System of Monitoring the Technical State of Intra-Zone Optical Cables

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***Abstract*— This article discusses with the development of a hardware and software complex for monitoring the technical state of cables. A method for optical-digital monitoring of additional losses using fiber-optic sensors is proposed. The use of a single-mode optical fiber is a promising trend, since fiber-optic sensors developed on its basis demonstrate high accuracy, fast response to changes and excellent linearity of characteristics. Laboratory studies of an experimental sample of the hardware and software complex have proven its operability and high sensitivity with sufficiently high linearity of characteristics and noise immunity.**

***Keywords*— optical cable, monitoring, optical losses, hardware and software complex, optical fiber, deformation, light spot.**

I. Introduction (*Heading 1*)

The rapid development of fiber-optic technologies has almost completely replaced copper conductors with optical ones. However, despite all their advantages, there are a number of unsolved problems. Telecom operators must have means of centralized control over the state of intra-zone fiber-optic transmission lines to quickly respond to their damage and guarantee the protection of transmitted information against unauthorized access. The development of a hardware and software complex for monitoring the technical state of cables is an extremely urgent task for intra-zone telecommunication systems. Currently, there is no intelligent system capable of monitoring damage or reduced throughput of fiber-optic cables in real time.

There is a lot of information in literature of optical fibers, fiber optic transmission lines, and telecommunication guide systems using fiber optic technology [1-4]. A fiber optic sensor requires a light source, such as a laser or LED, to emit a light wave. This wave passes through the sensor and hits a photodetector, where the optical signal is converted into an electrical signal. The operating principles, the design, the history, and applications of fiber optic sensors (FOS) are well documented in literature [5-6]. An optical fiber does not emit electromagnetic fields during the data transmission, making it impossible to intercept the information. This has given it a reputation as a highly secure means of communication. However, with the development of new anti-intrusion technologies, the situation has changed [7]. A review of the existing systems of monitoring and controlling the technical condition of extended objects using fiber optic systems has already been conducted previously, and the results have been published [8-10].

The proposed hardware and software complex for monitoring the technical state of cables (HSCTS) uses a single-mode optical fiber. This type of fiber has a significantly lower attenuation coefficient compared to multi-mode fibers, while this type operates on extended objects up to 50 km. When using a multi-mode optical fiber of the G.651 standard, the interference level is significantly lower compared to a single-mode fiber of the G.652 standard. However, due to distance limitations, a multi-mode fiber cannot be used in the further studies.

Damage to fiber-optic cables (FOC) and switching optical equipment can be caused by construction work or soil excavation, i.e., when the human factor causes it; by foundation erosion or soil subsidence; by cable rupture due to an external mechanical impact; as a result of theft or attempted unauthorized access, and by the other man-made causes. The circuit of the hardware and software complex for monitoring the technical state should have the function of monitoring the technical state of the FOC by measuring additional losses and providing protection against unauthorized access. The circuit will also include an optical reflectometer that is an effective tool for accurate detection and localization of the FOC damage. The circuit of the hardware and software complex for monitoring the technical state will consist of two blocks: one of them is designed for optical-digital analysis of the light spot characteristics, and the other one is for analyzing changes in the reflectogram parameters.

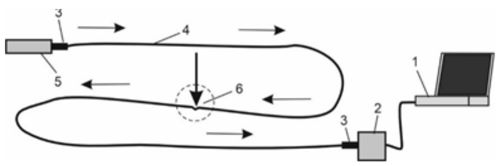
The Optical Time Domain Reflectometer (OTDR) reflectometry method has also been used by other researchers for monitoring the technical condition and protecting the perimeters of extended objects. The proposed scheme highlights such advantages as low power consumption, the presence of a distributed fiber-optic sensor, and high immunity to electromagnetic interference. Since the fiber-optic cable can be laid on supports near high-voltage power lines, the automated monitoring and technical condition system must be adapted to these conditions.

II. RESEARCH METHODS AND EXPERIMENTAL PART

In previous studies [11], the dependence of increasing additional losses on the increase in the load on the lateral face of the optical fiber was investigated. When mechanically acting on the lateral face of the fiber of the ITU-T G.652.D standard, a photoelastic effect occurs that , leads to changing the refractive index..

To control additional losses and light transmission in the optical fiber, a set of equipment consisting of two devices was used. The first one is a VIAVI (JDSU) SmartPocket OLS-34 optical radiation source (USA) with the range of 900-1625 nm and the deviation of ±10 nm. The details of its technical characteristics can be found on the website [12]. The second device is a VIAVI (JDSU) SmartPocket OLP-38 optical power meter (USA) that has the absolute measurement error of ±0.2 dB (±5%) and the wavelength range of 780 to 1650 nm. The information of its characteristics can be found on the website. To measure additional losses and backscatter, an OTDR model YOKOGAWA AQ1200E from a Japanese manufacturer was used. To minimize the dead zone effect, a compensation coil with the 0.2 km long optical fiber was included in the system.

To develop a fiber-optic sensor of the distributed or quasi-distributed type, several components are required: a radiation source, an optical fiber, and a data processing unit with a device for outputting information. A simplified diagram of the fiber-optic sensor is shown in Figure 1. If the impact is exerted on the optical fiber at the point of occurrence of microbend 6, where the beam leaks into the surrounding space, then the lost part of the light wave will represent additional losses. In this case, the greater the additional losses, the lower the intensity, and this dependence is direct and obeys the linear law. The arrows in the diagram show the path of the light wave along the optical fiber.



1 - personal computer with software; 2 - data processing device with photodetector; 3 - optical connector; 4 - optical fiber, 5 - radiation source (semiconductor laser) with the wavelength of 650-1550 nm; 6 - point of mechanical action on the optical fiber

Figure 1. A simplified diagram of the optical fiber sensor.

Then the hardware and software complex for monitoring the technical state processes the data and provides a numerical solution. It filters random interference and identifies it. The proposed optical-digital analysis method evaluates changes in the pixel pattern of the light spot along the optical fiber shell.

The refractive indices of optical fiber (OF) correspond to the inequality $n_1<n_2 n_1<n_2$, where the values for the core are n_2=1.4625, n_2=1.4625, and for the cladding n_1=1.4570, n_1=1.4570. The density of the cladding is lower than that of the core. Semiconductor lasers with the wavelength of 650, 850, 1310 or 1550 nm can be used for the operation of the fiber-optic sensor. The optical wave passes through the OF, and when mechanically acted upon, the properties of the light wave change, which is recorded by a photodetector. The photodetector then converts the optical signal into the electrical signal, after which the signal enters the data processing and output device.

The key aspect of the study is the development of a new technical solution and approach to data processing that will provide a fundamentally important difference from already widely studied and well-known methods, such as optical interferometry, reflectometry and fiber Bragg gratings. In this case, the concept of optical-digital analysis of the light spot parameters located on the surface of the photomatrix is used. In this case, the photodetector is located at the end of the optical fiber, at its output. An increase in optical losses in the optical fiber can be detected using a photomatrix. The use of a photomatrix is the key difference from the use of a single-pixel photodetector, which is the basis of existing methods. HSCTS monitors changes in the parameters of the light spot along the cladding, while changes in the intensity of the core light spot are completely excluded from the analysis.

Figure 2 shows a screenshot from a computer screen with a positive and negative image of a light spot. Two areas are highlighted on the negative: area 1 corresponds to the image of the optical fiber core, and area 2 to the image of its cladding.

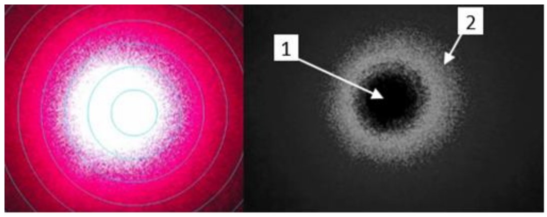


Figure 2. A PC image on the surface of the photomatrix.

For adequate operation of the HSCTS, it is necessary to ensure the semiconductor laser stability using a current and voltage stabilizer. The permissible deviation of the wavelength of the radiation source should not exceed 5 nm. It is also important that the laser is coherent. It has been established that with increasing the length, attenuation in the optical fiber decreases. This factor should be taken into account if the fiber-optic communication line has a significant length.

The HSCTS transforms changes in the light spot parameters, recording the level of additional optical losses when changing its intensity and forming a modified pixel pattern. Figure 3 shows how external influence affects the pixel pattern of the light spot.

Figure 3. A PC screenshot.

Increasing the force applied to the optical fiber causes the pixels to change color from black to white. The stronger the force applied to the fiber optic line, the more microbends occur and the higher the level of additional losses [13]. It is worth noting that the light spot has irregularities in its outlines, especially noticeable at the boundary between the core and the sheath of the optical fiber. The HSCTS allows distinguishing between impacts on the fiber optic line and evaluating interference caused by external factors, such as temperature changes or gusts of wind. The proposed HSCTS system provides high protection of measuring channels against interference. It analyzes changes in the pixel pattern of the light spot and signals the alarm in case of detecting unauthorized access.

As the impact strength increases, a more significant transition of pixels from black to white is observed. During the experiments, several cases were recorded when the impact exceeded the established limits. In such situations, there was triggered the alarm designed to protect against unauthorized access. The HSCTS has a step-by-step sensitivity change function, which is especially important for taking into account external interference.

Optical adapters and SC connectors with the ferrule of 2.5 mm in diameter were used to connect fiber-optic cables. Optical power losses at each connection did not exceed 0.3 dB. To monitor reliably the condition of the cables and to ensure data accuracy, it was necessary to configure an automated technical state monitoring system.

The automated technical state monitoring system (ATMS) was developed based on compiled statistically typed programming languages. The development process used a version of Python and components of the OpenCV (Open Source Computer Vision Library) library. The controlling and measuring optical channels could be configured in different ways, both identically and with slight differences in settings. Figure 4 shows the HSCTS interface operating in a dual-channel mode with two fiber-optic sensors.

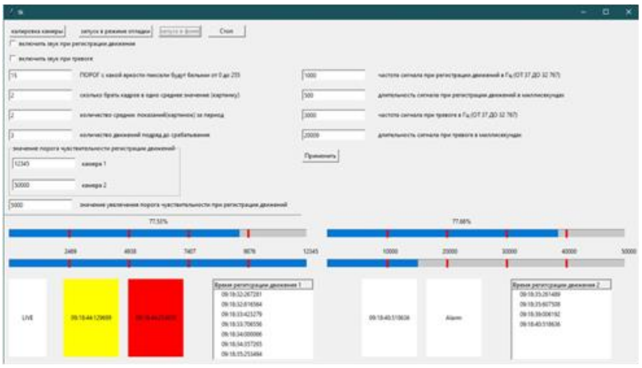


Figure 4. A HSCTS interface.

The technique allows tracking changes in the derivative of the light spot intensity and the increase in additional losses over a set time. HSCTS is capable of monitoring not only the intensity of the light spot but also its shape. It performs the numerical analysis of the level of additional losses in the optical fiber during microbending in real time.

The HSCTS and FOS were calibrated using a force-reproducing machine that is used to verify and calibrate various strain gauges. This machine is in a good working order and undergoes regular verification. The HSCTS was prepared for field testing at real objects of the telecommunications network of the Kazakhtelecom JSC (Figure 5) [14].

During the tests, a four-channel HSCTS was used, to which four quasi-distributed FOSs and one distributed sensor were connected.

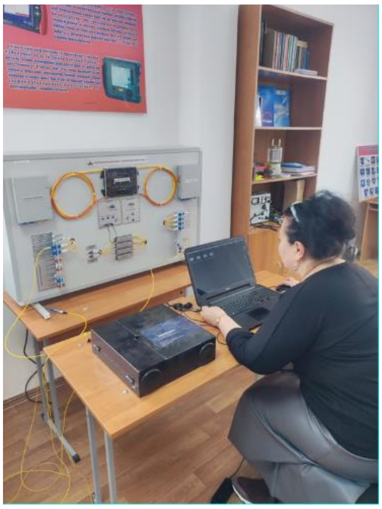


Fig. 5. Conducting tests.

III. CONCLUSIONS

The results of testing the HSC sample confirmed its operability and demonstrated high reliability when triggered for a quasi-distributed fiber-optic sensor affecting one of four zones (1-4). The accuracy of determining the damage zone of the fiber-optic cable was also confirmed.

The HSCTS can be designed in different layout options and with a different number of channels, depending on specific circumstances and production needs. In such cases, various factors and operating conditions are taken into account. Thus, the HSCTS configuration is selected based on the real conditions of the telecommunications network.

The probability of the system triggering reached 0.87 when affecting the fiber-optic cable, which corresponds to the response error of within 13%. In the future, it is planned to increase the probability of response to 0.9, while simultaneously reducing the probability of false response to 0.1.

ACKNOWLEDGMENT *(Heading 5)*

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ABBREVIATION

FOS - fiber optic sensors.
HSCTS - hardware and software complex for monitoring the technical state of cables.
OTDR - Optical Time Domain Reflectometer.
FOC - fiber-optic cable.
ATMS - automated technical state monitoring system.
OF - optical fiber.

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