effect of number of wrapping turns on the output current of laser source at different bending diameters for single-mode optical fiber of length 1.4 m.

Sr.	Wrapping turns (N)	Output current ($\times10^{-6}$ A) Bending diameter (D) 2 cm	4 cm	6 cm	8 cm	10 cm	12 cm
1	0	190	190	190	190	190	190
2	1	158	160	164	169	173	178
3	2	138	144	148	154	158	163
4	3	124	128	132	134	137	146
5	4	104	111	117	122	128	133
6	5	87	95	100	107	113	115
7	6	68	76	81	91	97	101

TABLE 3. The effect of number of wrapping turns on the output current of laser source at different bending diameters for single-mode optical fiber of length 1.8 m

Sr.	Wrapping turns (N)	Output current ($\times10^{-6}$ A) Bending diameter (D) 2 cm	4 cm	6 cm	8 cm	10 cm	12 cm
1	0	190	190	190	190	190	190
2	1	152	158	162	165	170	177
3	2	133	140	146	152	159	162
4	3	117	121	129	131	139	146
5	4	100	108	115	120	124	135
6	5	85	92	98	105	111	114
7	6	64	72	78	89	95	103

TABLE 4. The effect of number of wrapping turns on the output current of laser source at different bending diameters for single-mode optical fiber of length 2.2 m

Sr.	Wrapping turns (N)	Output current ($\times 10^{-6}$ A)					
		Bending diameter (D)					
		2 cm	4 cm	6 cm	8 cm	10 cm	12 cm
1	0	190	190	190	190	190	190
2	1	147	153	159	163	168	175
3	2	128	138	144	150	156	162
4	3	111	117	126	130	137	144
5	4	93	104	112	118	127	133
6	5	77	87	95	104	109	117
7	6	60	68	73	77	88	101

A falling trend in output current is observed for all fiber lengths as the numbers of the wrapping turns increased. However, this output is observed to be increased with an increase in macro-bending diameter at a fixed number of wrapping turns. The variations in attenuation coefficient per unit length of single-mode optical fiber at a fixed length; *i.e.*, 1 m, 1.4 m, 1.8 m and 2.2 m with wrapping turns (1 to 6) and bending diameter (2 cm to 12 cm) are shown in Fig. 2. It is found that attenuation coefficient increased with increase in wrapping turns and decrease in external bending diameter. Moreover, it changed with the length of optical fiber and found highest for fiber length 2.2 m and lowest for 1.0 m. The effect of wrapping turns (1 to 6) and bending diameter (2 cm to 12 cm) on the bending loss of single-mode optical fiber at a particular length; *i.e.*, 1 m, 1.4 m, 1.8 m and 2.2 m is represented in Fig. 3.

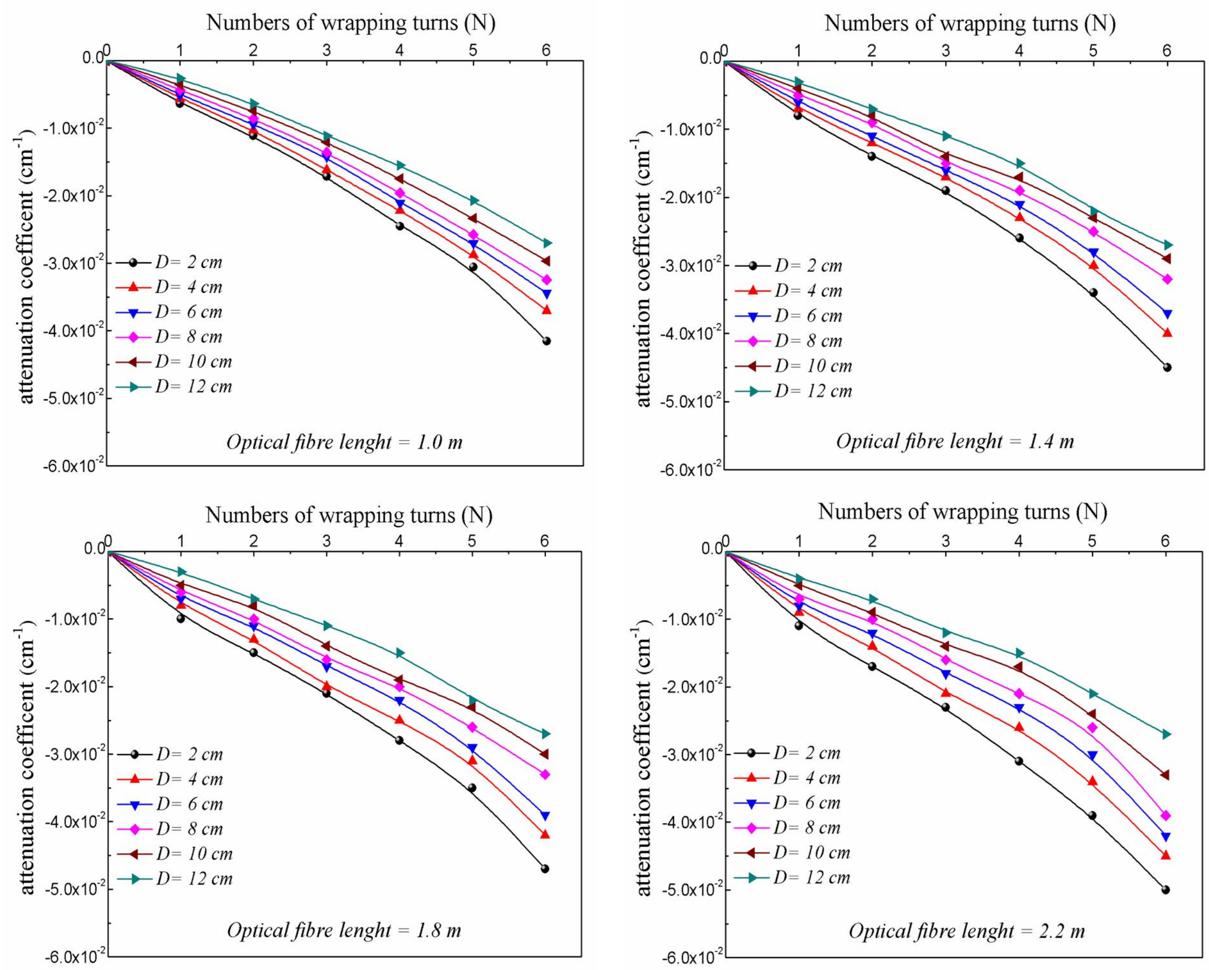

FIG. 2. The effect of wrapping turns (1 to 6) and bending diameter (2 cm to 12 cm) on the attenuation coefficient of single-mode optical fiber at a particular length; *i.e.*, 1 m, 1.4 m, 1.8 m and 2.2 m.

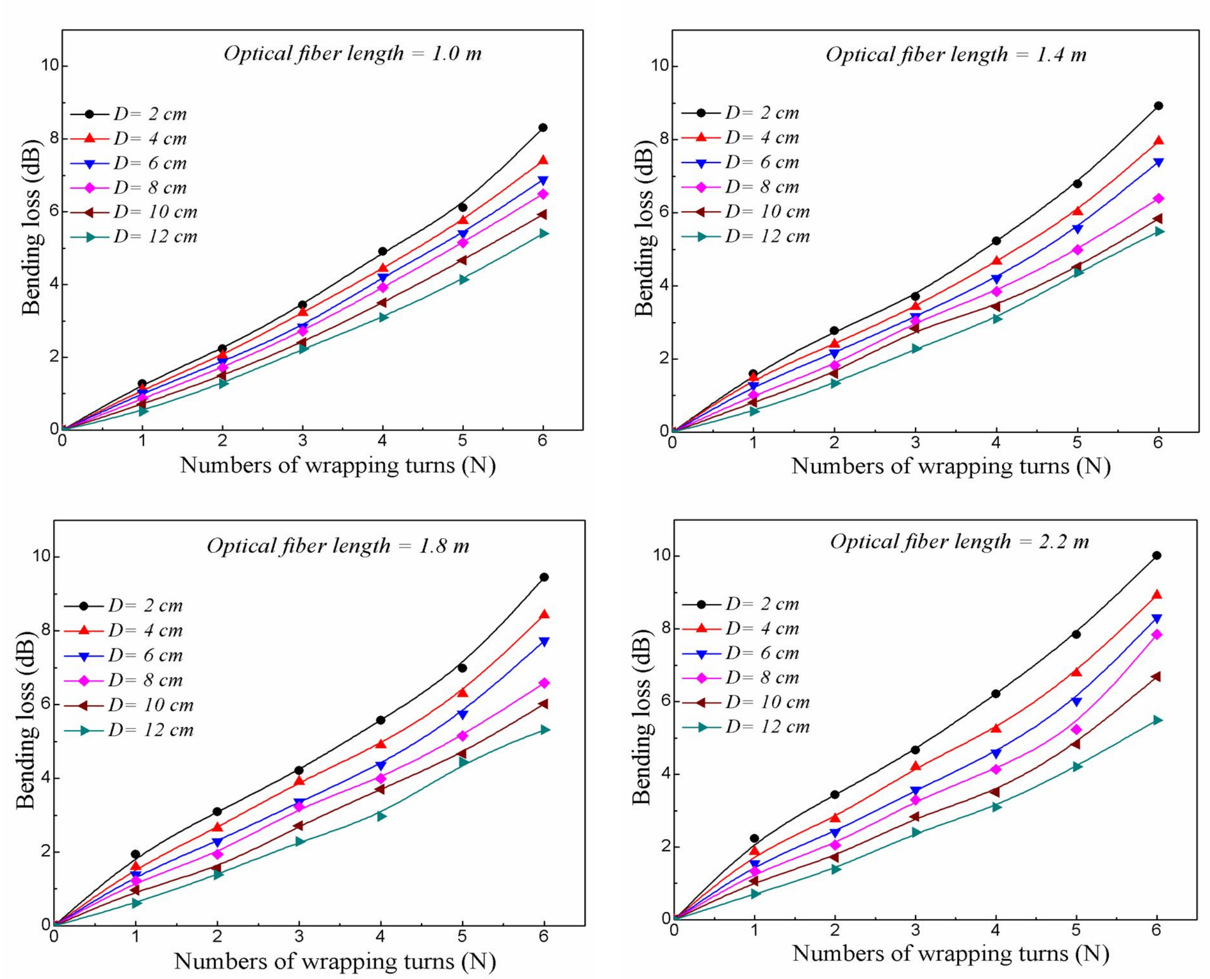

FIG. 3. The effect of wrapping turns (1 to 6) and bending diameter (2 cm to 12 cm) on the banding loss of single-mode optical fiber at a particular length; *i.e.*, 1 m, 1.4 m, 1.8 m and 2.2 m.

It is shown that the bending loss depends on the number of wrapping turns of the single-mode fiber which provides varied values of bending loss with each step size. It is observed that when the wrapping turn increases, the bending loss directly increases. A direct linear relationship between the bending loss and wrapping turn has been estimated. Similar type of variation in bending loss with wrapping turns was also reported in literature [13]. It is also predicted from the results that for a particular length of a single-mode optical fiber, the bending loss decreases with increase in bending diameter from 2 cm to 12 cm (Fig. 4). It has also been observed that for a fixed length of the fiber, as the bending diameter increases, the sharpness in the reduction of bending loss *w.r.t.* number of turns; *i.e.*, slope of the curve slightly decreases, which indicates that susceptibility of the fiber to these losses depends on the bend diameter and can be minimized by increasing the bending diameter.

Moreover, this loss is found high for smallest bending diameter; *i.e.*, 2 cm and low for the highest bending diameter; *i.e.*, 12 cm, while the attenuation coefficient has the opposite trend for compressible fiber lengths (Fig. 4). This indicates that smaller bending diameter and larger wrapping turns promote higher bending loss which increases with the increase in the length of the fiber, while it decreases with increase in bending diameter. A similar variation in the power loss of the optical fiber with bending radius and wrapping turns at a wavelength of 1550 nm is also reported in literature [4, 14]. The present analysis suggests that to reduce the power loss during transmission, the external bending diameter should be kept large and the number of wrapping turns should be kept small.

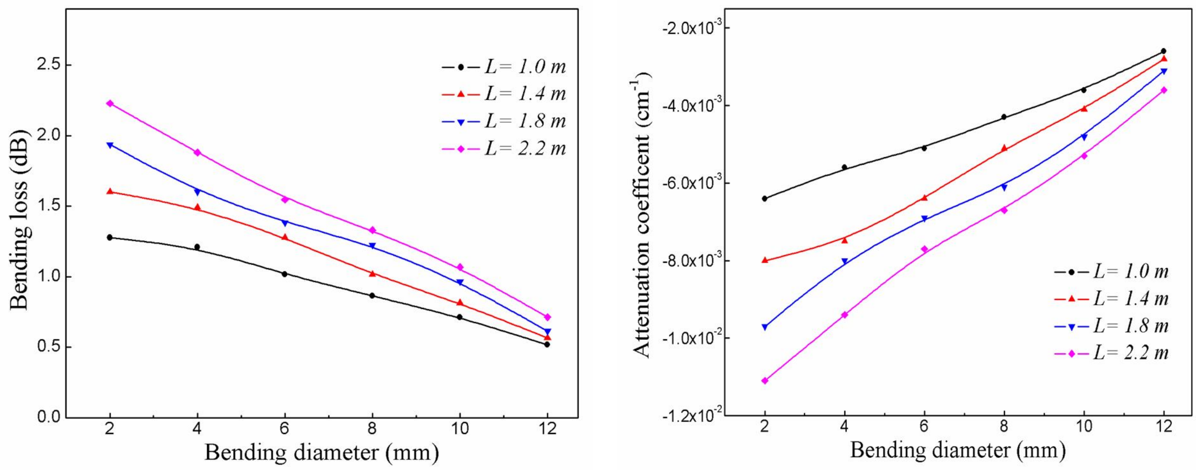

FIG. 4. The effect of bending diameter (2 cm to 12 cm) on the bending loss (left) and the attenuation coefficient (right) of single-mode optical fiber with different lengths (1 m, 1.4 m, 1.8 m and 2.2 m).

Conclusion

In the present study, the bending loss in the optical power of a single-mode optical fiber because of different wrapping turns and variable bending diameters has been investigated. It has been observed that as the number of wrapping turns of the optical fiber increases and the bending diameter decreases, the bending loss through the fiber increases linearly and sharply. Also, it is observed that as the length of the fiber increases, the bending loss and attenuation coefficient change up to an appreciable extent. It is found that the external bending loss of optical power, when propagating through the optical fiber, increases as the bending diameter decreases and wrapping turns increase. The accomplished investigation and experimental results are compatible with the theoretical studies within the uncertainty limits.

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