

OPTICAL FIBRES AND FIBREOPTIC SENSORS

PACS numbers: 42.81.Cn; 42.81.Gs
DOI: 10.1070/QE2009v039n11ABEH014171

Polarisation reflectometry of anisotropic optical fibres

Yu.A. Konstantinov, I.I. Kryukov, V.P. Pervadchuk, A.Yu. Toroshin

***Abstract*. Anisotropic, polarisation-maintaining fibres have been studied using a reflectometer and integrated optic polariser. Linearly polarised pulses were launched into the fibre under test at different angles between their plane of polarisation and the main optical axis of the fibre. A special procedure for the correlation analysis of these reflectograms is developed to enhance the reliability of the information about the longitudinal optical uniformity of anisotropic fibres.**

Keywords: *reflectometry, fibre optics, polarisation-maintaining fibres, correlation analysis.*

Anisotropic fibres (maintaining the polarisation of an input beam) are widely used in fibreoptic sensors of physical variables. They play a particularly important role in fibreoptic gyroscopes (FOGs), whose accuracy is determined to a significant degree by the parameters of the fibre, in particular by its birefringence. An important requirement for the quality of anisotropic fibres is good longitudinal uniformity, which is a necessary condition for optical reciprocity, fundamental to the theory of FOGs [1, 2].

There are a number of mature techniques for the control of the fibre uniformity [3]. Usually, these rely on optical reflectometry with standard equipment. Optical interrogation pulses (in particular, linearly polarised) are launched into the fibre to be studied, and then the backscattered power is measured. This approach reveals and locates all optical inhomogeneities in the path of pulses throughout the fibre length.

Anisotropic fibres that are known to be nonuniform in structure can be measured using polarisation reflectometry [3] or low-coherent reflectometry [4, 5]. These techniques enable more adequate analysis of backscattering in complex structures in comparison with standard techniques.

Here, we propose another approach to raising the precision in analysis of the structure of anisotropic fibres. Panda-type fibres (JSC PNPPK) were characterised by a modified polarisation reflectometry technique. To reveal and locate defects with greater precision, we used a special correlation analysis procedure intended for detailed studies of particularly important fibres and fibreoptic components.

The experimental setup used in our studies is shown schematically in Fig. 1. To bring the fibre under test out of the dead zone of the reflectometer (Photon Kinetics 8000), a spooled buffer fibre (800 m of Corning SMF28) was connected to its output. The output end of the buffer fibre was fusion-spliced to the input of the integrated-optics polariser coupled to a lithium niobate substrate. The end face of the other fibre output of the polariser and that of the fibre under test were butt-joined in an immersion liquid.

Length/m	3360
Optical attenuation/dB km^{-1}	1.2
Cutoff wavelength/nm	1210
Mode field diameter/μm	6.9
h parameter/m^{-1}	3.2×10^{-6}
Birefringence	5.5×10^{-4}

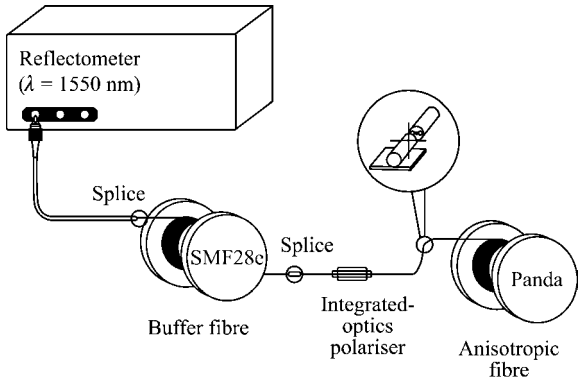

Figure 1. Schematic of the experimental setup.

The fibre under study had the following parameters:

After each measurement, the fibre was rotated around its central axis through 30°, so that six reflectograms were obtained for each fibre.

Next, the data were analysed. Since the software supplied with the reflectometer is not suited to export reflectograms into popular formats, dedicated software was written for data analysis and processing.

Yu.A. Konstantinov, I.I. Kryukov, V.P. Pervadchuk, A.Yu. Toroshin
Institute of Photonics and Optoelectronic Devices, Perm State Technical University, Komsomol'skii prosp. 29, 614990 Perm, Russia;
e-mail: nworhm@rambler.ru, root@ppk.perm.ru, pervadchuk@mail.ru

Received 25 June 2009; revision received 23 September 2009
Kvantovaya Elektronika **39** (11) 1068 – 1070 (2009)
Translated by O.M. Tsarev

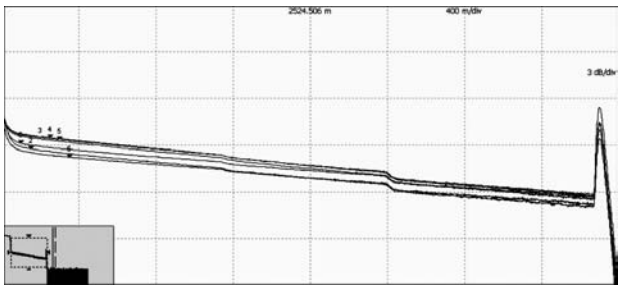

Figure 2. Reflectograms of anisotropic fibre at different angles between its main optical axis and the plane of polarisation of the input pulse.

Figure 2 shows typical reflectograms as displayed on the monitor of the instrument. The portions corresponding to the buffer fibre are omitted.

Local features ('events') in reflectograms corresponded to both optical loss inhomogeneities, typical of reflectometry, and local inhomogeneities in fibre anisotropy. These latter are most frequently caused by deviations in fibre geometry or equipment errors (small-radius bends, criss-cross, local compression or stretching). The acceptable level of inhomogeneities can be found out after appropriate quantitative evaluation and design testing of fibres that are used in various fibreoptic components and products.

The reflectograms demonstrate repeatability of structural defects in the anisotropic fibre at different angles between the plane of polarisation of the interrogation pulse coming from the reflectometer and the optical axis of the fibre. The variation in signal amplitude is due to alignment errors where the beam is coupled into the fibre. Note, however, the relatively high noise level in the portion of the reflectograms that corresponds to the anisotropic fibre, which hinders direct data analysis. The main idea of subsequent data processing is to transform the data set to a single function whose maxima will correspond with a high degree of certainty to structural inhomogeneities of the fibre.

To further analyse the reflectograms, which, after a primary transformation, had the form of discrete functions of the linear coordinate along the fibre, we determined their cross-correlation coefficient. The horizontal axis common to the six reflectograms was divided into segments of the same length. The correlation coefficients were determined for each pair of reflectograms in each segment by the well-known formula [6]

$$r = \sum_{i=1}^{n}(u_i - \bar{u})(\upsilon_i - \bar{\upsilon})\left(\sum_{i=1}^{n}(u_i - \bar{u})^2\right)^{-1/2}\left(\sum_{i=1}^{n}(\upsilon_i - \bar{\upsilon})^2\right)^{-1/2},$$

where u and υ are the initial values of the signal functions, and $\bar{u}$ and $\bar{\upsilon}$ are their averages over the segment.

In this way, we obtained 15 coefficients for each segment. Next, we determined the average cross-correlation coefficient of the polarisation reflectograms in each fibre section. Clearly, the selection of the fibre section length depends on the specific purpose and the length scale of the inhomogeneities of interest.

If no event was observed in a particular fibre section, the reflectograms were assumed to be uncorrelated by virtue of the random nature of the scattering process (homogeneous section). In contrast, a relatively large correlation coefficient

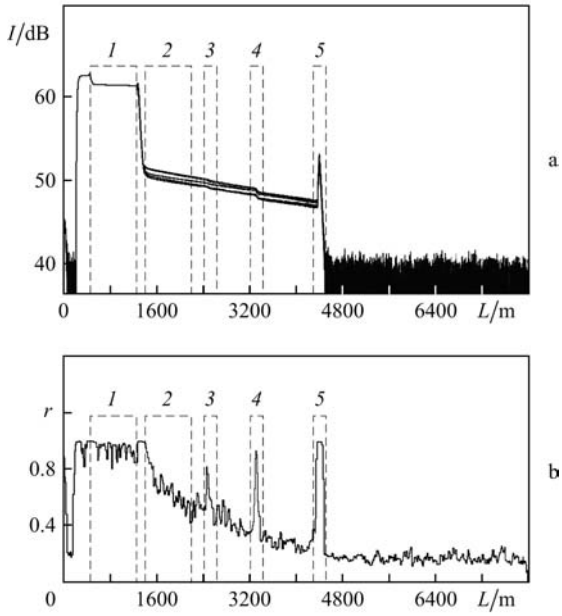

Figure 3. (*a*) Reflectograms and (*b*) correlogram of anisotropic fibre: (*1*) buffer fibre; (*2*) fibre section under test in which no inhomogeneities were detected; (*3*) event (fibre microbending); (*4*) event (fibre criss-cross on the spool); (*5*) reflection from the free fibre end.

in one of the segments was considered evidence of fibre nonuniformity, which had a regular effect on the corresponding reflectograms.

The results obtained as described above are presented in Fig. 3. In portion (*1*) (buffer fibre), the reflectograms have a large average correlation coefficient (close to unity) due to the high homogeneity of the isotropic fibres, the low noise level and near identity of the reflectograms. The correlation coefficient in portion (*2*) (test fibre section in which no inhomogeneities were detected) is much smaller (0.4–0.8). The gradual decrease is most likely due to instrumental errors: the dependence of the noise level in the reflectogram on the signal amplitude. The event in portion (*3*) – fibre microbendings – shows up as a slight drop in the reflectogram and as a distinct peak with a correlation coefficient of 0.8 in the correlogram. The event in portion (*4*) is a fibre criss-cross on the spool, with a cross-correlation coefficient of ~ 0.9. The cross-correlation coefficient for the reflection from the free fibre end is ~ 0.98.

Thus, the proposed procedure for the correlation analysis of polarisation reflectograms enables substantially more adequate localisation and quantification of optical inhomogeneities in anisotropic fibres. It allows one to achieve the goal of key importance for fibre manufacturers and users: rejection of fibres unsuitable for precision measuring systems by simple instrumental means.

Clearly, this procedure can be used to solve another important problem: to monitor the winding quality of anisotropic fibres, particularly in fibreoptic sensing elements.

References

1. Lefevre H.C. *The Fiber Optic Gyroscope* (Boston: Artech House, 1993).
2. Andronova I.A., Malykin G.B. *Usp. Fiz. Nauk*, **172** (8), 849 (2002).

3. Listvin A.V., Listvin V.N. *Reflektometriya opticheskikh volokon* (Reflectometry of Optical Fibres) (Moscow: LESARart, 2005).
4. Davé D.P., Akkin T., Milner T.E. *Opt. Lett.*, **28**, 1775 (2003).
5. Volkov P.V., Ivanov V.V., Markelov V.A., Novikov M.A., Ustavshchikov S.S. *Trudy nauchnoi konf. po radiofizike. Kvantovaya radiofizika i optika* (Proc. Conf. on Radiophysics: Quantum Radiophysics and Optics) (Nizhnii Novgorod: NNGU, 2005) p. 377.
6. Goodman J.W. *Statistical Optics* (New York: Wiley-Interscience, 1985; Moscow: Mir, 1988).