Research Properties of the Mandelstam – Brillouin Scatter in the Polarization Maintaining Single-Mode Fibers

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Abstract. Results obtained in experimental studies of properties of the Mandelstam – Brillouin scatter in the polarization maintaining single-mode fibers are given in this paper. Experimental data for varieties of such fibers as “Panda” kind are analysed. Traces obtained by BOTDR are presented.

Differences in traces when turning the axis of sections with optical fiber “Panda” at a certain angle are shown.

Analysis of the experiment results revealed important dependence differences of the polarization maintaining fibers from the same dependences of others optical fiber kinds.

1. Introduction

The polarization maintaining single-mode fibers (“Panda”, “Bow-tie”) has found practical application in control of polarization state, for instance, in optical gyroscopes, interferometric sensors and communication systems [1 – 4].

The crucial task of the optical fibers (OF) early diagnostics is obtaining credible information about fiber physical state. Early detection of “problem” fiber section (section with bends and microbends, increased mechanical strain and modified temperature, etc.) enables us to take essential measures to remove the failure before the OF break.

It is considered that an ordinary optical reflectometers are not able to solve this task, therefore, a Brillouin reflectometry method is applied in this case [1, 5].

Mindful that the “Panda” OF has important differences in the MBBS property behavior, the study of these properties with various levels of input signal power and different temperatures are of special interest [1, 2].

2. The theory

The Brillouin optical time-domain reflectometers (BOTDR) are applied to detect FOCL sections with mechanical OF strain and modified temperature.

The Brillouin reflectometry method based on the analysis of the Mandelstam – Brillouin backscatter spectrum (MBBS) in waveguide which is observed with the introduction of increased power radiation into the OF lay the foundation for BOTDR. In addition, components of the MBBS have displacement of frequencies on the value proportional to the OF strain degree and its temperature.

We can get a strain distribution along an OF, find their properties and consider the causes of these changes in MBBS by analyzing the position of MBBS “peaks” ($f_B$ is a Brillouin frequency shift and a maximum frequency of MBBS) [5 – 8].

One of the polarization maintaining fiber (PMF) kinds is “Panda”. PMF keep the polarization state of the input signal because of the significant birefringence. The birefringence is result of mechanical
stress anisotropy caused by structure of the fiber, owing to mass into the workpiece cylindrical elements from germanosilicate glasses symmetrically on both sides of the core [1 – 3].

3. Statement of the problem
Experimental studies with BOTDR “AQ 8603” were made to research the MBBS properties in “Panda” OF in different conditions.
The OF for researches were provided by the Perm scientific center of the Ural branch of the RAS and by “Incab” LLC (Perm).
The cladding diameter of the “Panda” OF is 80.5 µm, the core diameter is 6.4 µm, the stem diameter is 17.2 µm [1, 2].
The research of MBBS behavior of various OF kinds as well as their dependences on external mechanical influences and temperature was performed in previous papers [6 – 8].

4. The research results
In the first experiment the MBBS was researched in waveguide composed of normalizing coil standard OF (G.652), spliced with “Panda” OF (the diameter is 80 µm, B is 6.5), which was welded with another “Panda” OF (the diameter is 80 µm, B is 7.5), where B is a parameter characterizing the level of modal birefringence.
Fig. 1 shows BOTDR-trace displaying the MBBS distribution along the waveguide at room temperature (+25 °C) and in the absence of mechanical strain.
The OF joints (welded connections) are well visible in Fig. 1 by the sharp variation of MBBS.
The sharp variation of the amplitude in the “Panda” OF joint is a result of polarization losses due to the fiber axes mismatch.

![Figure 1. BOTDR-trace of the waveguide contained “Panda” fibers.](image)

Fig. 2 shows a multi-trace (dependences of the strain along waveguide, the profile of MBBS, the width of MBBS and the losses) applicable to BOTDR-trace of MBBS distribution indicated in Fig. 1.
As Fig. 1 – Fig. 3 show the MBBS of “Panda” OF has the only one maximum ($f_B$) which frequency is 10.411 GHz for B = 6.5 (Fig. 1 – Fig. 2) and $f_B$ is 10.424 GHz for B = 7.5 (Fig. 3).
(OF-G.652 has the $f_B = 10.84$ GHz).
Figure 2. Multi-trace of the waveguide contained “Panda” fibers.

Figure 3. A distribution pattern of a strain along the waveguide.

Fig. 3 shows the strain pattern along the waveguide applicable to traces presented in Fig. 1 and Fig. 2. The average strain of the “Panda” OF is about −0.86 % (B = 6.5) and −0.83 % (B = 7.5). Besides that, the initial level value \( f_{B0} \) of G.652 is taken for calculating of the strain (average strain of OF-G.652 is about 0.02 %). In the following experiment the axis orientation of the “Panda” OF section was changed. The OF section was separated and turned by a certain angle relative to the normal “Panda” OF, then these sections were joined by welding.
Fig. 4 demonstrates a BOTDR-trace displaying the MBBS distribution along the waveguide at room temperature (+25 °C) and in the absence of strain.

A characteristic variation in an amplitude related to the polarization mismatch of “Panda” OF sections is observed at the welded connection.

Fig. 5 and Fig. 6 show the multi-traces applicable to BOTDR-trace of MBBS distribution indicated in Fig. 4. The marker is set on the initial “Panda” OF section as shown in Fig. 5.

The marker was moved from the initial section of the “Panda” OF to the turned section around 45° relative to the normal OF.

It is obvious that the MBBS maximum wasn’t changed its position (Fig. 4 – Fig. 6).
In the following experiments, some sections of a similar waveguide with “Panda” OF were placed in the heating chamber or were cooled [2, 6].

The Brillouin frequency shift ($f_B$) of the “Panda” fiber in experimental researches was changed from 10.39 GHz (temperature $-10^\circ C$) to 10.53 GHz (temperature $+140^\circ C$). Whereby the strain of the “Panda” OF changed from $-0.91\% (-10^\circ C)$ to $-0.64\% (+140^\circ C)$ (initial level $f_{B0}$ of G. 652 is taken for calculating of the strain [1, 6]).

In terms of experiments the temperature graphs of the strain and $f_B$ for the “Panda” fiber pass appreciably below the applicable properties of other OF kinds [6–8]. The temperature dependences of the relative $f_B$ shifts for different kinds of polarization maintaining fibers obtained as a result of experimental studies of MBBS using other methods are presented in [3, 4].

Fig. 7 (MBBS distribution) and Fig. 8 (multi-traces) show the BOTDR-trace of the PS887-A270318 type of “Panda” PMF.

As Fig. 7 and Fig. 8 show the MBBS of PS887-A270318 PMF has the single maximum, which frequency is 10.565 GHz.

Also the experimental studies of the fiber bends influences on the BOTDR-reflectograms were carried out with “Panda” PMF. It turned out that the “Panda” fiber has the least sensitivity to bending in the form of a half-loop.

The researches have shown that bends of “Panda” PMF with a diameter of half-loop less than 10 mm are visible in the BOTDR-reflectogram (at the expense of the amplitude reduction and change of the graph steepness). (Bends of the G. 652 and G. 657 fibers were detected in the reflectograms only for half-loop diameter less than 25 mm [9]).
5. Conclusion
The MBBS profiles of fibers of different kinds and companies are appreciably different. The obtained results of researches detected significant differences in the MBBS properties and strain for “Panda” OF. The temperature characteristics of the strain and $f_0$ of the “Panda” OF are below than the applicable properties of other OF kinds [5 – 8].
Overall trends in MBBS “peak” \( f_B \) and strain changes in “Panda” PMF depending on the temperature bear a similarity with other kinds of optical fibers [6 – 8]. In addition, it is necessary to finalize an OF orientation relative to the core axis at the junction of “Panda” OF sections, as mismatch of the optical axis orientation leads to important polarization losses.

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References

[1] Bogachkov I V 2017 Research characteristics of the Mandelstam – Brillouin scattering in specialized single-mode optical fibers *International Conference Dynamics of Systems, Mechanisms and Machines Proceedings* (Omsk) pp 1–6

[2] Kompaneets O E, Bogachkov I V and Trukhina A I 2017 Experimental researches of Mandelstam – Brillouin backscattering features in “Panda” optical fiber *Systems of Signal Synchronization, Generating and Processing in Telecommunications (SINKHROINFO-2017) Proceedings* (Kazan) pp 1–6

[3] Smirnov A S, Burdin V V, Petukhov A S, Drozdov I R, Kuz'minykh Ya S, Besprozvannyykh V G and Konstantinov Yu A. 2015 Birefringence in anisotropic optical fibres studied by polarised light brillouin reflectometry *Quantum Electronics* 45, 1 pp 66-68

[4] Kim Y H and Song K Y 2015 Characterization of Nonlinear Temperature Dependence of Brillouin Dynamic Grating Spectra in Polarization-Maintaining Fibers *Journal of Lightwave Technology* 33, 23 pp 4922–4927

[5] Bogachkov I V and Gorlov N I 2016 Joint testing of optical pulse reflectometers of various types for early diagnostics and detection of “problem” sections in optical fibers *IEEE 13th International Conference on Actual Problems of Electronic Instrument Engineering (APEIE–2016) Proceedings* (Novosibirsk) vol 1 chapter 1 pp 152–156

[6] Bogachkov I V 2017 Temperature Dependences of Mandelstam – Brillouin Backscatter Spectrum in Optical Fibers of Various Types *Systems of Signal Synchronization, Generating and Processing in Telecommunications (SINKHROINFO-2017) Proceedings* (Kazan) pp 1–6

[7] Bogachkov I V 2018 A Classification of Optical Fibers Types on the Characteristics of the Mandelstam – Brillouin Backscatter Spectrum *IEEE Ural Symposium on Biomedical Engineering, Radioelectronics and Information Technology (USBEREIT-2018) Proceedings* (Ekaterinburg) pp 308–312

[8] Bogachkov I V 2018 Detection of initial level of Brillouin frequency shift in optical fibers of different types *Journal of Physics: Conference Series* 1015 (2018)

[9] Bogachkov I V and Trukhina A I 2018 A Detection of Bends of the Optical Fibers by Using Brillouin Reflectometer *Systems of Signal Synchronization, Generating and Processing in Telecommunications (SINKHROINFO-2018) (Minsk)* pp 1 – 4