Macrobending Loss Measurements of G.657 Fiber with Suppression of Ripple Effect Induced by Whispering Gallery Modes

Chunsheng Li[1, 2], Tao Wang[2], Linyin Li[3], and Xiaoguang Zhang[1]

[1]State Key Laboratory of Information Photonics and Optical Communications, Beijing University of Posts and Telecommunications, Beijing, China 100876, xgzhang@bupt.edu.cn

[2]Beijing Blade Science & Tech Co, Ltd., Beijing, China 100876, lwm1975@qq.com

[3] Quality Supervision and Test Center for Cables and Communication Equipments of information industry, Sichuan, China 610062

Abstract： During the macrobending loss performance tests of ITU-T G.657 fiber under small bending radius, the test results show big differencesin many tests for the same test samples and conditions. Research shows that the main reason for the difference is Whispering gallery modes phenomenon in small bending radius [1]. The inappropriate test conditions can affect the accuracy of macrobending loss test results. In the test of product validation and field application, single wavelength light source and optical power meter were often used. How to judge whether there is effect existing and how to remove the Whispering gallery modes influence in the testing process has become the key to correctly test macrobending loss by light source and optical power meter. This paper introduces the method of eliminating Whispering gallery modes effect during the macrobending test under small bending radius by single wavelength light source and optical power meter.

1. Introduction

With the fast pace of development of FTTH in China, bending insensitive single mode fibers like G.657 fiber are widely used the FTTH system. Macrobending loss is one of the key issues to be test for G.657 fibers. Theoretically, macrobending loss shows an exponential function curve with respective to the wavelength when the radius of the fiber is fixed. But for practical fiber there is strong ripple effect in the measurement of bending loss induced by so called Whispering Gallery Modes (WG modes) when radius of the fiber is small [1]. It is found that this kind of ripple or oscillation is result of the interference of guided propagating optical signal in the fiber core with radiating modes (WG modes) reflected by the cladding-buffer interface or the buffer-air interface. And oscillating bending loss curve is not repeatable and stable for the reason of the irregular nature of the reflections. The standard IEC 60793-1-47 [2] gives a curve fitting method to smooth the curve, but we need the effective measurement methods to suppress the ripple or oscillation in order to get more accurate measurement.

In this paper, we verify experimentally the oscillating phenomenon of the spectral bending loss curve, and also propose a ripple suppression method by immersing the fiber into some carefully chosen index matching material solution. The experiments show that two proposed methods are very effective.

2. Measurement Experiment and Principle

2.1. The principle of whispering gallery modes

The whispering gallery modes are the result of the interference of guided mode in the core with the radiating modes (WG modes) reflected by the cladding-buffer interface or the buffer-air interface, as shown in Fig. 1.

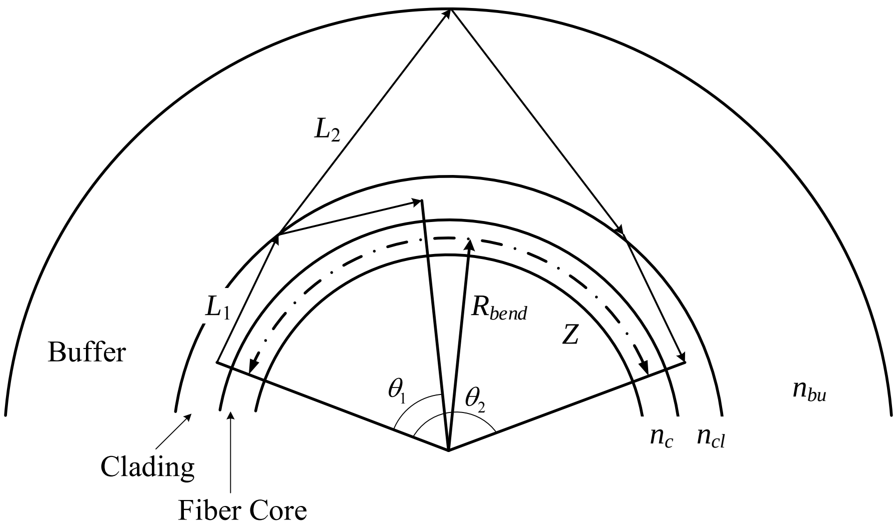

Figure 1. Bend geometry and formation of whispering gallery modes.

The constructive interference condition for interference between the guided mode with ith group of WD modes, corresponding to the maximum of the ripple, is (1).

$$\frac{2\pi}{\lambda} l_i - \beta Z_i + \phi_i = 2\pi N_i \quad (1)$$

where li is the optical path of the ith WD mode, λ is the wavelength, β is the propagation constant of the core guided mode, Z_i is the arc length over the angle θi , ϕ_i is phase shift at the corresponding interface, N_i is the integer[3].

2.2. Measurement setup

The measurement setup for macrobending loss of the fiber under test is shown in Fig. 2. A monochromator filters the monochromatic light working at the wavelength ranging from 1400nm to 1650nm. The filtered monochromatic light is fed into the fiber under test, and output power is measured, where the fiber is arranged at first as the reference power level measurement, and then is bended N turns for macrobending loss measurement [4].

Therefore in the bending loss tests should be arranged with larger radius circle and more turns. But we can see from Figure 3 that even if we make the bending fiber lager circle and many turn wrapping, the macrobending loss curves also show to some extent unrepeated and unstable and make the measurement inaccurate. So the bending loss measurement methods with ripple suppression should be found.

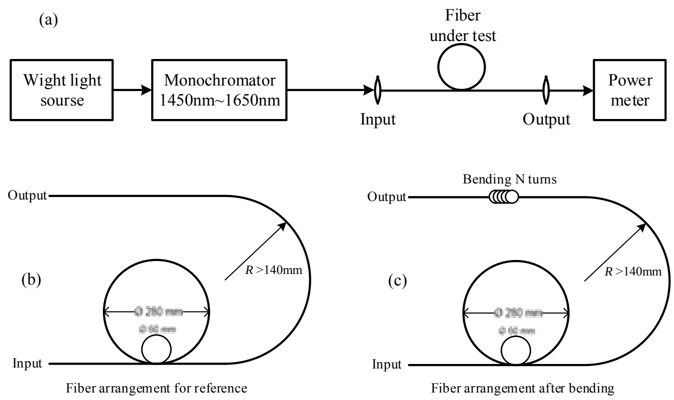

Figure 2. (a) Macrobending loss measurement setup, (b) The fiber arrangement for the measurement of reference power level, (c) The fiber arrangement after bending.

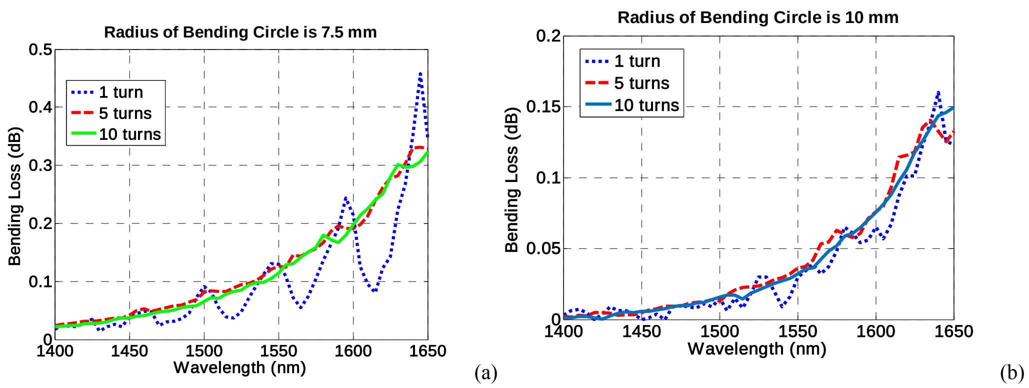

Figure 3. Bending loss results when the fiber is bent in 1, 5, and 10 turns, with radius of bending circle is (a) 7.5 mm and (b) 10 mm respectively.

3. Ripple Suppression by fiber immersed in the Index Matching Solutions

If we found some index matched materials, solid or liquid, revolve around the fiber under test, the reflections from interfaces outside the fiber core [5].

Table 1 lists the indices of the cladding, buffer, and two index matched materials. By using this kind of materials we can greatly suppress or remove the WD mode induced ripple, and will discussed in detailed as follows.

Table 1. The indices of fiber cladding, buffer, and two matched materials

	Cladding	Buffer	C11H12O2	C3H8O3
Indices	1.462	1.480	1.558	1.473

3.1. Fiber immersed in ethyl cinnamate solution

We can see from Table 1 that the index of ethyl cinnamate (C11H12O2) is larger than that of buffer. If we let the fiber under test immersed in matching solution of ethyl cinnamate, the total reflection cannot occur at the buffer-matching material interface, leads to effective suppression of the bending loss ripple.

Fig. 4(a) demonstrates the measurement results when the fiber is in 1 turn circle of radius 7.5 mm with or without immersed in the solution of ethyl cinnamate. It is clear that with immersed in the solution, effective suppress is achieved.

If the experiment just mentioned above is repeated with the fiber being bent 10 turns, the ripple is almost absent and test curve is nearly smooth exponential, meaning the effect of WD mode is eliminated (Fig. 4(b)).

3.2. Fiber buffer removed and immersed in glycerol solution

Glycerol which is also called propanetriol (C3H8O3) has an index of 1.473, which is larger than cladding, and smaller than buffer. If we remove the buffer out and let the fiber without buffer being immersed in glycerol solution, the total reflection cannot occur at cladding-glycerol interface. Therefore the ripple effect can also be suppressed.

Fig. 5 shows the experiment. In the experiment, a section of the fiber' buffer is removed, and then is bent to be a circle of radius 7.5 mm being immersed in glycerol solution. The comparison is made between the case mentioned in Section 3.2 and the case here. It is clear that the method of buffer removed combined with immersed in glycerol solution can effectively depress the ripple.

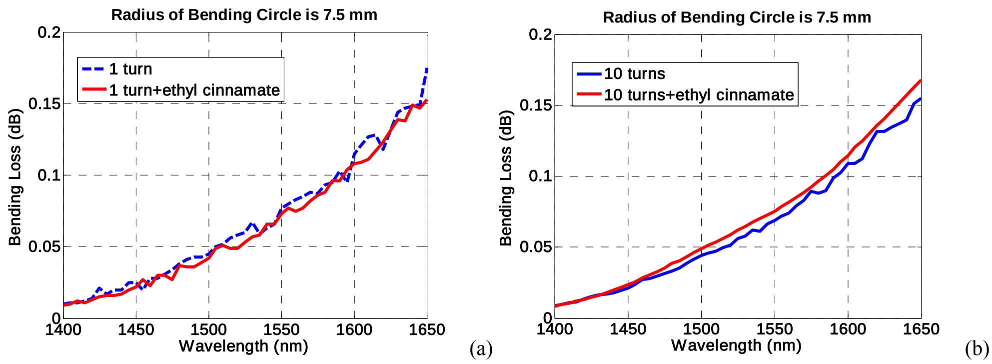

Figure 4. Bending loss results when the fiber is in 1 and 10 turn circles of radius 7.5 mm (a) with or (b) without immersed in the solution of ethyl cinnamate.

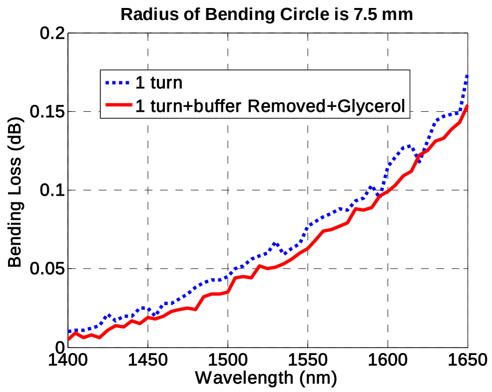

Figure 5. Bending loss results when the removed fiber is in 1 circle of radius 7.5 mm with immersed in the solution of ethyl cinnamate.

3.3. Statistical analysis

Because long wavelength such as 1625nm has more serious oscillation, so select 1625nm as typical wavelength to research this oscillation phenomenon. Using above methods, the single wavelength light source and optical power meter are used for measurement of macrobending loss at 1625nm fifteen times, to test the macrobending loss of the same fiber sample by the methods of 1 loop,10 loops,1 loop+ Ethyl cinnamate and 1loop+strip coating+ glycerin and the average value and standard deviation are calculated respectively. The results are listed in Table 2.

Table 2. The statistical results (15 samples) for different cases mentioned in the text

Statistical item	1 turn	10 turns	1 turn + C11H12O2	1 turn + buffer removed + C3H8O3
Mean value	0.126333	0.130933	0.128133	0.131267
Standard Deviation	0.029250	0.008312	0.010501	0.016342

For N statistical samples, the standard deviation σ reflects to some extent distribution convergence or the accuracy. Therefore the bending loss measurement with 10 turn circles ($\sigma = 0.008312$) is more accurate than that with 1 turn ($\sigma = 0.029250$) for the reasons mentioned above. The ripple suppression methods are effective. Among them 1 turn + C11H12O2 is better.

4. Conclusion

Obviously ethyl cinnamateor glycerol matching method is not applicable to field optical fiber macrobending loss measurement. Method of multiple coils is the most convenient, and recommended in the field tests. In general, 10 loops are easy to operate andobtain a more stable test results. In the laboratory absorbent matching method should be prior recommended for high test efficiency and accuracy.Combined with the method of multi circle, the method of ethyl cinnamate matching is best choice in laboratory.

5. Acknowledgments

Special thanks to Shixin Yang of Coring Company for his help to this paper. The project was supported by Fund of State Key Laboratory of Information Photonics and Optical Communications (Beijing University of Posts and Telecommunications), P. R. China ” .

Reference

[1] You Shanhong, Hao Sujun, 2004, Analysis and Test of Bend Loss in Single-mode Fiber, *ACTA PhotonicSinica*,Vol. 32, No. 4, pp. 409-411

[2] IEC 60793-1-47, 2009, Optical fibers-Part 1-47: Measurement methods and test procedures Macrobending loss”, *Edition* 3.0 2009-03

[3] R. Morgan, J. D. C. Jones, P. G. Harper and J. S. Barton, 1991, Observation of secondary bend loss oscillations arising from propagation of cladding modes in buffered monomode optical fibers, *Opt. Commun.*, 85(1), pp.17-20

[4] Li Linyin,Gan Lu, Li Chunsheng, Song Zhituo, 2014, Measurement of Macrobend Spectral Loss for Bend Insenstive Single Mode Fiber, *Modern Transmission*, No. 4, pp. 63-65

[5] Siping Ning, and Onno R. Bresser,eds，2014, Use of Weighted Least Square Fitting Methods in Macrobending Loss Tests on Single-mode Fibres, in Proceeding of the 62nd *IWCS*, Providence, Rhode Island, pp. 92-96