Application of two-mode fiber in voltage sensor

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A new mode patter's demodulation technique is put forward. Researches of experiment and theory show that the coupling efficiency of two kinds of different fibers depends on the relative offset between the two fibers when the core diameter of the information pick-up fiber is a little smaller than the major semi-axes of the elliptical-core two-mode fiber. Especially, when the relative offset $\delta \approx 1$, fusing splice coupling efficiency reaches peak value. Furthermore, based on the new demodulation scheme, the sine voltage signal applied on the piezoelectric lead zirconate titanate (PZT) is obtained and the detection precision of the system is within $\pm 0.2\%$ when the voltage changes between 0.1 and 20 V.

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Two-mode fibers have been used in the past as sensors for measurements of pressure[1], strain[2], vibration[3], acoustic waves[4] etc.. Two-lobe far-field intensity distributions are obtained at the output by exciting appropriate modes within the fiber[5]. The standard method of analysis involves a measurement of the exchange of optical power between the two lobes in order to determine the nature of the external perturbation. With two modes propagation in the fiber, an external disturbance causes a differential phase shift between the modes which in turn resulting in variation in the intensity patterns of the modes. Periodic variations in the intensity patterns such as oscillation of power between the lobes are examples of changes which can be used for voltage sensing application[6]. Compared with fiber Mach-Zehnder or Michelson interferometers, two-mode fiber voltage sensors are simpler in that no separate arm and no fiber couples are needed, and they are less susceptible to environment noise[7].

The related detection techniques for two-mode fiber sensors have been suggested. An elementary technique involves the placement of a spatial demodulation in the form of a pin-pole, which samples only part of the far-field pattern[8]. Another optical signal processing technique that uses a charge coupled device (CCD) array for the analysis of the pattern at the output of a highly multimode fiber sensors has been also demonstrated[9]. Most such methods used in the past required the output fiber to display the far–filed pattern on the monitoring system.

The interference patterns of the output of two-mode fiber are different[10]. The interference pattern of circular-core two-mode fiber is almost elliptical, while the interference pattern of elliptical-core two-mode fiber under the condition of proper selection of the ellipticity is approximately circular. Therefore, when using photoelectric diodes with single mode fiber to pick up interference information, circular-core two-mode fiber should match elliptical-core single-mode fiber, while elliptical-core two-mode fiber should match circular-core single-mode fiber.

The demodulation diagram of elliptical-core two-mode fiber interference patterns is shown in Fig. 1. Two single-mode tapered fibers are placed very close to each other and spliced onto the output end of the two-mode fiber. Using a fusing splicer, the two tapered fibers with photoelectric diodes are fused together at the output of two-mode fiber. Elliptical-core two-mode fiber is circled on the piezoelectric lead zirconate titanate (PZT) and the sine voltage is also applied on it. Therefore, the oscillation of the voltage signal results in the deformation of PZT which brings the longitudinal change of fiber, while the fiber length change simultaneously makes intensity distributions and interference patterns oscillation. By actively monitoring the two outputs from demodulators, quadrature phase-shifted signals can be obtained. During the experiment, the chosen fiber is the France HWT-FIB-PMF fiber whose center operation wavelength λ_0 is 1310 nm and cutoff wavelength λ_{cut} is 1280 nm. The light source is an 850-nm multimode S850-G-I-20 SLD laser diode, which launched linearly polarized light into a two-mode elliptical-core fiber which was wrapped around a piezoelectric cylinder PZT.

For the convenience of studying here, making use of symmetry of the interference pattern, we merely think of the instance that one of the two single mode fibers takes over the interference patterns of elliptical-core two-mode fiber.

In the Cartesian coordinate system attached to the two-mode fiber, labeling $E_1(x,y)$ the E-field distribution of the pick-up fiber LP_{01} mode and labeling $E_2(x,y)$ the E-field distribution of the two-mode fiber, neglecting the reflection at the interface, the coupling efficiency can be

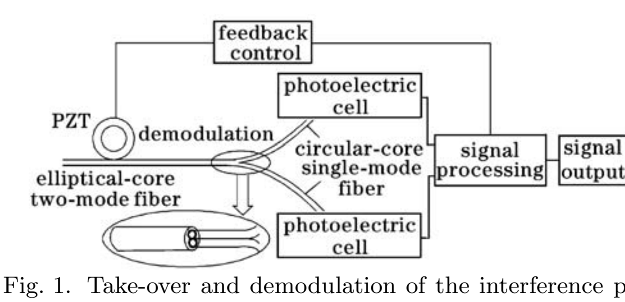

Fig. 1. Take-over and demodulation of the interference pattern of elliptical-core two-mode fiber.

written as[11]

$$\eta = \left[\frac{1}{2Z_0}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} n\left(x,y\right)E_2\left(x-\Delta,y\right)E_1\left(x,y\right)\mathrm{d}x\mathrm{d}y\right]^2, \quad (1)$$

where Δ is the axis offset in the x-direction between the single mode circular-core fiber and elliptical-core two-mode fiber, $n\left(x,y\right)$ is the refraction index of the pick-up fiber.

Assume that the interference pattern of elliptical-core two-mode fiber is circular and the mode of the circular-core pick-up single-mode fiber is characterized by a $1/e^2$ power radium W_0. Then based on the Eq. (1), it is easy to see that the coupling coefficient η between the two fibers is

$$\eta = 2\frac{w_y}{1+w_y^2}\frac{w_x}{1+w_x^2}\left[1+\sqrt{2}\frac{w_x}{1+w_x^2}\delta\right]^2\exp\left(-\frac{\delta^2}{1+w_x^2}\right), \quad (2)$$

where $w_x = W_x/W_0$, $w_y = W_y/W_0$, $\delta = \Delta/W_0$. When the radius of the fundamental mode of elliptical-core two-mode fiber in the y-direction is equal to the mode radium of the single mode circular-core fiber, $w_y = 1$, Eq. (2) becomes

$$\eta = \frac{w_x}{1+w_x^2}\left[1+\sqrt{2}\frac{w_x}{1+w_x^2}\delta\right]^2 \times \exp\left(-\frac{\delta^2}{1+w_x^2}\right). \quad (3)$$

Set $W_x/W_y = 1.4$, Fig. 2 shows the coupling efficiency between single-mode circular-core fiber and elliptical-core two-mode fiber for $\Delta\varphi = 0$.

Figure 2 illuminates that when the axis offset $\delta \approx 1$, the coupling efficiency reaches peak value, it is advantageous for signals picked-up. Therefore, before the experiment, the core radium of the pick-up fiber should be chosen carefully to obtain more information. Commonly, the core diameter of the pick-up fiber is a little smaller than the core radium of the circular-core two-mode fiber or the major semi-axes of the elliptical-core two-mode fiber.

In view of above discussion, we can obtain the voltage signal when the sine voltage signal with amplitude of 2.68 V and frequency of 50 Hz is put on the PZT. In the experiment, the input and output signals show the oscillation of the interference intensity, as shown in Fig. 3, which is almost consistent with the previous simulation results. The precision of the voltage detection is within ±0.2% when the voltage changes between 0.1 and 20 V.

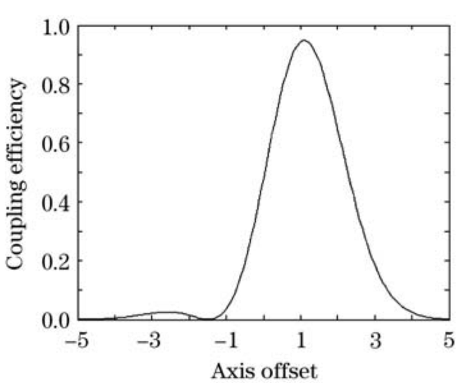

Fig. 2. Coupling efficiency between single-mode circular-core fiber and elliptical-core two-mode fiber.

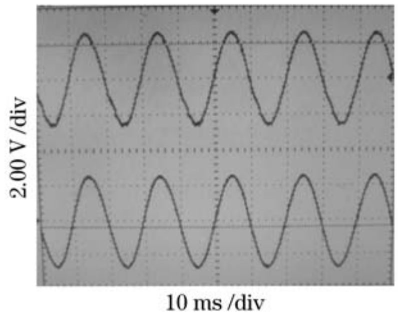

Fig. 3. Output (upper) and input signals (lower) in experiment.

In conclusion, the single mode pick-up fiber with different core shapes should be chosen properly in order to improve coupling efficiency and increase system detection precision based on different two-mode fibers. The two-lobe interference signals can be transmitted to diodes by two single-mode fibers which are fused together to the output of elliptical-core two-mode fiber. Importantly, based on the new demodulation techniques, the coupling efficiency reaches maximum when the core diameter of the pick-up fiber is a little smaller than the major semi-axes of the elliptical-core two-mode fiber and the axis offset δ is about 1. Furthermore, theory and experiment prove that the voltage signal can be efficiently detected and the detection precision of the system is within ±0.2% when the voltage changes between 0.1 and 20 V.

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