7. Bend-Induced Loss in a Single-Mode Fiber

(Dated: January 25, 2021)

I. OBJECTIVE

To study bend-induced loss in a single-mode fiber

II. APPARATUS

1. Optical breadboard
2. He-Ne Laser and Laser aligner
3. Microscopic objective (20X) and holder
4. xyz-translational stage
5. Pin hole photodetector with multimeter and holder
6. Two fiber chucks
7. 2 post bases and 3 posts
8. Single-mode (NA = 0.1) fiber of more than 1m length
9. Fiber cleaver
10. Index matching liquid
11. Multi Spool kit.

III. THEORY

Radiative losses occur whenever an optical fiber is subjected to extrinsic perturbations like bend of a finite radius of curvature, and such losses are known as bend loss. An optical fiber can have two types of bends: (1) random microscopic bends as we saw in previous experiment and (2) macroscopic bends having radii that are large compared to fiber diameter.
The bending loss can be exlpained by examining the modal electric field distributions as shown in fig.(1):

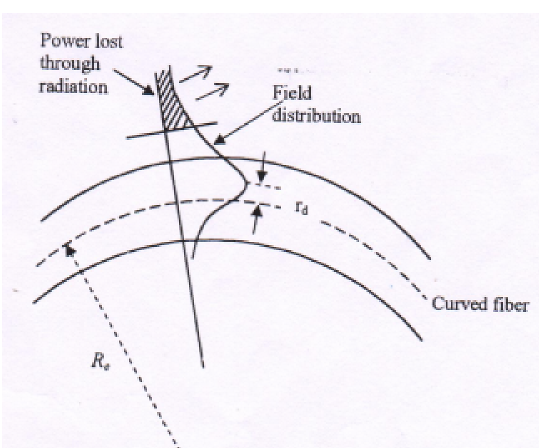

FIG. 1. representation of the bending loss in a section of fiber bent into an arc of radius R_c

The bending loss can be accounted for by the transition losses and the macrobend losses. The predominant effect of curvature on the fundamental mode is to shift the peak of the field distribution radially outwards by a distance r_d from the fiber axis. This shift within the Gaussian approximation of the field, is given as:

$$r_d = \frac{\beta^2 w_o^4}{2R_c} \quad ....(1)$$

Where β is the propagation constant of the mode in the straight fiber, R_c is radius of curvature of the bend and w_o is the Gaussian spot-size(or Mode Field radius).
The pure bend loss coefficient (in dB per unit length of the bent fiber) in a single moded step index fiber is given by:

$$\alpha \approx 4.34 \left(\frac{\pi}{4aR_c}\right)^{1/2} \left(\frac{U}{VK_1(W)}\right)^2 \frac{1}{W} exp\left[-\frac{4R_cW^3\Delta}{3aV^2}\right] ...(2)$$

where, a is the core radius of the fiber, R_c is the radius of curvature of the bent fiber, $K_1(x)$ is the modified Bessel function of second kind. The parameters U,W,V and Δ are defined through:

$$U = a\sqrt{k_o^2 n_1^2 - \beta^2}$$

$$W = a\sqrt{\beta^2 - k_o^2 n_2^2}$$

$$V^2 = U^2 + W^2$$

$$\Delta \cong (n_1 - n_2)/n_2$$

$$k_o = 2\pi/\lambda_o$$

However, in the experiment, a few turn are given to the fiber so that the loss is measurable and then α is calculated as follows:

$$\alpha = -\frac{10}{L} log\frac{P_2}{P_1} \quad .....(3)$$

Where, L is the length of the fiber(within the bend) i.e. $2\pi R$x (no. of turns), P_1 is the output power without the bend in the fiber and P_2 is the output power with the bend in the fiber.

IV. PROCEDURE FOLLOWED

Light was coupled into the single mode fiber in the similar manner as it was done in the 1^{st} experiment to obtain maximum coupling.
After obtaining maximum coupling, the photo detector was mounted in front of output end of the fiber and adjusted such that it obtains maximum power, that reading was noted down as maximum power without any bend. Then Multi spool kit was taken and diameter of each spool partition was measured using Vernier Calliper. Then it was mounted on the breadboard and the fiber was wound over the spool partition with largest diameter as much as it could be and the power was noted down. Then successively, the spool with smaller diameter was used and corresponding power was written along with the no. of turns.
The no. of turns were reduced as the spool became smaller and smaller to get detectable values.

V. EXPERIMENTAL DATA

A. Bend Induced Loss with experimental method.

TABLE I. Experimental method

Radius of the spool (cm)	No. of turns	Total length of bent fiber L (cm)	Output Voltage (V)	Normalized Power	Absorption coefficient α
2.0025	7	88.0299	0.247	1	0
1.61	9	90.9972	0.246	0.991919	0.000387
1.2575	11	86.8681	0.244	0.975856	0.001222
1.0025	10	62.957	0.234	0.897507	0.007459
0.8575	10	53.851	0.154	0.38873	0.076201
0.7075	5	22.2155	0.042	0.028914	0.692712
0.605	3	11.3982	0.013	0.00277	2.243782
0.5125	2	6.437	0.003	0.000148	5.951765

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B. Theoretical method

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TABLE II. Theoretical nature of Bend Induced loss

Radius of the spool(cm)	Absorption coefficient α
2.0025	0.000000766
1.61	0.0000505
1.2575	0.002230105
1.0025	0.035369812
0.8575	0.172624494
0.7075	0.903589762
0.605	2.243782
0.5125	8.058183305

VI. GRAPHS AND CALCULATIONS

Using the values from Table I and Table II, the following graph is obtained:

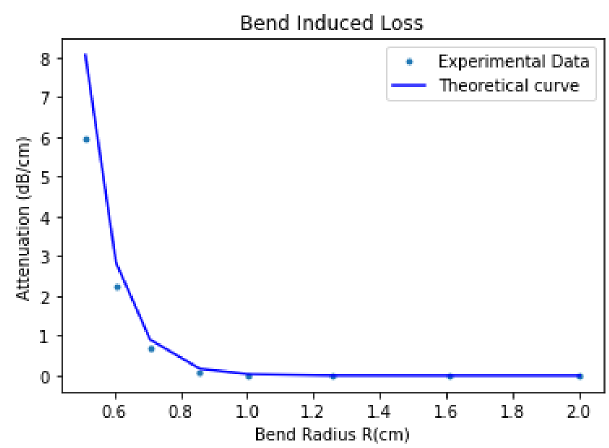

FIG. 2. Theoretical curve and experimental points

A. Calculation of $\alpha(theoretical)$

On putting appropriate values of all the terms in eq.(2), we finally get:

$$\alpha \approx 4.34 \left(\frac{\pi}{4aR_c}\right)^{1/2} \left(\frac{U}{VK_1(W)}\right)^2 \frac{1}{W} exp\left[-\frac{4R_cW^3\Delta}{3aV^2}\right]$$

$$\alpha = 1187.3 * \frac{exp(-10.3941 * R)}{R^{0.5}}$$

Using this equation we got the theoretical values for absorption coefficient.

VII. RESULT

We got a really good graph in terms of relation between theoretical and experimental values. And as we can see that after a certain value of L, the loss becomes so high. Therefore, there is a limit to which fiber can be bend.

[1] YOLUX setup Manual,*School of Physical Sciences,NISER*

[2] A.K Ghatak and K. Thyagarajan,*Introduction to Fiber Optics*, Cambridge University Press,Cambridge(1998)