

Analysis and application of fiber bending in high-speed optical communication

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Fiber Bending causes the bending loss, which mainly reduces the optical signal noise ratio (OSNR) of the optical transmission signal. When the fiber is bent to a certain degree, it will cause an interrupt signal. In this paper, we do the theoretical analysis and simulation for fiber bending, and present some engineering application examples.

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Optical fiber bending has a significant impact on the 100G and above the high-speed optical communication, and thus the industry has done a lot of research: the experiment^[1] for single-mode fiber bending loss with the bending radius (1 to 8 mm) and varying wavelength (1530 ~1565 nm) has been carried out, and the results show the oscillations of the bending loss with a bending radius and the wavelength. In order to reduce the bending loss in the long-distance optical fiber communication and the bending loss in the fiber laser to obtain a single-mode output, the speed method is used to explain the fiber bending-loss mechanism^[2]. The bending loss increases with the decrease of the curvature radius, and increases with the increase of the core radius as well as the wavelength. The loss of the high-order mode is greater than the low-order mode. Thus, we can achieve a single-mode output fiber laser by increasing the radius of the mode field and controlling the bending radius to reduce the bending loss of the fiber whose radius is less than the critical.

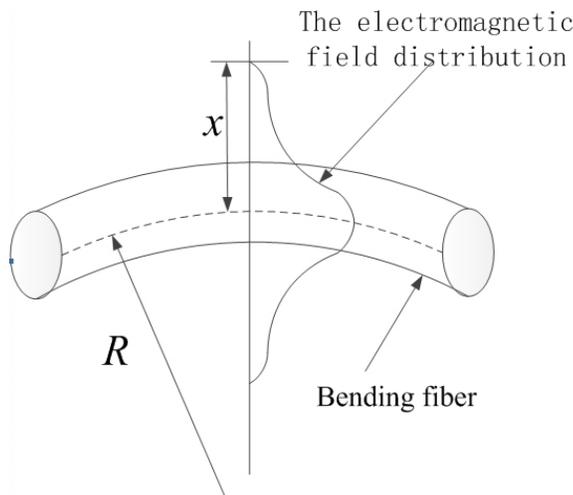


Fig. 1. Sketch map of the bending loss in bending fiber.

The principle of optical fiber-bending loss mechanism is shown in Fig. 1; the field distribution of the guided mode in the core and cladding is prior to propagation along the fiber axis as a whole, and the same phase of the electric and magnetic fields stays in one plane. The speed of the field away from the center side is faster than the side close to the center of curvature as the fiber is bent. When it exceeds a certain critical curvature, guide mode will turn into a radiation mode and then part of the light energy from the cladding will leak out, thus cause the fiber loss. The D. Marcuse theory model shown below is used for analysis. Based on the solution of Maxwell's equations, the electric field components of the cylindrical waveguide are as follows:

$$E_z = A[J_v(\kappa a)/H_v^{(1)}(i\gamma a)]H_v^{(1)}(i\gamma r') \cos(v\theta) e^{-i\beta_g R\phi} \quad (1)$$

$$E_\phi = \frac{A\gamma}{2\beta_g} \frac{J_v(\kappa a)}{H_v^{(1)}(i\gamma a)} [H_{v+1}^{(1)}(i\gamma r') \sin(v+1)\theta + H_{v-1}^{(1)}(i\gamma r') \sin(v-1)\theta] e^{-i\beta_g R\phi}, \quad (2)$$

$$\kappa = \frac{2\pi}{\lambda}, \gamma = (\beta_g^2 - n_2^2 \kappa^2)^{1/2},$$

$$A = \left(\frac{4(\mu_0/\epsilon_0)^{1/2} \gamma^2 P}{e_v \pi n_2 V^2 |J_{v-1}(\kappa a) J_{v+1}(\kappa a)|} \right)^{1/2}, e_v = \begin{cases} 2 & v = 0 \\ 1 & v \neq 0 \end{cases}$$

$V^2 = \kappa^2 a^2 (n_1^2 - n_2^2)$, where $\beta_g R\phi$ represents the propagation factor, $H_v^{(1)}$ on behalf of order is the first type of Hankel function, J_v means the Bessel function, which is deduced from the bending loss factor

$$2\alpha = \frac{\sqrt{\pi} U^2}{e_v W^{3/2} \sqrt{a} R V^2 K_{v-1}(W) K_{v+1}(W)} \cdot \exp\left(-\frac{2W^3}{3a^2 \beta^2} \frac{R}{a}\right), \quad (3)$$

where $U = \sqrt{k^2 n_1^2 - \beta^2} a$, $W = \sqrt{\beta^2 - k^2 n_2^2} a$, $V = \sqrt{n_1^2 - n_2^2} k a$, n_1 is the refractive index of the optical core, n_2 is the refractive index of the cladding layer, $k = 2\pi/\lambda$ is the wave number of the free space. R represents the bending radius of the optical fiber, a is the optical core radius, β is the propagation constant. The fiber is in the base mode when $e_v = 2$. The link in the bending loss satisfies the equation $L_s = 10 \log_{10}(\exp(2\alpha L))$, where L is the arc length of the fiber, and L is a function of the opening angle of the bending portion θ and the bending radius R .

We create a fiber bending-loss theoretical model and evaluate the relationship between bending loss coefficient α_m and wavelength, microbend cycle. On setting the microbending fiber deformation function as the sinusoidal format $f(z) = D(t) \sin qz$, $D(t)$ is the external signal, which represents the bending amplitude, q is the spatial frequency and z is the distance, which points to the incident end of the optical fiber. Approximate expression of microbending loss coefficient α ^[3] can be obtained according to the theory of fiber mode.

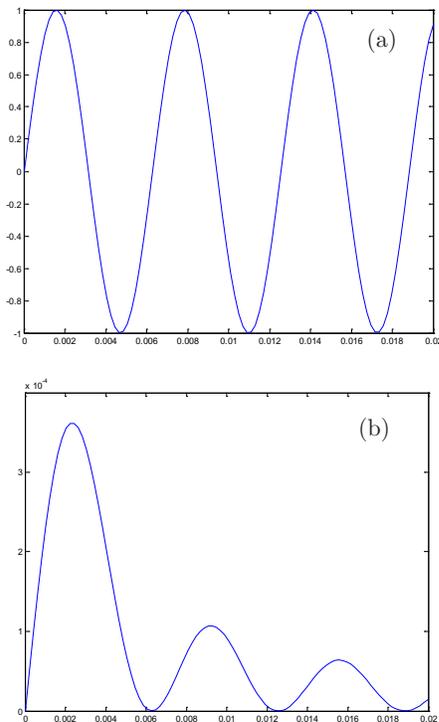


Fig. 2(a) Fiber microdeformation function; (b) Relationship between microbending loss coefficient and length.

$$\alpha_m = \frac{1}{4} K D^2(t) L \left| \frac{\sin[(q - \Delta\beta)L/2]}{(q - \Delta\beta)L/2} \right|^2, \quad (4)$$

where L is the length of the microbending deformation generated in the fiber, $\Delta\beta$ is the fiber-optic light wave-propagation constant difference and K is the scale factor.

The simulation results are shown in Fig. 2, and we can come to the conclusions: 1) α_m is proportional to the square of the bending amplitude $D(t)$ —the greater the amplitude of the bending mode coupling is, the higher the loss is. 2) α_m is proportional to the length L of the fiber bending formation—the longer the length is, the greater the loss is. 3) α_m is related to the fiber microbending cycle, and when it comes to the resonance where $q = \Delta\beta$, the microbending loss reaches its maximum.

- (1) We analyse the peak value and the peak spectral width caused by the microbending loss factor, and the corresponding relationship between the above factors are shown below.

1. $q = \Delta\beta$

$$\alpha_{m_{max}} = \frac{1}{4} K D^2(t) L$$

2. $q \neq \Delta\beta$

$$(q - \Delta\beta)L/2 \approx k\pi \quad k = 0, \pm 1, \pm 2, \dots$$

$$L \approx \frac{2k\pi}{(q - \Delta\beta)} \quad k = 0, \pm 1, \pm 2, \dots$$

This situation corresponds to the case, which is shown in Fig. 2b.

- (1) Attenuator: attenuator is in the control state to reduce the transmission power of the apparatus. An attenuator will be used as long as the transmission fiber-turn laps need to introduce an external device, and the attenuation amount can be controlled by the number of turns of a given radius;
- (2) Identification fiber-optic measurement system: when manufacturing a microbending to a fiber, the measured curve will appear in the corresponding position of a large level, and then you can easily judge the optical fiber to confirm the fiber sequence.

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