The detection of pre-crash sections of the optical fibers using the Brillouin reflectometry method

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Abstract. The generation of monitoring systems for fiber optical communication lines are examined. The developmental results of pre-crash sections detected both by an optical time domain reflectometer and the Brillouin optical time-domain reflectometer were achieved. The detection subjects of the pre-crash sections under mechanical stresses (strained) or with changed temperature by traces are argued. An advantage of the Brillouin optical time-domain reflectometer for early diagnostics of fiber optical communication lines is obtained.

1. Introduction
Mainstreaming of fiber optical communication lines (FOCL) in present day information and communications systems reduced to the vital task of monitoring and early diagnostics of optical fibers (OF) in the laid optical cables (OC).
The timely detection and eliminating of “problem” sections in OF such as sections with disruption of an “optical path”, temperature and strain modified, bends and microbends, and sections with an unauthorized access to OF of FOCL and so on are crucial task of monitoring and early diagnostics of FOCL [1 – 3].
The main tasks of monitoring systems are follows:
– remote monitoring of active and passive fibers;
– automatic failure detection and determination their location;
– OC failure notification;
– timely fixation of obtained results;
– OC parameter variation predicting [1, 2].
The aforementioned tasks can be solved by applying an automatic monitoring system of FOCL including an optical time domain reflectometer (OTDR), which can detect failures and damages in OF as well as an attenuation at any point of a fiber waveguide. The OTDR operation is based on the backscattering technique [1].
The remote fiber test systems (RFTS) are produced by a number of companies. The examples of monitoring systems on the Russian IT market are ONMSi (“JDSU”, “VIAVI solutions”), NQMSfiber (“EXFO”), Geozondas 7102 (“GEOZONDAS”), FiberTest (“Agizer”), PROFIMAX (“2TEST”) and others.
To organize the functional continuous monitoring of FOCL, it is necessary to find the right RFTS system depending on the network topology, the reliability requirement, as well as the system cost for the planned network and its further growth [2].
The timely detection and eliminating of “problem” sections in OF such as sections with disruption of an “optical path”, temperature and strain modified, bends and microbends, and sections with an unauthorized access to OF of FOCL and so on are crucial task of monitoring and early diagnostics of FOCL [2 – 4].
It is necessary to have a true information on physical state of OF in the laid OC to evaluate reliability of FOCL.

It is believed that the ordinary OTDR are not able to detect sections with increased strain in OF or modified temperature. For this reason the Brillouin and Raman reflectometry methods has found application in the detection such “problem” sections in FOCL [2 – 4].

For some companies the information on control of strain and temperature changes in the OF is useless, as a result they apply ordinary OTDR.

It will be proved below that companies which are interested in improving reliability and life cycle of FOCL, early detection of “pre-crash” sections with increased mechanical strain and modified temperature should apply a Brillouin optical time-domain reflectometer (BOTDR) as a part of the monitoring system.

2. The theory

The ONMSi monitoring system is made of hardware component containing the server, client stations, remote test units (RTU), control equipment for OF and software support. Central server with Oracle database are the main parts of the system. They are applied to store and run all system information. RFTS can monitor not only “light” (active), but also “dark” (passive) OF. The testing of “dark” OF is performed at the wavelength of an optical traffic signal.

The monitoring of “light” OF is carried out not at the operating wavelength. For instance, the wavelength of 1625 nm is used. Therewith, to test “light” OF it is necessary to apply secondary passive members: multiplexors and filters to combine and combine optical signals propagating in the OF [1, 2].

Remote test units are settled at certain points along the communication line. The RTU is made of optical switch for connection to different fibers and one or two OTDRs (the E81162C module by JDSU). The OTDR can detect splices, connectors, macrobends, splitters, and check on losses on the inhomogeneities, reflections and attenuation.

The information received from all RTU passes to the Oracle database.

Client stations are made integral with the central server. They provide access to all system information for technical centers and support adjustment and documentation of network structures. All alarms are locked in the central server, which sends alarm messages to the suitable operators.

It is necessary to have a true information on physical state of OF in the laid OC to evaluate reliability of FOCL.

The life cycle of OF depends on a degree of its strain and temperature [3 – 6].

The increased strain of OF (within the order of 0.2 % or more) has an impact on the life cycle of FOCL. In case of buried OF the multifarious ground deformation, caused by different reasons can affect the appearance of mechanical strains in OF. Even minor movements of the ground layers can lead to degradation of OF in OC [3 – 6].

For the first time these problems appeared in Japan due to frequent earthquakes and high density of building, bridges and highways.

In the context of up-to-date aerial technology of FOCL (stringing of OC on electric transmission line and so on) as in the case of conventional electric wire, the problem of icing of the OC sections during winter time occurs. Therefore, some OC sections under weight of ice can lose shapes that will lead to OF strain reducing life cycle of FOCL [5 – 9].

Temperature changes in the OF, which can be appeared because of the damage in the cable routing, are other issues affecting the FOCL life and its operation efficiency [6 – 8].

In reference to the aforementioned problems it is necessary to have a true information on mechanical strains and temperature changes in the OC.

The ordinary OTDR are not able to detect OF sections with increased strain in OF or modified temperature [3].

To detect the mechanical strain of FOCL or sections with modified temperature the Brillouin optical time-domain reflectometers are applied [6 – 8].
The Brillouin reflectometry method lay the foundation for BOTDR. 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. The MBBS components have a frequency shift proportional to the OF strain and its temperature. We can achieve a distribution of OF strains, find their characteristics and decompose the causes of these changes in MBBS by studying the position of MBBS peaks along the waveguide and calculating the Brillouin frequency shift ($f_B – MBBS$ peak) [4 – 7].

3. Statement of the problem
Experimental studies with OTDR Е81162С JDSU, OTDR “EXFO FTB-400”, BOTDR “AQ 8603”, BOTDR “MTS-8000” were performed to analyze the trace features of OF under influence of dangerous factors. The exploration of MBBS behaviour of different OF types as well as their dependences on external mechanical influences and temperature was carried out in previous works [7 – 12].

4. The research results
To examine the operation of the ONMSi monitoring system for FOCL the following experiment was carried out. The alarm status was created in one of the FOCL sections in which patch cord has been partially detached from the OF under test. When this alarm had been located, the ONMSi sent an alarm message to the remote user. The massage was contained information on failure location, possible cause, distance from the nearest orienting point, deviation from reference and link loss. Also, the alarm traces were attached here by the message.

Fig. 1 shows the trace at the “failure location” in real time (alarm – “2” arrow) and the trace (reference – “1” arrow) in normal condition of the line (the time preceding an alarm).

From the trace we can see that the alarm is critical. The permissible attenuation threshold has been significantly exceeded at the failure section (“2”), what caused the alarm in the OF. In that the OTDR measures an optical OF length, it is necessary to estimate the physical OF length and only then...
identify the specific failure location of the FOCL taking into consideration the OF bends, guide index and OF velocity factor in OC to eliminate the alarm \([1, 2]\). When the patch cord had been returned to a previous position the monitoring system sent the message to remote users about cleared alarm. The trace of the real time OF state was enclosed here with the massage. It shows that trace of the waveguide returned to normal position, and the FOCL OF came back to normal operation (“1”)..

The detection of pre-crash sections with increased mechanical strains \([7 – 9]\) and modified temperature is of special interest \([6, 12]\).

Fig. 2 shows a detailed OTDR trace with a “problem” section (in the range of 1.2 km), which was affected by heating, cooling and longitudinal stretching.

![Figure 2. OTDR trace for a “problem” section.](image)

Changes are not observed in OTDR trace with the problem OF section. (Changes are within the limits of the OTDR \([3]\).)

The “problem” section is clearly detected by the BOTDR \([3 – 6]\).

Fig. 3 shows a detailed BOTDR-trace of MBBS with cooled “problem” section for the same fiber waveguide.

![Figure 3. BOTDR-trace of MBBS for cooled “problem” section.](image)

The shift of the MBBS in the direction of decreasing \(f_0\) \((F1)\) is clearly visible on the trace at the cooled section. The frequency was 10.84 GHz under normal conditions, and then became 10.80 GHz.
Fig. 4 demonstrates a graph of strain distribution for the same fiber waveguide at cooled “problem” section corresponding to the MBBS distribution in Fig. 3.

![Graph of strain distribution for the cooled “problem” section.](image1)

**Figure 4.** Graph of strain distribution for the cooled “problem” section.

The BOTDR-trace for the same fiber waveguide with point stretching in the longitudinal direction of the “problem” section is shown in Fig. 5 (the longitudinal stretching force was 0.5 N, the OF cladding was not removed).

An inconsiderable shift of the MBBS \( f_{Bs} \) was observed in the direction of increasing \( f_B \) (F2), \( -f_{Bs} \) became 10.86 GHz (MBBS profiles are shown in the lower right corner of the BOTDR-trace and the frequency of the MBBS peak is dedicated).

![BOTDR-trace with stretching influence on the OF section.](image2)

**Figure 5.** BOTDR-trace with stretching influence on the OF section.

Fig. 6 shows the corresponding to the MBBS distribution in Fig 5 a graph of strain distribution for the same fiber waveguide under stretching of “problem” section.

There is a slight increase of strain (0.03%) in the stretch section (solid arrow in Fig. 6) relative to the unstrained section (dashed arrows in Fig. 6).
Thus, BOTDR successfully detected the “problem” OF section with both modified temperature [3, 6] and increased strain [7, 9], which the OTDR couldn’t found.

In the following experiments, the OF of the laid OC are investigated, where the “problem” sections with different degrees of OF degradation are detected.

The reason of this situation is a failure of two OF in OC (OTDR of monitoring system detected the OF failure), although the OTDR didn’t find failures in other OF.

The light signal in the OF, which are under increased strain (more than 0.2 %), causes the growth of microcracks impending during OF production. In the end it leads to the microcrack extension while in operation resulting in OF degradation and its premature failure.

Fig. 6 shows the BOTDR-trace of the MBBS pattern along the OF. The identified “problem” section ($f_{B1}$) with a significant change in MBBS ($f_{B1}$ is a shift $f_B$) is marked by a solid arrow. In this case, the MBBS profile at the normal section is marked by a dashed arrow ($f_{B2}$ is 10.82 GHz).

The MBBS shift is noticeable in the problem section towards higher frequencies (F2), which is due to a significant OF strain in this section.

With the cooperation of CJSC “Moskabel–Fujikura” we found the OF failure and the pre-crash OF sections with increased strain.

Fig. 8 shows a detailed BOTDR-trace of the MBBS pattern in the “problem” OF section.

The MBBS changes are marked by solid arrows in the “pre-crash” waveguide section, and the MBBS profile is indicated by dashed arrows.

The trace demonstrates that the shift moves up in frequency (F2). The $f_{B1}$ is 10.92 GHz in this section. Although the information is still passed on this OF, and OTDR doesn’t find any problem OF sections. This OF is in pre-crash condition and it can come into down state with two fibers mentioned above that have already failed and their failure has been detected by OTDR.
Figure 7. BOTDR-trace of the MBBS in the “problem” OC.

Figure 8. Detailed trace of MBBS in the “problem” OF section.

Fig. 9 and Fig. 10 show the BOTDR multi-traces (dependences of the strain along OF, MBBS profile, width of MBBS and losses) in which both a “pre-crash” OF condition (Fig. 9) and a “problem” OF state (Fig. 10) are seen.
Figure 9. BOTDR multi-trace in the “pre-crash” OF.

Figure 10. BOTDR multi-trace in the “problem” OF section.
From the BOTDR multi-trace in the “pre-crash” OF condition (Fig. 6) we can find that the strain is more than 1 %, attenuation increases and the MBBS profile becomes inoperative (this MBBS profile is shown in Fig. 8 in the lower right corner). Thuswise, it is desirable to replace this OF with a new one, even after eliminating the factors that led to a mechanical OC load, because under such conditions the OF live is significantly reduced. There is a potential OF failure in this section.

In the BOTDR multi-trace as shown in Fig. 10, the OF is in the “problem” state, but after the elimination of the load for all OC fibers, this fiber will return to normal state with the previous operation. The strain grew 0.2 % in this section ($f_{B_1} = 10.91 \text{ GHz}$) relative to the unstressed state. The strain changes in the normal and stressed sections are marked by several dashed lines.

BOTDR-reflectogram of the “problem” fiber place located in the laid OC, some section of which was under the influence of a strong displacement force is shown in Fig. 11.

**Figure 11.** MBBS graphs in the “problem” OF section.

**Figure 12.** BOTDR multi-trace in the “problem” OF section.
The significant shift of the MBBS maximum (from 10.84 GHz ($f_{B0}$) up to the frequency 11.08 GHz ($f_{Bs}$)) is observed in the place with dangerous strain. Fig. 12 shows the BOTDR multi-traces corresponding MBBS graphs presented in Fig. 11. As can be seen from the multi-traces, the strain in the place of the mechanical action on the OC increased by more than 0.45 %, which is dangerous for the OF. As follows from the analysis of BOTDR-traces for OF of OC under test, the sections of the route were localized, which required a hard research the factors that caused dangerous mechanical loads on the OC. After eliminating these factors and restoring the “problem” OF sections, the FOCL returned to its normal operation.

5. Conclusion
The analysis of traces with pre-crash and potentially “problem” sections showed that BOTDR found such OF sections in advance of its failure, however, OTDR could not detect it. OTDR can detect such sections only if the optical path is already broken. Therefore, the BOTDR detected the “problem” OF area to its break, which the OTDR wasn’t found. OTDR can only detect areas when the optical path has already broken. The method of Brillouin reflectometry allows early OF diagnostics of FOCL to be carried out, also it helps to detect unauthorized access and clear problem areas in OF at an early stage that enable load factors to be cleared. Monitoring systems with usual OTDR can’t solve this task. Moreover, a significant difference in MBBS profiles is observed in OF of various kinds, which can be used to classify the OF in OC [13, 14]. There are even different initial values of $f_{B}$ [13, 14] for the same OF kinds of various manufacturers [13, 14].

Acknowledgments
The work was performed with the financial support of the Ministry of Education and Science of the Russian Federation within the scope of the base part of a State Assignment within the sphere of scientific activity (Project No. 8.9334.2017/8.9). The author would like to thank partners from CJSC “Moskabel–Fujikura” (Moscow) for assistance in carrying out the experiments with BOTDR “Ando AQ 8603”.

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