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A pressure-sensitive fiber optic connector for loss analysis of physical contact

Zhenfeng Gong, Ke Chen, Wei Wang, Yang Yang, Wei Peng, Qingxu Yu, Xinlei Zhou *

School of Physics and Optoelectronic Technology, Dalian University of Technology, 2 Linggong Rd, Ganjingzi District, Dalian 116024, China

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ABSTRACT

We design and fabricate a physical contact (PC) type pressure-sensitive fiber optic connector (FOC), which can be used to measure the contact force and analyze the contact loss caused by the contact force between two PC type FOCs. A fiber Bragg grating (FBG) is wrote on the fiber tip of the connector. The relationship between the Bragg wavelength of the FBG and the contact force exerted on the connector head is got by experiment with a stress sensitivity of 5.4 pm/N. We use this pressure-sensitive FOC for loss analysis of PC type FOCs. The relationships between contact force and insertion loss (IL) of three PC type FOCs have been got experimentally. Finally, finite element simulation results demonstrate the effectiveness of the system.

1. Introduction

Optical fiber communication systems and optical sensing systems become more and more important in our daily life. Fiber optic connector (FOC) is the fundamental passive optical device in optical fiber transmission systems and it plays a substantial role in connecting the two cores of glass fiber ends. The performance of the FOC has a direct impact on the reliability and performance of the optical fiber related systems [1–4]. Insertion loss (IL) and return loss (RL) are two important parameters to measure the optical performance of the FOC. From viewpoints of optical characteristics, low IL and high RL are required for the FOC that used at the interfaces between optical fibers. Many factors can influence IL and RL of FOC, such as end gap, end-face roughness, core and numerical aperture mismatch, angular misalignment, dust and so on. Many papers have been published to discuss the influences of different factors to IL and RL [5–9]. In order to obtain low IL and high RL, polishing the spherical end-face in a polishing machine using polishing films with various diamond abrasive grit sizes have been proposed [5–7]. Duan et al. discussed the influences of apex offset on IL and RL of FOCs [8]. A group of optimum kinematic variables, which can minimize apex offset, are derived in it. In these factors, end gap is the most important factor that deteriorates optical performance of FOC because the difference of refractive index between air and optical fiber can cause a high reflection [9]. To eliminate the end gap, suitable contact force needs to be applied to the ceramic ferrules. The contact force must be large enough to make sure the end gap can be eliminated. However, excessive force also causes redundant losses as the elasto-optical effect will change the refractive index of the fiber. Therefore, contact force needs to be measured accurately. However, there are few researches about the influence of the contact force before because the contact force is hardly to measure. Even the contact force can't be measured in industrial production. We have given a brief analysis of influence of contact force in our early work [10]. But the contact force couldn't be measured directly, so the experimental results may not be accurate.

In this paper, we fabricate a physical contact (PC) type pressure-sensitive FOC and develop a method to measure the contact force between the two end-faces, and analyze the relationship between contact force and IL & RL. The theoretical curves are in good agreement with experimental values. The results in this paper can provide a reference guide for the manufacture of the FOC.

2. Basic and Operating Principle

2.1. IL and RL caused by air gap

In precision grinding of the connector end-face, the fiber end protrudes or withdraws slightly from the ceramic ferrule end-face. The end-face geometry causes the end gap between two mated connectors, as shown in Fig. 1(a). To eliminate the end gap, axial contact force is usually applied to the ceramic ferrules, which can deform the ceramic ferrule end-face, as shown in Fig. 1(b).

* Corresponding author.
E-mail address: xlzhou@dlut.edu.cn (X. Zhou).

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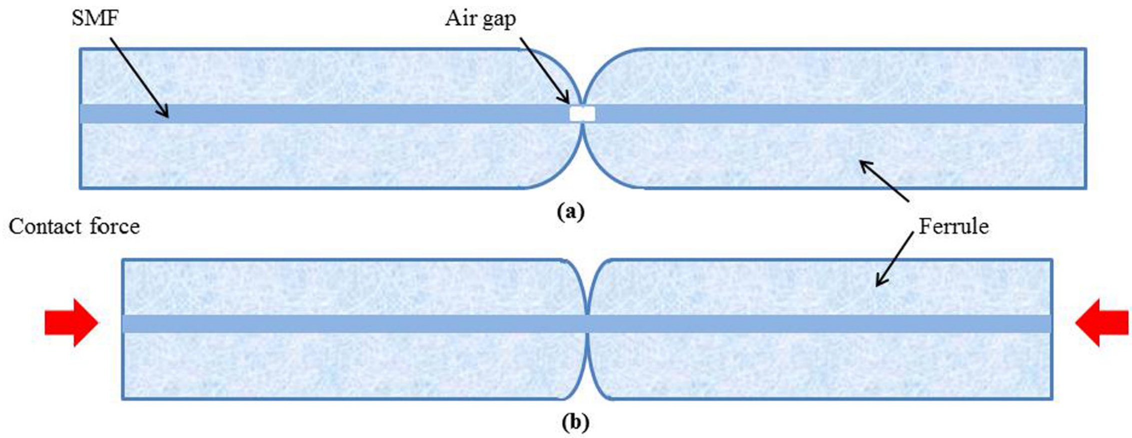

Fig. 1. (a) Schematic diagrams of two PC type connectors with air gap, (b) elimination of end gap by applying axial contact force.

Analysis of the IL and RL caused by air gap can be based on multiple reflections behaving like a Fabry-Perot interferometer. Based on the multiple beam reflection theory, transmission coefficient and reflection coefficient of FOC with a gap is defined as [2]:

$$T = I_t/I_i = (1-R_0)^2/[(1-R_0)^2 + 4R_0\sin^2(2\pi nl/\lambda)] \quad (1)$$

$$R = I_r/I_i = 4R_0\sin^2(2\pi nl/\lambda)/[(1-R_0)^2 + 4R_0\sin^2(2\pi nl/\lambda)] \quad (2)$$

where I_t, I_i and I_r are, respectively, the transmitted light power, the incident light power, and the returned light power, l is the gap size, λ is the wavelength, and R_0 is the reflection coefficient at the fiber end that can be determined by the Fresnel reflection equation:

$$R_0 = [(n_0 - n)/(n_0 + n)]^2 \quad (3)$$

where n_0 and n are the refractive index of the fiber core and the air, respectively. From Eqs. (1) and (2), we can see that the IL and RL depend on the gap size l when the wavelength has been fixed. Then the IL and RL can be expressed as:

$$IL = -10\log(T) \quad (4)$$

$$RL = -10\log(R) \quad (5)$$

From above we analyze that the minimum IL and the maximum RL can be get simultaneously when the gap size is zero. Therefore, appropriate contact force need to be applied to the ceramic ferrules to eliminate the air gap.

2.2. Principle of the pressure-sensitive FOC

Fig. 2 is the schematic of the pressure-sensitive FOC. Firstly, we write a fiber Bragg grating (FBG) by ultraviolet-writing technology on one end of a single mode fiber (SMF). The SMF is then glued in the center hole of a PC type FOC' zirconia ceramic ferrule. Used the conventional technology of grinding optical fiber end-face, the PC type pressure-sensitive FOC is fabricated.

Once a FBG has been realized, it basically works as a wavelength selective filter for propagation radiation along the optical fiber. If light from a broadband source is coupled into the optical fiber with a FBG written in it, then a narrow band of light is reflected at the FBG location, while the rest of the spectrum is transmitted. According to [11], when applying axial stress on the fiber, the corresponding Bragg wavelength shift can be described as:

$$\Delta\lambda_B/\lambda_B = (1-P_e)F/(ES) = (1-P_e)\Delta L/L \quad (6)$$

where λ_B is the Bragg wavelength and $\Delta\lambda_B$ is the variation of the Bragg wavelength, F is axial stress applied on the fiber, S is the cross-section area and E represents Young's modulus of the polymer, ΔL and L represent the expansion increment and length of the FBG, respectively, P_e is the effective photo-elastic constant of the fiber core material which can be described as:

$$P_e = n^2/2[p_{12} - \gamma(p_{11} + p_{12})] \quad (7)$$

where n is the effective refractive index of the core, p_{11} and p_{12} are components of the strain optic tensor, and γ is Poisson's ratio of the core. For a typical quartzose single mode fiber, $p_{11} = 0.121$, $p_{12} = 0.270$, $\gamma = 0.17$, $n = 1.456$, so $P_e \approx 0.22$. From Eq. (6), we can see that there is a linear relationship between variation of the Bragg wavelength $\Delta\lambda_B$ and the axial stress F, and the expansion increment of the FBG ΔL.

3. Experiments and discussion

We get the relationship between the Bragg wavelength of the FBG on the tip of the pressure-sensitive FOC and the contact force exerted on the connector head experimentally. The structure of the experiment system is shown in Fig. 3. Firstly, the pressure-

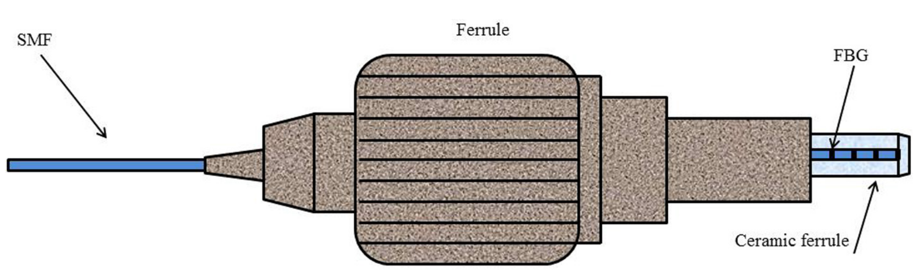

Fig. 2. Schematic diagram of the pressure-sensitive FOC.