

Conference Paper

A Determination of the Initial Level of the Brillouin Frequency Shift in Optical Fibers of Different Kinds

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Abstract

A dependence of the hyper-acoustic wave velocity on characteristics of the optical fiber core is analyzed in this paper. The values of Brillouin frequency shifts for various types of optical fibers at room temperature and without longitudinal tensile force are presented. Having database of profiles of the Mandelstam – Brillouin backscattering spectrums for fibers of different kinds and manufacturers allow to classify the optical fibers in the optical cables and detect damaged sections of fiber optical communication line.

Keywords: optical fiber, strain, Brillouin frequency shift, Brillouin reflectometry, hyper-acoustic wave.

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1. INTRODUCTION

To ensure a longstanding operating of fiber optical communication line (FOCL), it is necessary to eliminate the longitudinal mechanical strains (upward of 0.2 %) in its optical fibers (OF).

To detect sections of FOCL with high strain of the OF or changed temperature Brillouin optical time domain reflectometry (BOTDR) and Brillouin optical time domain analysis (BOTDA) [1 – 3] are applied.

In BOTDR Mandelstam – Brillouin backscattering spectrum (MBBS) along OF is logged and evaluated.

An important advantage of BOTDR compared to BOTDA in the search for “problem” sections of OF, that are within the optical cables, is sufficient access to only one end of the OF.

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2. THE THEORY

The electromagnetic wave from the light signal source is partly dissipated in the back direction with change of frequency in the Mandelstam – Brillouin scattering (MBS) by acoustic phonons.

The Brillouin frequency shift (f_B) in OF is defined by:

$$f_B = f_L - f_S = 2f_L v_A n / c = 2v_A n / \lambda_L, \tag{1}$$

where f_L is the laser radiation frequency (λ_L – laser radiation wavelength), f_S – frequency of Stokes component, c is the light velocity, n is the refractive index of the OF core, v_A is the hyper-acoustic wave velocity in OF:

$$v_A = \sqrt{\frac{\epsilon_Y (1 - \mu_p)}{\rho (1 + \mu_p) (1 - 2\mu_p)}}, \tag{2}$$

where ϵ_Y is the Young’s modulus of OF, μ_p is the Poisson’s ratio for OF, ρ is the OF core density.

A dependence graph of the hyper-acoustic wave velocity of the optical fiber on the Poisson’s ratio is presented in Fig. 1.

If $\mu_p = 0.17... 0.22$ for fused quartz, then the substitution of μ_p values in (2) gives the equation

$$v_A = (1.03...1.07) \sqrt{\epsilon_Y / \rho}, \tag{3}$$

which improves generally accepted equation [1 – 3]

$$v_A = \sqrt{\epsilon_Y / \rho}, \tag{4}$$

as it includes a number of factors related to the OF core structure.

The relative change in the core density of quartz OF at small strains is connected to the relative stretching by the formula [4]

$$\Delta\rho/\rho = -0.66\Delta L/L. \tag{5}$$

Change of Brillouin frequency shift (Δf_B) with OF temperature (T) is characterized by a linear dependence:

$$\Delta f_B(T) = f_B(T) - f_{B0} = C_t \cdot (T - T_0), \tag{6}$$

where C_t is the linearization factor depending on wavelength with particular Young’s modulus, $f_B(T)$ is the frequency of MBBS maximum, T_0 is an initial temperature (e.g., typical room temperature), $f_{B0} = f_B(T_0)$ [14].

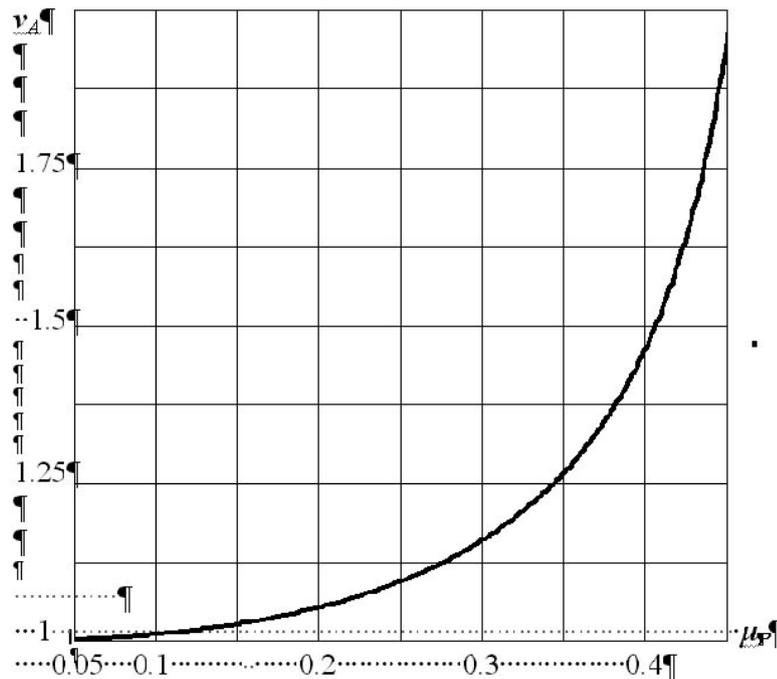


Figure 1: The dependence of $v_A(\mu_p)$

Change of Brillouin frequency shift (Δf_B) with a degree of strain (s_ϵ) at a specific OF section is also described by a linear dependence:

$$s_\epsilon - s_{\epsilon 0} = \Delta s_\epsilon = \frac{f_B(s_\epsilon) - f_{B0}}{f_{B0} \cdot C_T} = \frac{\Delta f_B(s_\epsilon)}{f_{B0} \cdot C_T}, \quad (7)$$

where Δs_ϵ is the change of OF strain with respect to the initial value ($s_{\epsilon 0}$); $f_B(s_\epsilon)$ is Brillouin frequency shift as a function of strain; f_{B0} is the initial value of f_B ($f_{B0} = f_B(s_{\epsilon 0})$); C_T is a linearization coefficient at a certain temperature depending on wavelength; Δf_B (z) is the f_B as a function of initial value of f_{B0} .

The investigation of MBBS in OF from different manufacturers, OF with different laws of dispersion behavior and with various structures of the OF core [5 – 9] are of particular interest, since the power levels of the signal injected into OF are significant in Brillouin reflectometry.

3. STATEMENT OF THE PROBLEM

Experimental researches with BOTDR “Ando AQ 8603” with the cooperation of CJSC “Moskabel-Fujikura” (Moscow) were performed to examine the MBS features in single mode optical fibers of different types, the MBBS profiles of optical fibers, the temperature dependencies, and MBBS behavior from various influences.

4. EXPERIMENTAL RESULTS

The theoretical and experimental investigations show that “initial level” (f_{B0}) for normal conditions (at room temperature and in the absence of mechanical stresses – longitudinal strains) are varied based on different types of OF and manufacturers [5 – 14].

It is necessary to define “initial level” of f_{B0} and the coefficients for temperature and strain changes of OF for each kind of OF.

Table 1 below presents the values of f_{B0} for all studied varieties of OF.

TABLE 1

Type of OF	f_{B0} values, GHz	recommended value of f_{B0} , GHz	v_A , km/s ($n = 1.468$)	n_e ($v_A = 5.7$ km/s)
G.652	10.82... 10.85	10.84	5.71	1.468
G.653 (DSF)	10.47... 10.49	10.47	5.53/5.63/5.72	1.42/1.45/1.47
G.655 (NZDSF)	10.61... 10.64	10.63	5.61	1.443
G.657	10.77... 10.80	10.79	5.70	1.466
EDF	10.68... 10.70	10.70	5.64	1.450
“Panda”	10.40... 10.42	10.41	5.50	1.413

G.652 is a standard widespread single mode fiber.

G.653 is a dispersion-shifted single mode fiber (DSF) [7].

NZDSF (G.655) is a non-zero dispersion-shifted single mode optical fiber [8].

G.657 is a single mode fiber with high resistance to bending.

EDF is an erbium-doped fiber [13].

“Panda” is a kind of polarization maintaining fiber (PMF) [10 – 12].

In use for calculations f_{B0} from the table 1, the strain dependencies on temperature for various OF are practically identical.

The values of v_A are obtained by the formula (1) for the values of f_{B0} from the table 1 (in case of $n = 1.468$).

The values n_e (equivalent values of n) are obtained by the formula (1) for the values of f_{B0} from table 1 (in case of $v_A = 5.7$ km/s).

The findings of researches indicate that the MBBS profiles of optical fibers of various types and manufacturers are different.

In addition, with different impacts on the fiber (the temperature changes or the changes of the longitudinal tensile force) in its profile not only the value of Brillouin frequency shift (f_B), but the form of the MBBS can be changed.

For example, MBBS profiles of the G.653-DSF for normal conditions (at room temperature and in the absence of mechanical stresses) are presented in Fig. 2

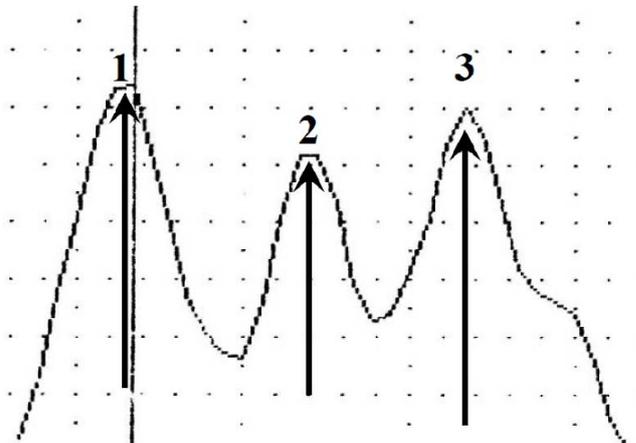


Figure 2: The DSF profile without longitudinal tensile force.

The first peak is observed on a frequency of 10.46 GHz, the second peak – on a frequency of 10.66 GHz and the third peak – on a 10.86 GHz.

Under the influence of the longitudinal tensile force of 2 N, not only shift of the first peak on a frequency of 10.55 GHz, but some change in the MBBS shape are observed, that is shown in Fig. 3 (relative levels of the second and the third peaks have changed).

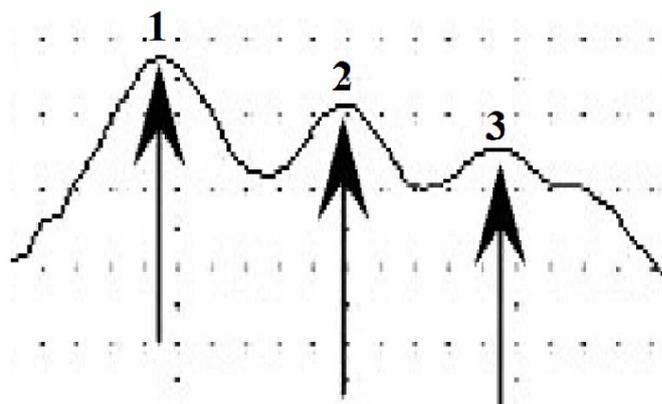


Figure 3: The DSF profile with longitudinal tensile force of 2 N.

By increasing the longitudinal tensile force to 5 N (or in case of significant temperature changes) the MBBS graphs near the second and the third peaks can be “smoothed” that is presented in Fig. 4

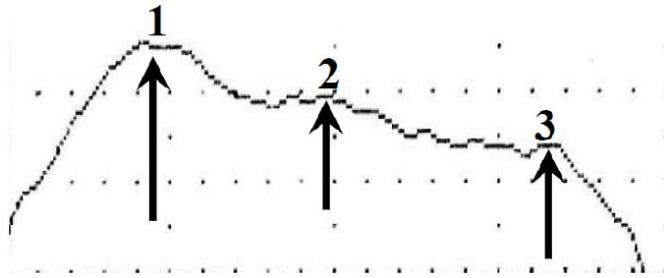


Figure 4: The DSF profile with longitudinal tensile force of 5 N.

This effect can be explained by the presence of different layers in the OF core structure that have the most pronounced in DSF.

The example of the usual DSF core structure is shown in Fig. 5.

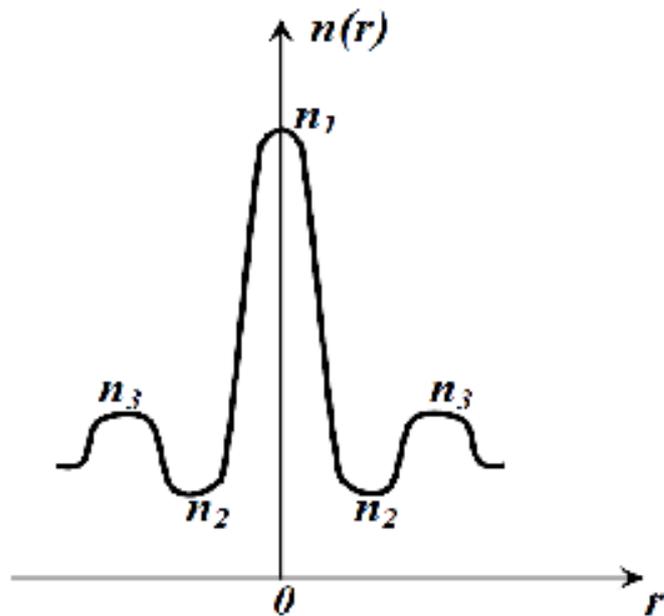


Figure 5: The dependence of the DSF core refractive index on the core radius $n(r)$.

The dependence of the core refractive index on the core radius $n(r)$ demonstrates that some layers have different refractive indexes (n_1, n_2, n_3) (Fig. 5).

This effect can be explained by the presence of different layers in the core structure of the fiber that are most pronounced in the DSF. Multiple acoustic modes are generated in the DSF. Each of these modes exerts the influence on the shape of the MBBS (the appearance of additional peaks) of the light signal.

Analysis of equation (1) shows that the velocity change of hyper-acoustic wave or the refractive index value of the fiber core affect the changes of the f_B . In external influence on OF (the temperature change, the transverse or longitudinal force), the reaction of the different layers in the fiber core structure may be different. In this case,

for each layer the conditions (the layer density, the refractive index of the material and the hyper-acoustic wave velocity in the layer) are changed in its own way, leading in the result to change the shape of the MBBS in OF.

5. CONCLUSION

Presence of database of MBBS profiles for different OF types and manufacturers provides an opportunity to classify OF in FOCL, and to detect fault sections [7 – 11].

The possibility of structure and composition determination of the layers forming the OF core, according to the obtained MBBS profiles and frequencies of all MBBS peaks is of practical value, since the introduction of doping material and change in their concentration affect the hyper-acoustic wave velocity in OF and the effective refractive index.

To detect sections with modified temperature and strain, it is desirable to have a reference BOTDR-trace for the investigated OF in normal conditions (at room temperature and in the lack of mechanical stress). Such trace facilitates the timely detection of “problem” section in FOCL, and therefore, the elimination of this situation prior to the fiber breaking of FOCL.

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