Modeling of Bend Losses in Single-Mode Optical Fibers

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***Abstract* — The dissemination of the optical fibers structures, especially in the access network had impose new challenges. In this work we present the study of macro bending losses in single mode optical fibres, namely the bend loss as a function of the Radius of Bend for SMF fiber are given. The experimental results are compared with the results from the improved formula for bend loss determinate by R. Shermer and J. Cole.**

I. Introduction

Due to the boost of signals inside the optical fiber, the optical power circulating on fibers is increasing day by day. One of the consequences of this power increase is a temperature increase in the localizations where the signal losses are higher. The temperature increase can be sufficient to initiate the fiber fuse phenomenon, which results in the fiber destruction.

As is well known macro bending can significantly increase the losses on fibers. Typically, these losses can be very significant when a *critical radius* value is reach. This critical radius is much larger (often tens of centimeters) for single-mode fibers with large mode areas, when compared with small mode areas fibers[1].

In Fig.1 we can see a scheme of a macro bend in a fiber, when some illustrative ray traces are displayed inside the fiber core. Light is lost from the core to the cladding when the ray incident angle (in the core-cladding interface) do not reach to total internal reflection critical angle (θ_c).

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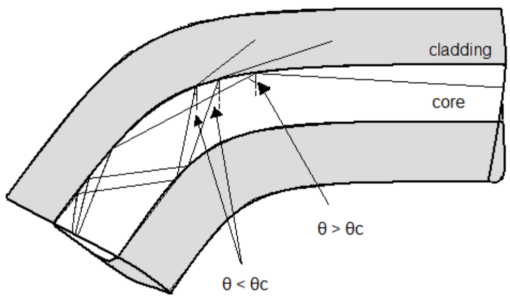

Fig. 1. Macro bending schematic in a optical fiber.

Theoretical investigations related with the bending of fibers began in the 70s, when Dietrich Marcuse presented a formula for curvature loss in optical fibers [2]. In the 1980s, Harris and Peters, presented experimental loss measurements as a function of the wavelength and bending radius [3]. Recently, Ross Schermer and James Cole, presents the same formulism that Marcuse but with some adjustments to correct the bending induced stress [4]. They had compared the results with experimental data and with numerical results obtained with the beam propagation method.

II. Theory

A. Bent Fiber

To achieve the formula of bend loss describe in [4] is necessary to account bend stress on fiber. Transforming the circularity curved fiber into an equivalent straight fiber we can obtain the modified index distribution. We can use the equation (1) for slow bends ($x<<R$), where R it's the fiber bend and x is the position on bend direction (figure 2):

$$n' = n_{material} \cdot e^{\left(\frac{x}{R}\right)} \approx n_{material} \cdot \left(1 + \frac{x}{R}\right) \qquad (1)$$

The refractive index of a stress bend fiber (n') suffers a distortion in relation to the unstressed situation: comprehension along the inner half of the fiber, towards the center of the bend, and tension along the outer half. This can be expressed:

$$n_{material} = n\left[1 - \frac{n^2 x}{2R}\left[P_{12} - \nu(P_{11} + P_{12})\right]\right] \quad (2)$$

where P_{11} and P_{12} are components of the photo-elastic tensor and ν is Poisson's ratio.

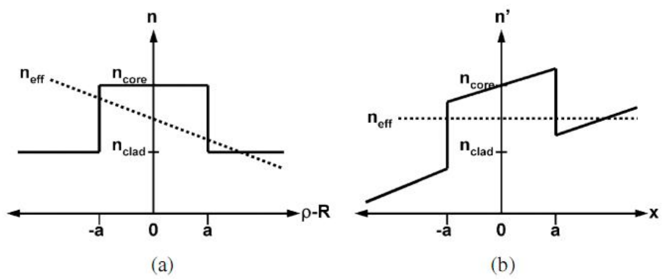

Fig. 2. Refractive index distribution of an unstressed bent fiber and its equivalent straight fiber after conformal map [4].

Using expressions (1) and (2) is possible to define the equivalent bend radius as [4]:

$$R_{eff} = \frac{R}{1 - \frac{n^2}{2}\left[P_{12} - \nu(P_{11} + P_{12})\right]} \quad (3)$$

For silica fiber, $R_{eff}/R \approx 1.28$.

B. Marcuse's Loss Formula

The Marcuse simplified bend loss formula for optical fiber [2] adapted to include fiber stress [4], is given by

$$2\alpha = 4.343 \frac{\pi^{1/2}\kappa^2 \exp\left(-\frac{2\gamma^3 R_{eff}}{3B_z^2}\right)}{2R_{eff}^{1/2}\gamma^{3/2}V^2 K_{m-1}(\gamma a)K_{m+1}(\gamma a)} \quad (4)$$

Here 2α is the power loss in dB/length, K is the first order modified Bessel functions, and m is the azimuthal mode number. Note that this formula it is only applicable to LP modes. The field decay rates in the core and cladding can be expressed, respectively as

$$\kappa = \sqrt{k_{core}^2 - \beta_z^2} \quad (5)$$

$$\gamma = \sqrt{\beta_z^2 - k_{clad}^2} \quad (6)$$

Here βz is the propagation constant, being obtained by numerical simulation techniques for straight fiber [5]. The typical value used in the calculus displayed in the figure 4 re show in table I.

Table I
Parameters used in (4)

λ	1.550 μm
a	4.1 μm
n_{clad}	1.440
NA_{index}	0.117

III. Experimental results

Fig.3 shows the essential details for the experimental setup used in the work. The optical signal, generated in a external cavity laser, is boosted by an EDFA and injected in fiber under test. The signal was analyzed with an optical spectrum analyzer (Q8384 Advantest). The bends were imposed using a wooden slab with different diameters holes.

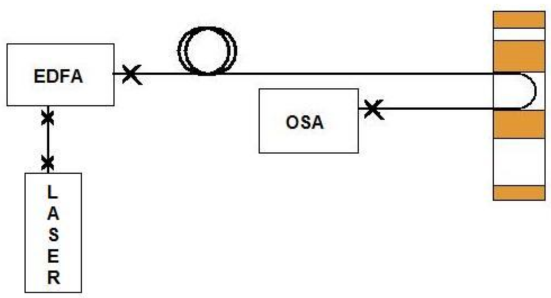

Fig. 3. Experimental setup used to characterize the bend loss on single mode fiber optic.

The tuned of the laser wavelength allows the measurement of the bending losses as function of the wavelength.

IV. Discussion

Figure 4 show the experimental bend loss data, for the wavelength of 1550 nm, as function of the fiber bend radius. A small discrepancy between the improved bend loss formula and the experimental results is observed. In order to study this difference we should consider the derivation of expression (4) [4]. There were many approximations made, but the most significant is that the modes must not change during bending.

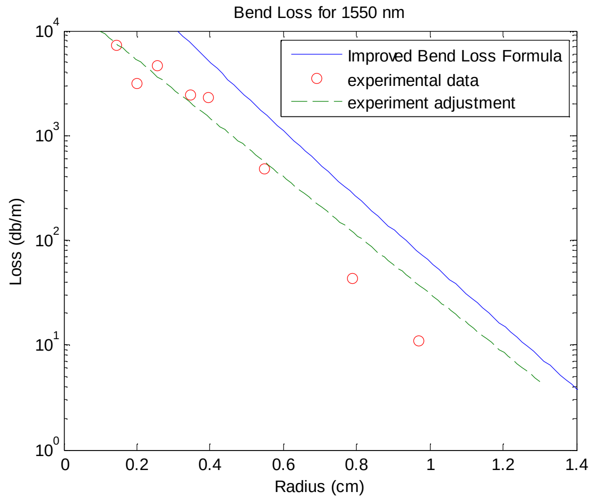

Fig. 4. Comparison of experimental and theoretical data for the bend loss of SMF fiber.

The mode propagation constants, which differ with radial position, as shown in Figura 2(a), were also assumed to match those of the straight fiber at x=0[4].

The discrepancy between results can also be explained due to the design of the experiment. The wooden slab needs to be replacing by some system that ensure the radius correctly measure. This is relevant since a small change in the radius induce a significant change in the attenuation value.

Despite of all this facts, the fitting adjustment between the experiment data and theoretical expression has a good correlation factor (R^2=0.97).

Figure 5 present the experimental loss spectrum as function of the bending radius.

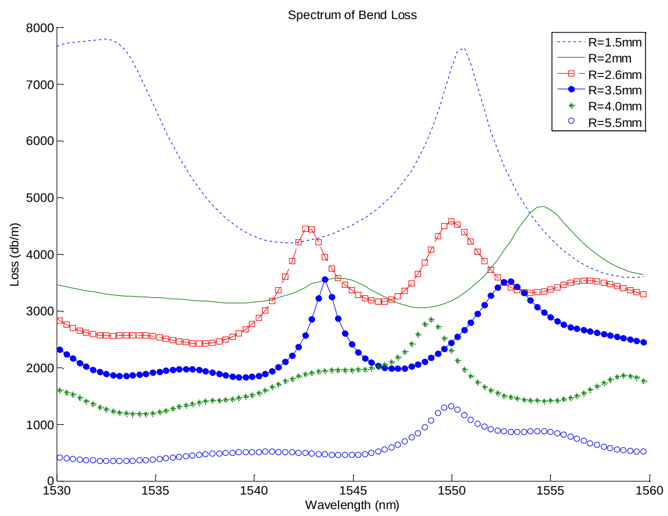

Fig. 5. Experimental spectrum of bend loss results for SMF fibers as function of the bending radius.

In Fig.5 we can observed that the loss is wavelength dependent, as predicted by the theoretical model. It can also be observed the existence of periodic peaks losses in the spectrum. These phenomena can be explained due to the impact of reflection occurring at the interface between the cladding, the coating layer and air on the bending losses [6-7].

IV. Conclusion

In this work we have presented the simulation results for the bend losses dependence on the bend radius of single mode optical fiber. The obtained experimental results were in agreement with the theoretical model values, considering the experimental uncertainty.

Further investigations are going on.

The relevance of this work is related with the increase of the optical power propagated in the fibers and the dissemination of the optical fiber structure into the access network, where is difficult to control the installation conditions, resulting in small bending radius fiber deployment. These two factors can result in a catastrophic fiber destruction due to the fiber fuse effect.

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