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Bending Effect on the Single Mode Optical Fibers

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Abstract: Bending effects on the transmission of optical signal are investigated on a single mode optical fiber (SMOF) of 10 m length, core radius of 5 μm and optical refractive index difference 0.003. The bending radii (R) were between 0.08 and 0.0015 m. A great decrease in the amplitude is shown for radii below 0.01 m. Sudden break down occurs for radii less than 0.0015 m. Birefringence (B) is difficult to measure for long fibers. Meanwhile, B was found by comparing with calibrated fiber of the same properties but of length of 0.075 m. The results show an increase in propagation constant *($\Delta\beta$)* and the decrease in beat length *(L_b)*, and show that bending decreases the critical radius of curvature (R_c) related to B. The changes induced on the initial phase of the signal are shown for bending curvatures of radii 0.06, 0.03 and 0.005 m. The linear phase retardation is found to increase more rapidly for bends of R< 0.05 m. The degree of polarization decreases smoothly for bends of R>0.01m. Below this curvature, the fluctuation and great instability in the polarization- state of the output signal are easily detected. All these features are very important in using SMOF in sensitive optical devices especially in long distance fiber communications.

Introduction

The basic equations of the two hybrid modes of HE_{11} were derived by Yeh [1] and lately by Cantrell et al. [2]. Single mode optical fibers (SMOF) are especially characterized by the transmission of these twin modes. Meanwhile the polarization properties of these fibers are easily modified by environmental factors as: twists and bends.

The change of the circular cross-section to an elliptical form under bending strain induces modal birefringence (B) [3]. The main opto-geometrical factor is the difference in the optical index where $n_1>n_2$ of the core and cladding respectively. The related induced modal birefringence is given by the relation [4]:

$$B = \left(\beta_x - \beta_y\right)\left(\frac{2\pi}{\lambda}\right)^{-1} \qquad (1)$$
$$= \Delta\beta / k$$
$$= n_x - n_y = \Delta n$$

where β_x and β_y are the propagation constants of the two sub-fundamental modes HE_{11}^{x} and HE_{11}^{y}, n_x and n_y are their relevant refractive indices under bending effect. Hence $\Delta\beta$ is the retardation per unit length. The phase retardation induced by this birefringence for a given length of fiber (*L*) is:

$$\phi_{(L)} = L\Delta\beta \quad \text{(rad)} \qquad (2)$$

Meanwhile the birefringence is related to the radius of bending (R) by the relation [5]:

$$\Delta n = o.133\left(\frac{a}{R}\right)^{2} \qquad (3)$$

where (a) is the core radius of the fiber. Then the mode propagation difference $\Delta\beta$ can be related to R as:

$$\Delta\beta = k.\Delta n \qquad (4)$$

$$= \left(\frac{0.268\pi}{\lambda}\right)\left(\frac{a}{R}\right)^{2} \qquad \text{(rad/m)}$$

Large bending losses occur at a critical radius of curvature (R_c), which is estimated for weakly guiding fibers, i.e., $n_1 \sim n_2$ [5] as:

$$R_c = \frac{a}{2n_1\Delta n} \qquad \text{(m)} \qquad (5)$$

The beat length (L_b) corresponding to an increase in phase of 2π, represents also the weight of the birefringence and is given by:

$$L_b = \frac{\lambda}{B} = \frac{\lambda}{\Delta n} \qquad \text{(m)} \qquad (6)$$

All these changes in birefringence, beat length, and phase retardation induce a partial energy transfer between the two modes in the fiber.

As a result, the degree of polarization (P) is automatically changed for each bending. Because the circular cross-sectional area of the fiber core becomes of elliptical form under this bending effect. (P) is usually related to the visibility , defined as [6]:

$$P = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \qquad (7)$$

where I_{max} and I_{min} are the two extreme intensities of the output signal.

Bending inflicts also the initial phase to shift. For long fibers rotation of $2m\pi$ affects the birefringence, where m= 0, 1, 2, ….

Experimental Setup and Measurements

The experimental setup is shown in Fig. (1). The CW laser (1) of λ= 632.8 nm was used with a chopper (2) of a frequency of about 5 MHz. The pulsed source, was first linearly polarized by means of a polarizer (3) then a quarter wave plate (4) was placed to produce circularly polarized light launched into an microscopic lens (5) of Mx100 was focused into the first end of SMOF (6). The second end was focused through an analyzer (7), on a photodetector (8).

An electronic circuit amplifier was used to enhance the output signal and to reduce as possible the induced noise of any external or internal sources. The signal was well detected by the CRO screen (9). For more accuracy, the output was connected to a computer (10) where the signal readings were averaged for each 50 pulses. The readings were obtained for the maximum, minimum and the amplitude of the signals. All these readings were locked–in and were saved digitally to be lauded to different subroutines.

The desired calculations and figures are as shown in Figs. (2) to (8) obtained for the different relations mentioned above drawn by MATLAB programs in use.

The single mode optical fiber used (6) was of 10 m length, core radius of 5 μm, and refractive index difference of 0.003.

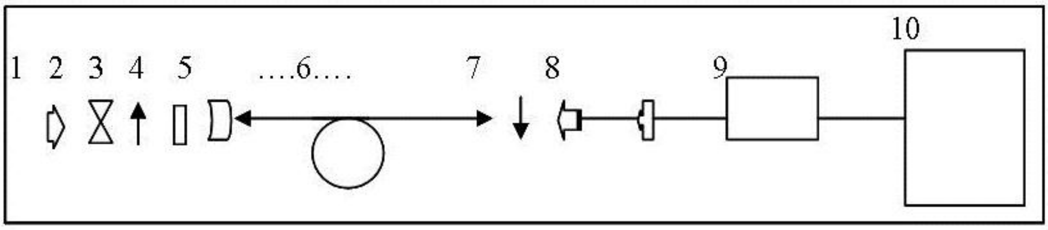

Fig. (1): The setup of the experiment.

Results and Discussion

This experimental work confirms that bends cause the disturbances of the cascaded total internal reflections of rays inside the core. The losses produced are mainly because of the increase in leaky rays at the outer side of the core in the cladding. The decrease in amplitude of the output signal for bending curvature (R) between 0.08 and 0.0015 m is clear. The normalized output signal versus R is shown in Fig. (2).

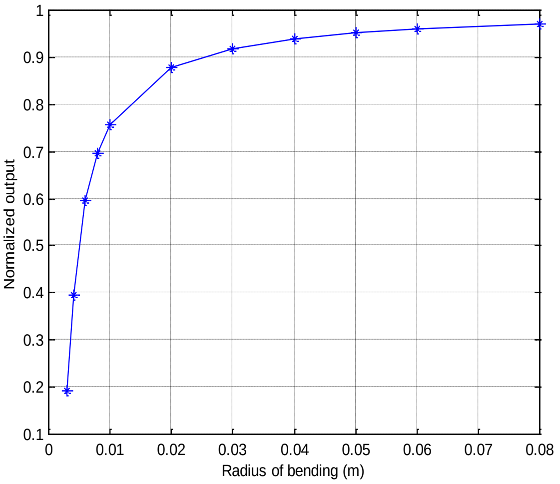

Fig. (2): Bending effect on the output signal.

For R<0.01m the decrease is very sharp and below this radius a sudden break down of the fiber occurs.

Bending effect on modal birefringence (B) is compared theoretically and experimentally Fig. (3). The error in readings increases for R<0.005m.

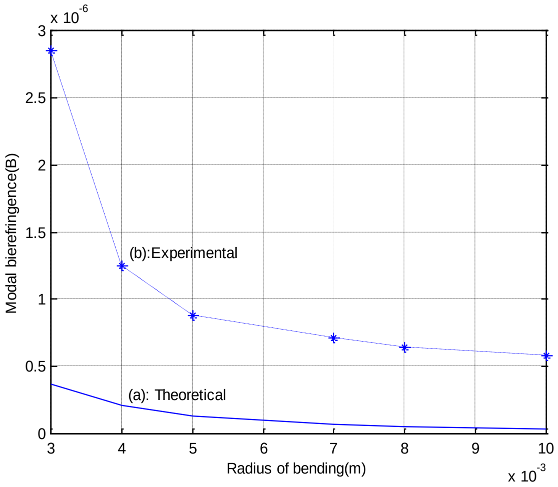

Fig. (3): Bending effect on modal birefringence

The propagation constant increases rapidly for bends of radii less than 0.003 m. This explains the decrease in beat length of the fiber as shown in Figs. (4) and (5-a). The critical radius (Rc) related to B is of order of 10^{-12} m (Fig 5-b).

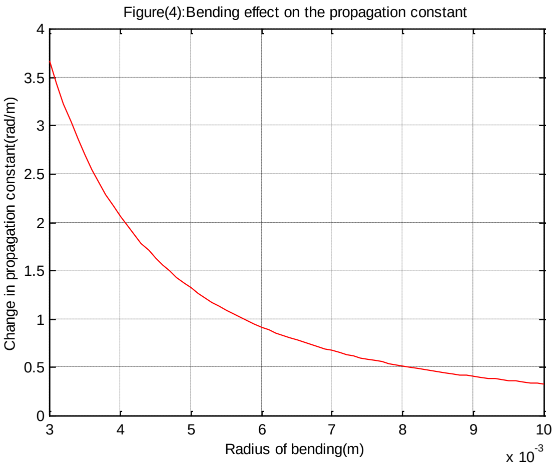

Fig. (4): Bending effect on the propagation constant

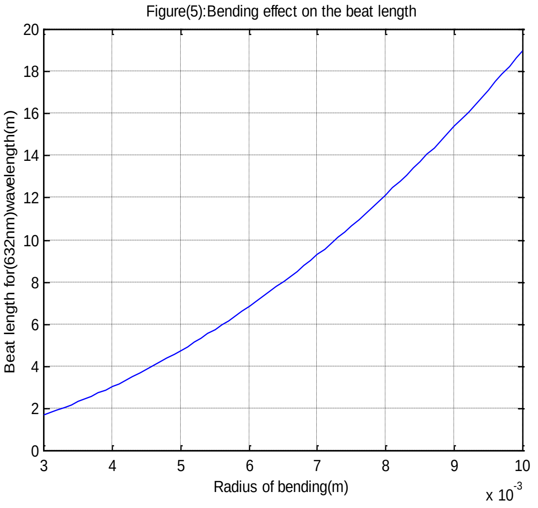

Fig. (5-a): Bending effect on the beat length

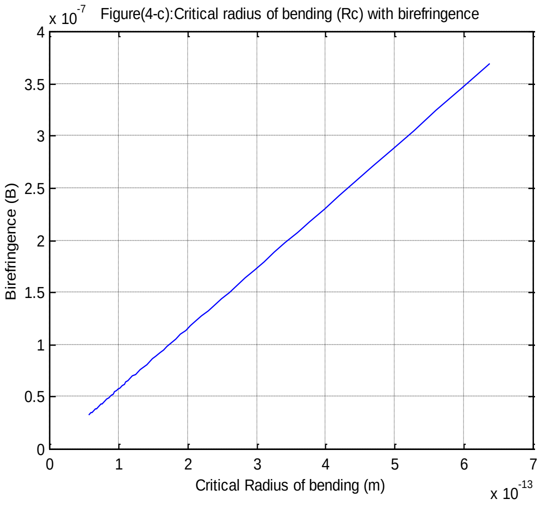

Fig. (5-b): Critical radius of bending (Rc) with birefringence.

The bending effect on the performance of the polarization -state of the signal shows that even relatively minor perturbations can significantly degrade the output of the circularly polarized launched signal. The output shift in the polarization angle is shown for two relatively large radii of R=0.06 and 0.03 m, and a small one of 0.005 m (Fig. 6). These readings are very difficult to be repeated exactly for the case of long fiber and especially for the last radius of bending. Peaks appear surprisingly sometimes because of the temporal mode interfering inside the core of the fiber.

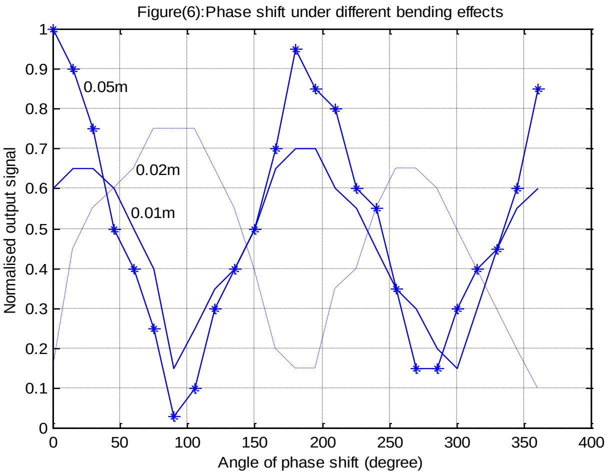

Fig. (6): The initial phase shift and the deformation of the output signal under different bending radii

Moreover, the bend induces linear phase retardation. A comparison for two fibers of 10m and 0.75 m length is shown in Fig. (7).

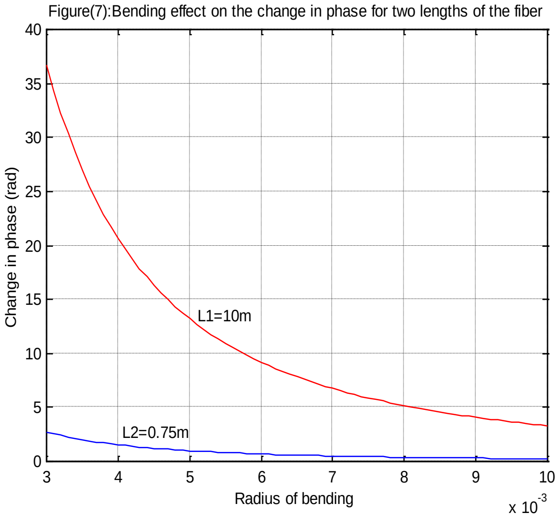

Fig. (7): Bending effect on the change in phase for two lengths of the fiber

Finally, the degree of polarization (P), calculated from Eq. (7), seems to decrease smoothly for bending radii R>0.01 m. Below this curvature, it degenerates dramatically, and great perturbation of the output polarized – state is clearly detected at R<0.01 m, see Fig. (8).

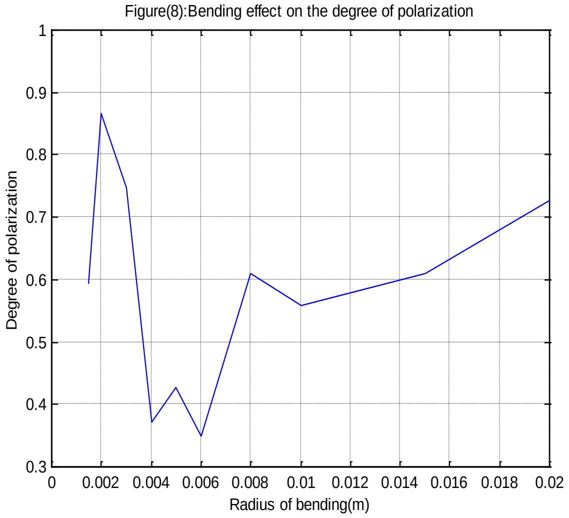

Fig. (8): Bending effect on the degree of polarization

All figures are drawn without curve-fitting program since they show clearly the experimental results.

Conclusions

The experts in the technology of communication are trying to make optical communication faster and more efficient especially by means of laser-optical fiber coupling. The relevant features of birefringence and relative phase shift of the input signal seem to reduce the transmission efficiency. Polarization maintaining fibers are a solution. Coating fibers with hard cleavage prevent undesirable bending to introduce the modal birefringence and polarization hazards. Meanwhile, when optical fibers are used as connectors between different opto-electronic devices, the bent and twist of this connector must be considered. Polarized launched signal degenerates rapidly under any bending effect. The output-detected signal is greatly and rapidly affected

Researches are continuously undergone to enhance the visibility and capacity of transmission for the long distance optical fiber communication systems. The soliton, which seems to be a new solution for these long distance systems, can be affected as well. Therefore, birefringence caused by bending is an update turning point in studying the new optical fiber communication events.

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تأثير الانحناء على الليف البصري الأحادي النمط

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الخلاصة

تمت دراسة تأثير الانحناء على انتقال الإشارة الضوئية في ليف بصري أحادي النمط طوله (10) متر ونصف قطر لبه (5) مايكرومتروبفرق في معامل الأنكسارمقداره (0.003) . ان نصف قطر الانحناء (R) كان بين (0.0015-0.08) متر. ان هبوطا كبيرا في الشدة تظهر في حالة انصاف اقطار اقل من (0.01) متر. أما عند نصف قطر انحناء أقل من (0.0015) متر فان الليف ينكسر بصورة مفاجئة . إن قياس الانكسار الثنائي النمطي(B) في ليف بطول (10) متر صعب جدا وخاصة للانحناءات ذات أنصاف الأقطار الصغيرة. لذلك فأن (B) وجدت من مقارنتها بما تم الحصول عليه في حالة ليف بذات المواصفات ولكن بطول (0.75) متر. أوضحت النتائج أن هناك زيادة في فرق ثابت الانتشار $\Delta\beta$ وانحدار في طول الضربة (L_b) وكما تظهر إن الانحناء يؤثر سلبا على نصف القطر الحرج (R_c) المعتمد على الانكسار الثنائي النمطي. أن هذه التغيرات مؤثرة أيضا على الطور الأولي للإشارة لانحناءات بأنصاف أقطار (0.005,0.03,0.06) متر. أن التأخر في الطور الخطي يظهر زيادة سريعة في حالة أنصاف أقطار انحناء اقل من (0.05) متر في الليف البصري . كما لوحظ أيضا أن درجة الاستقطاب تقل بصورة تدريجية لانحناءات اكبر من (0.01) متر ، إما دون هذا الانحناء فأن التذبذب وعدم الاستقرار في حالة الاستقطاب للإشارة الناتجة تظهر بصورة واضحة جدا ولأي تغيير موضعي في حالة الليف. هذا ما يجعل الليف البصري كمتحسس جيد لأي تأثير خارجي يطرأ عليه وهو في حالة انحناء . أن أهمية هذه الدارسة تكمن في الكثير من التطبيقات وبشكل خاص عند استخدامه في الاتصالات ولمسافات بعيدة .