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Influence of polarization extinction ratio on distributed polarization coupling detection*

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Distributed polarization coupling in polarization-maintaining fibers can be detected by using a white light Michelson interferometer. This technique usually requires that only one polarization mode is excited. However, in practical measurement, the injection polarization direction could not be exactly aligned to one of the principal axes of the PMF, so the influence of the polarization extinction ratio should be considered. Based on the polarization coupling theory, the influence of the incident polarization extinction on the measurement result is evaluated and analyzed, and a method for distributed polarization coupling detection is developed when both two orthogonal eigenmodes are excited.

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In polarization maintaining fibers (PMFs), due to all kinds of intrinsic and extrinsic perturbations, one polarization mode may be coupled into the other orthogonal axis[1-4], which is called distributed polarization coupling (DPC) phenomenon. High spatial resolution and wide dynamic range can be achieved in distributed measurement of polarization coupling by using white light interferometry (WLI)[5], and a coupling point location accuracy of ±1.5 cm and a length resolution of 10 cm or better have been realized[6,7]. Usually, only one polarization mode is excited in the measurement of the coupling point in PMFs using WLI[8,9].The polarization direction of the injected light may not be exactly aligned to one of the principal axes in PMFs, so the influence of polarization extinction ratio should be considered. In this paper, a system to detect the spatial distribution of polarization coupling with 1 km high birefringence fiber is designed and implemented. Meanwhile, the influence of the polarization extinction ratio (PER) on the dynamic range, coupling intensity and coupling position in the measurement system are analyzed, when both two orthogonal polarization modes are excited.

The scheme of the DPC detection system is shown in Fig.1. It comprises a Michelson interferometer and a superluminescent diode (SLD) as the broadband source. Polarized broadband light is coupled into the PMFs under test with only one polarization mode excited. When there is one polarization coupling point, a small fraction of light is coupled into the other orthogonal mode. Because of the modal birefringence Δn_b, two polarization modes propagate at different group velocities. At the output of the fiber, an optical path difference (OPD) $\Delta n_b \times l$ is produced between the two orthogonal modes, where l is the fiber length between the coupling point and the fiber end. The OPD is compensated by a scanning Michelson interferometer, and white light interferogram is read out during the scanning process.

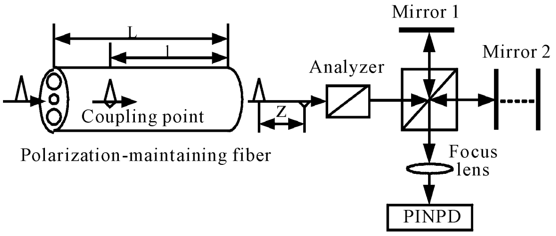

Fig.1 Scheme of the polarization coupling detection system

When there is only one coupling point in the fiber, the interferogram is expressed as,

$$I(d)=I_0\left\{\left|\gamma_0(d)\right|\cos(k_0 d)+\sqrt{h}\,\left|\gamma_0(\Delta n_b l-d)\right|\cos[k_0(\Delta n_b l-d)]\right\}, \tag{1}$$

where I_0 is the DC component of interference, $\gamma(x)$ is the optical coherence function of the light source, d is the OPD

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of the Michelson interferometer, $k_0=2\pi/\lambda_0$ is the wave number in free space, and h is the power coupling strength.

The corresponding read out interferogram is shown in Fig.2. The central maximal fringe I_{main} appears when the Michelson interferometer is in balance. The other two symmetrical interference packets I_{coupling} appear when the OPD produced in PMF is compensated by the Michelson interferometer.

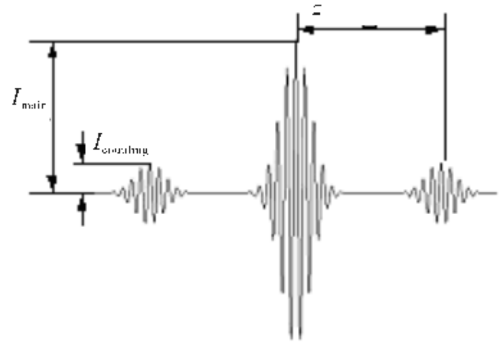

Fig.2 Read out interferogram with one coupling point existing

The power coupling strength h and position l can be calculated from the interferogram as follows,

$$h=20\times\lg\left(I_{\text{coupling}}/I_{\text{main}}\right)\ , \tag{2}$$

$$l=z/\Delta n_b\,. \tag{3}$$

As mentioned above, only one polarization mode excited in the PMF is considered. However in practical measurement, the polarization direction of the injected light may not be exactly aligned to one of the principal axes in the PMFs. So another polarization mode could be also excited. When both polarization modes are excited, the two orthogonal modes can be expressed as,

$$E_{x0}=A_{x0}\exp(\mathrm{i}\Phi_{x0})\ ,\ E_{y0}=A_{y0}\exp(\mathrm{i}\Phi_{y0})\ . \tag{4}$$

When there is one coupling point existing, polarization coupling will occur in both polarization modes as shown in Fig.4.

Assuming that the optical magnitude coupling strength is η at the coupling point, the output polarized modes from the fiber end can be expressed as the following,

$$\begin{aligned}E_{\mathrm{x}}&=A_{\mathrm{x}}\exp[\mathrm{i}(\Phi_{\mathrm{x0}}+kn_{\mathrm{x}}l_{\mathrm{AB}})]+\\&\quad\eta A_{\mathrm{y}}\exp[\mathrm{i}(\Phi_{\mathrm{y0}}+kn_{\mathrm{y}}l_{\mathrm{AM}}+kn_{\mathrm{x}}l_{\mathrm{MB}})]\,,\end{aligned} \tag{5}$$

$$\begin{aligned}E_{\mathrm{y}}&=A_{\mathrm{y}}\exp[\mathrm{i}(\Phi_{\mathrm{y0}}+kn_{\mathrm{y}}l_{\mathrm{AB}})]+\\&\quad\eta A_{\mathrm{x}}\exp[\mathrm{i}(\Phi_{\mathrm{x0}}+kn_{\mathrm{x}}l_{\mathrm{AM}}+kn_{\mathrm{y}}l_{\mathrm{MB}})].\end{aligned} \tag{6}$$

After both polarization modes are projected into the same polarization direction, interference between the two modes can be produced. There are four interference packets arising in the process of the OPD compensation. The read out intensity in the Michelson interferometer is shown in Fig.5. The first interference fringe appears when the two arms of the Michelson interferometer have an equivalent optical path. The forth packet is generated by the fiber end. The second and third packets are the interference patterns generated by the coupling point. Double interferential fringes will be produced, when both orthogonal polarization modes are excited.

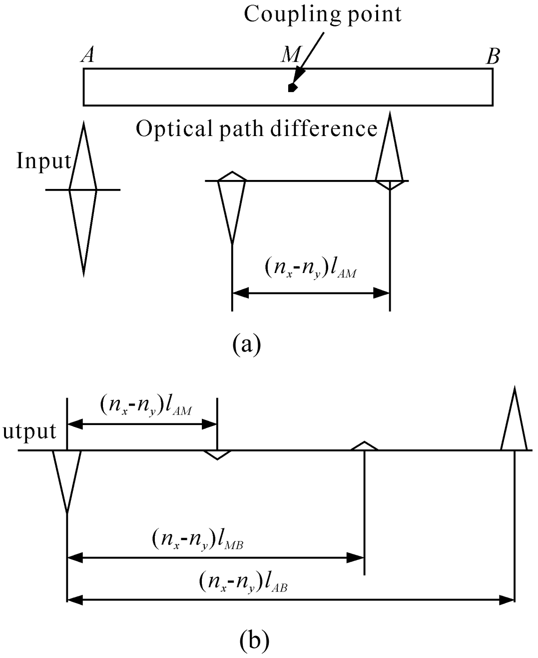

Fig.4 Polarization coupling with both polarization modes excited

When one polarization mode is excited, due to the angular alignment mismatch and non-linear polarized light, the same phenomena mentioned above will be also observed. According to eq. (2), three polarization coupling intensities will be obtained from the interferogram shown in Fig.5,

$$h_1=\left(\frac{\frac{1}{2}\eta A_x A_y}{\frac{1}{4}(\eta^2+1)(A_x^2+A_y^2)}\right)^2\ \text{幺L}\left(\frac{2\eta\frac{A_y}{A_x}}{1+\left(\frac{A_y}{A_x}\right)^2}\right)^2\ \text{幺L}\,4\eta^2\left(\frac{A_y}{A_x}\right)^2=$$

$$4\times h\times PER\ , \tag{7}$$

$$h_2 = \left(\eta/(1+\eta^2)\right)^2 \sim \eta^2 = h, \tag{8}$$

$$h_3 = h_1/(4\eta^2) = PER, \tag{9}$$

where h is the real coupling strength that we wish to acquire, which is equal to h_2. The third strength h_3 is corresponds to the incident polarization extinction ratio. h_3 can be also used to detect the mismatch of angular alignment. When the polarization extinction ratio in this detection system is too weak, another fake "coupling point" with a coupling intensity h_1 will appear, and it is undesirable.

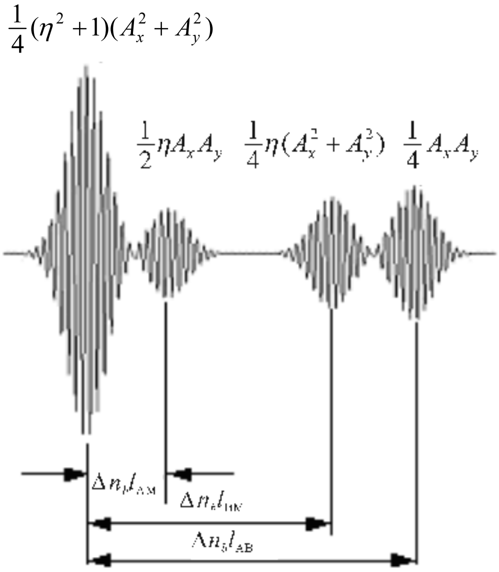

Fig.5 Polarization coupling interferogram with both polarization modes excited

The positions of the fake coupling point and the real coupling point are of central symmetry about the middle of the fiber. The false optical power coupling intensity can be got from eq.(7) and eq.(10).

$$h_1\,(\text{dB}) = \textit{Coupling intensity}\,(\text{dB}) + PER\,(\text{dB}) - 6, \tag{10}$$

$$\textit{Dynamic range}\,(\text{dB}) = PER\,(\text{DB}) - 6. \tag{11}$$

According to eq.(10), one can come to the conclusion that the polarization extinction ratio will affect the dynamic range in the DPC detection system. The dynamic range of the system will be restricted by eq.(11). For example, if the *PER* is -25 dB, the detectable sensitivity of the system is –70 dB, and then the system dynamic range will be limited from –39 dB to –70 dB. Coupling point with a coupling intensity larger than –39 dB will lead to a false weak coupling point. In order to enhance the dynamic range in the system, *PER* should be improved first. Meanwhile, it can be also proved that the *PER* does not affect the measurement of the coupling intensity and the true coupling point position as well as the spatial resolution in the system, because the real coupling point could be recognized based on the above analysis.

In conclusion, a new system to measure the distributed polarization coupling in PMFs is designed and implemented using white light interferometry. Both the power coupling intensity and the position can be detected. Based the on the mode coupling theory, the influence of the incident polarization extinction ratio on the measurement of the polarization coupling between the two eigenmodes in PMFs is analyzed. The *PER* will restrict dynamic range in this detection system to (*PER*-6)dB . If the incident *PER* is too weak, it will lead to a false judgment of the fake coupling point. will caused. The polarization extinction ratio does not affect the spatial resolution and other measurement functions in this distributed polarization coupling detection system.

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