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METHOD OF CONTROL THE MECHANICAL STATE OF THE OPTICAL FIBER OF THE DIELECTRIC SELF-SUPPORTING OPTICAL CABLE DURING OPERATION

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ABSTRACT

Context. One of the issues of theoretical and practical research studying phenomena that occur over time and lead to violations of the normative work of optical cables (OC) are ways to ensure and control their reliability during operation.

Today, electronic communication (telecommunications) has already gained significant integration and widespread use due to the urgent need to exchange large volumes of information between users or network devices at high speeds and over long distances, as well as the provision of a wide range of electronic communication services.

The electronic communication service has a high level of demand and consists in receiving and/or transmitting information through electronic communication networks, which is transmitted using electronic communication networks and services.

In an electronic communication network, the transmitting/receiving of optical signals is provided by the fiber optic transmission system (FOTS). It is capable of converting electrical signals from a variety of digital devices into optical signals and transmitting them over fiber-optic communication lines (FOCL), which is the main transmission medium in an electronic communication network.

The problem of ensuring the reliability of the FOCL, which includes a wide range of issues related to the development and production of all its elements, design, construction and technical operation of the communication line, continues to gain more and more importance.

In general, the transmitting/receiving of information between end users equipment, communication nodes, network devices (servers, databases, etc.) takes place through an electronic communication network.

Normative and technical documentations for fiber-optic communication lines regulates the control of the mechanical state of the optical cable during operation, but do not provide the full control of the mechanical state of the optical fiber to ensure the quality and reliability of the line during the specified service life.

As known, to ensure the reliability of the optical cable, as a rule, the permissible elongation of the optical fiber (OF) is $\varepsilon_{p\mathrm{OF}} < (0.2...0.25)$ %, adopted during the designing of the cable. However, during operation, the appearance of multiple excess of elongations exceeding these values is possible in the fibers.

Thus, the development and substantiation of methods for evaluating the mechanical characteristics of a dielectric self-supporting optical cable (DSOC) and the method of full control of the mechanical state of the optical fiber is necessary. The last can lead to premature failure of the optical fiber.

Objective. Development and substantiation of the method of control the mechanical state of an optical fiber of the suspended DSOC, as well as assessment of the conditions of deformation of optical fibers in its core with the appearance of longitudinal tensile/compressive loads during operation.

Method. Two ways of evaluating the mechanical characteristics of DSOC and the method of control the mechanical state of its fibers have been developed and proposed. For this, the following characteristics of the cable and fiber are adopted in the work: relative elongation of the cable and fiber (ε_{cx}, $\varepsilon_{\mathrm{OF}x}$), span length ($L_{\mathrm{s}x}$) of the line, cable sag in the span (f_x) and tensile load (TL) of the cable (F_{tlx}), which causes longitudinal deformation ε. At the same time, the method proposes to control the mechanical state of the optical fiber during the operation of the DSOC by determining its effective relative elongation according to the mechanical, physical and climatic conditions of the line location.

In the paper, it is proposed to measure and calculate the following mechanical characteristics, due to the developed reference data for the selection of the cable type and the climatic zone of the line location, measuring equipment and mathematical tools:

- equivalent mechanical tension in DSOC;
- calculated and actual cable sag in the span;
- actual effective relative elongation of the cable;
- actual tensile load acting on the cable.

The ways and method presented in the work allow a complete evaluation of the mechanical characteristics of the cable and control of the mechanical state of the optical fiber during operation of the DSOC. It creates an opportunity to monitor its changes to prevent the appearance of excessive loads during operation and failure of the fiber-optic communication line.

It is possible to recommend this method for use by relevant departments for technical operation of telecommunication lines and networks based on hanging optical cables.

Results. The work presents the results of the development and justification of the method of control the mechanical state of optical fibers of dielectric self-supporting optical cables during operation. For example, using the developed method, it is shown that in the cable OKL-3-D2A14 produced by PJSC “Odeskabel” in the conditions of the Odesa climate zone (Black Sea region), optical fibers with a span length of 100 m are subject to elongation by 0.16 %, and DSOC is subject to an actual tensile force of 2.722 kN. This result of the control of the mechanical state of the OF established that such span of the line ensures its mechanical integrity within the limits of the permissible deformation of 0.25 % adopted in the design of the cable, but exceeds its permissible tensile load of 2.6 kN.

Conclusions. The scientific novelty of the work results is that, for the first time ways of fully evaluating the mechanical characteristics of the DSOC during operation and the method of fully control the mechanical state of its optical fiber have been developed. It allows to monitoring changes in the mechanical state of the optical fiber of the cable.

KEYWORDS: relative elongation, dielectric self-supporting optical cable, optical fibers, mechanical stresses, longitudinal tensile load, physical and climatic loads.

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ABBREVIATIONS

FOCL is a fiber-optic communication line;

OC is an optical cable;

OF is an optical fiber;

DSOC is a dielectric self-supporting optical cable;

TL is a tensile load;

OFOCL is an overhead fiber-optic communication line;

CSE is a central strength element;

PSE is a peripheral strength element;

RTD is a domestic regulatory and technical documentations;

ADSS is an All-Dielectric Self-Supporting cable;

BR is a Brillouin reflectometer;

MPTL is a maximum permissible tensile load;

FR is a fiberglass rods;

AT is an aramid thread;

MPC is a maximum permissible relative elongation of a cable;

OM is an optical module tube of a cable.

NOMENCLATURE

$\varepsilon_{p\mathrm{OF}}$ is a permissible elongation of the optical fiber;

$\varepsilon_{ex\mathrm{OF}}$ is an excess length of the optical fiber;

ε_{pcx} is a permissible elongation of the optical cable at some condition;

ε_{cx} is a relative elongation of the cable at some condition;

ε_{apcx} is an actual additional relative elongation of the cable under certain climatic conditions;

ε_{mpc} is a maximum permissible relative elongation of a cable;

$\varepsilon_{\mathrm{OF}x}$ is a relative elongation of the fiber at some condition;

L_{sx} is a span length of the line at some condition;

f_x is a cable sag arrow in the span at some condition;

F_{tlx} is a tensile load of the cable at some condition;

F_{mtl} is a maximum permissible tensile load;

ε is a longitudinal elongation;

P_c is a weight of the cable;

D_c is a diameter of the cable;

α_{OC} is a temperature coefficient of linear expansion of the cable;

E_{eq} is an Young's modulus of the cable;

υ is a wind pressure;

Δt_h is a thickness of hoarfrost;

Δt_i is a thickness of ice;

σ_1 is an equivalent mechanical stress of the cable;

L_s is a length of the span of the OFOCL;

γ_1 is a specific load of the own weight of the cable;

f is a cable sag arrow in the span;

S is a cross-sectional area of the cable;

n is an overload factor;

σ_x is a equivalent mechanical stress;

γ_x is a specific load on the cable under physical and mechanical conditions of the climatic zone;

t_x is a cable temperature under certain conditions;

S_{SE} is a cross-sectional area of all strength elements of the cable;

g is a Galilean constant;

h is a dimensions of the OFOCL in the span;

R is a radius of the spiral arrangement of the element around the CSE;

ΔR is a distance between OF (or OF bundle) and the inner surface of the wall of OM tube;

h_s is a step of spiral laying of elements (OM or filler element) of the cable core around the CSE;

σ_{ax} is an actual mechanical stress of the cable along the length of the line span;

f_{ax} is an actual cable arrow sag in the span of the line;

F_{atlx} is an actual tensile load of the cable under the influence of certain conditions of the operating environment;

σ_{ax} is an actual mechanical stress of the cable obtained by measuring f_{ax};

σ_{axc} is an actual mechanical stress of the cable obtained by calculating f_{axc};

f_{ax} is a measured arrow of cable sag in the span of the line;

f_{axc} is a calculated arrow of cable sag in the span of the line.

INTRODUCTION

During the operation of a dielectric self-supporting optical cable, its optical fiber, as a rule, is under certain local or distributed along its length mechanical loads that create mechanical stresses. The mechanical stresses of the DSOC itself, suspended on the supports of the overhead fiber-optic communication line (OFOCL), appear under the influence of mechanical (cable weight, the radius of its bending in the clamps of the pole) and physical and climatic factors of the operating area (temperature, wind pressure, hoarfrost, ice, etc.). As known, changing the longitudinal mechanical actions on the cable leads to its tension or compression, that is, changes in its span length, sag and tensile load. Therefore, when choosing the design of the DSOC and calculating the conditions for its suspension and operation, it is necessary to take into account the constant action on the cable of mechanical, physical and climatic factors of the location of the OFOCL. At the same time, ensuring the proper technical condition of the line during the expected service life requires monitoring, first of all, the mechanical characteristics of the cable.

In turn, the sag of the DSOC in the span of the line under the worst conditions of its operation makes it possible to check the actual tension in the cable according to the value of the initial tension, which was during the building of the line. Therefore, during the year, the operation of the OFOCL takes place with a change in the mechanical condition of the DSOC and its fibers.

A complete assessment of the mechanical condition of the DSOC is based on the determination of the specific loads on the cable in the span of the OFOCL and its mechanical characteristics. The action of excess stresses in the optical fiber leads to the appearance of multi-zonal cracks in its material, which eventually destroy it, thereby reducing its service life. In general, ensuring the quality and reliability of the line during the specified period of

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operation requires monitoring the mechanical characteristics of the cable and the mechanical state of the fiber in combination with its maintenance.

Control of the mechanical state of the optical fiber during cable monitoring should be simple and easily accessible to the line operator's linear personnel.

In the regulatory and technical documentations for the projecting, building and operation of the OFOCL, there are no ways for assessing the mechanical characteristics of the DSOC and the method of control the mechanical state of its optical fiber. Therefore, the development of a method for improving the control of the mechanical state of optical fibers of dielectric self-supporting optical cables along the length of the OFOCL span is necessary and timely.

The object of study is the control of the mechanical state of the optical fiber of a dielectric self-supporting optical cable with a central strength element (CSE) made of a fiberglass rod and a peripheral strength element (PSE) made of aramid threads during the operation of the DSOC of the electronic communication network.

The subject of study is the mechanical state of the optical fiber of the DSOC, depending on the length of the OFOCL span and the conditions of its location in the electronic communication network.

The purpose of the work is development and justification:

– ways of assessing the mechanical characteristics of the DSOC along the length of the OFOCL span during operation;

– the method of control the mechanical state of the optical fiber of cable;

– analysis and discussion of the results of research of DSOC and its fiber according to the developed ways and method.

1 PROBLEM STATEMENT

Suppose there is DSOC model with a modular design, which contains a certain number of optical fibers and has technical characteristics that depend on its design features and purpose. First of all, these are: weight P_c and diameter D_c of the cable, equivalent temperature coefficient of linear expansion of the cable α_{OC} and the Young's modulus of the cable E_{eq}, permissible relative elongation of the cable ε_{cx} and fiber $\varepsilon_{\mathrm{OF}x}$, maximum permissible tensile load of the cable F_{tlx}. Such DSOC will be suspended on the poles of the OFOCL in a certain climatic zone of operation, which is characterized by the length of the line span L_{sx}, the cable sag arrow in the span f_x, the range of environmental temperatures, the pressure of the wind υ, the thickness of hoarfrost Δt_h and ice Δt_i at the worst climatic conditions. Under the influence of mechanical, physical and climatic loads, excessive loads may appear in the structure of the cable and optical fiber, which can lead to fiber breakage and failure of the communication line.

The task of control the mechanical state of the optical fiber and cable, determining the suitability of DSOC for successful operation in such climatic zone consists in determining and monitoring the implementation of the following conditions: $\varepsilon_{\mathrm{OF}x} < \varepsilon_{p\mathrm{OF}}$, $F_{tlx} \leq (0.65...0.70)F_{mtl}$.

In turn, the problem of assessing the mechanical state of the optical fiber and DSOC consists in that it is necessary to determine the actually acting loads on the OF and DSOC, which depend on the physical and climatic conditions of OFOCL operation, i.e. $\varepsilon_{\mathrm{OF}x}$, $F_{tlx} = f\,(P_c, D_c, \alpha_{\mathrm{OC}}, E_{eq}, L_{sx}, f_x, t_x, \upsilon, \Delta t_h, \Delta t_i\,)$.

For this purpose, it is necessary:

– to create a reference base of the method with the geometric and structural parameters of the DSOC elements, equivalent temperature coefficient of linear expansion α_{OC} and Young's modulus E_{eq} of the cable, physical and climatic conditions of operation;

– to develop and justify ways of assessing the mechanical characteristics of the DSOC during operation and the method of control the mechanical state of its optical fiber;

– analyze the results of control the mechanical characteristics of the DSOC along the length of the line span and, based on the values of the relative elongation of the optical cable, give conclusions about the mechanical state in the selected climatic zone;

– to determine the value of the actual mechanical characteristics of the DSOC and the mechanical state of its optical fiber;

– analyze the results of control the actual mechanical state of the optical fiber.

2 REVIEW OF THE LITERATURE

Analysis of international and domestic regulatory and technical documentations (RTD) and number of works by well-known authors in the field of fiber-optic communications, in particular, the development, production and operation of optical cables [1 – 12] showed the lack of completeness of research in this direction, and especially in the field of control of mechanical state of an optical fiber in DSOC during operation.

Thus, in the IEEE international standard "Standard for Testing and Performance for All-Dielectric Self-Supporting (ADSS) Fiber Optic Cable for Use on Electric Utility Power Lines" [1] there are requirements for the design, mechanical, electrical and optical characteristics of DSOC used on suspended engineering networks. Special attention is paid to maintaining proper optical fiber reliability and assessing overhead power line sag using a simple optomechanical system with optical fiber parameters.

In [2] it is shown approaches and recommendations for the selection of materials and the calculation of modular structures of cables and, first of all, strength elements in accordance with the requirements of international standards. The authors of the paper [3] proposed the method of evaluating the economic efficiency of multi-module optical cable designs based on mass-dimensional indicators, the results of which can be used for the selection of DSOC when designing OFOCL.

Some foreign and domestic authors [4–6] paid some attention to the study of some of the mechanical charac-

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teristics of DSOC and control of the mechanical state of the optical fiber. As it is known, during the projecting, building and operation of the OFOCL, the assessment of the mechanical characteristics of the DSOC and the control of the mechanical state of the optical fiber are necessary. However, the results of studies in [4, 5] of the stresses of the DSOC and the mechanical state of the optical fiber under the influence of tensile forces and the operating temperature of the line are insufficient. The last is proof of the need for a full assessment of the mechanical characteristics of DSOC and control of the mechanical state of the optical fiber.

Real elongation of an optical fiber can be both short-term and long-term. It can reach an undesirable value during cable operation, that is, greater than the calculated value in the cable design [5].

In [6], the results of the study of the influence of mechanical stress in a special single-mode optical fiber, which can maintain the state of polarization of transmitted light and have the ability to resist the effects of the environment, are presented. These results also confirm the need to control the mechanical state of the optical fiber of the DSOC during the operation of the OFOCL.

In addition, the current regulatory and technical documentations of Ukraine on the projecting, building and operation of OFOCL provides for compliance with the required technical state of the cable and its fiber. In the rules for the arrangement of electrical installations [7], it is recommended to perform the calculation of the mechanical state of the DSOC based on the value of the design loads using the allowable stress method, taking into account the residual deformation in the cable and the allowable loads on the fiber.

The regulatory and technical document of Ukraine in recommendations for hanging optical cables P 45-010-2002 [8] provides recommendations for hanging optical cables on the supports of overhead lines, power lines, railway contact networks and recommends cables with maximum tensile and crushing loads that have an increase in the coefficient OF attenuation is no more than 0.05 dB. The last also requires monitoring of the mechanical state of the DSOC and its fibers during the operation of the OFOCL.

In [9, 10], the method of control the reliability of an optical cable using a Brillouin reflectometer (BR) is shown, which works on the basis of the method of reproducing the physics of the effect of multi-zone cracks in the quartz fiber material. Depending on the stress in the material and the area of its location, the reliability and service life of the OFOCL is evaluated. In general, by BR establishes the nature of the dependence of the service life of an optical fiber on its tension, namely on the action of stresses.

The main drawback of the method is the complexity of operating the reflectometer and its cost, which is beyond the reach of most operators of fiber-optic communication lines.

Thus, the review of literatures sources shown that in a limited number of works the requirements and methods of assessment and even monitoring of some mechanical characteristics of the optical cable in the span of OFOCL are given. But they do not give a full assessment of the mechanical state of the DSOC and its optical fiber. In this regard, the development and substantiation of a cheap and easily accessible method of controlling the mechanical state of OF in DSOC during operation is necessary.

3 MATERIALS AND METHODS

To begin with, it is necessary to perform theoretical foundations of the method.

The peculiarity of the operation of DSOC suspended on the poles of OFOCL, compared to the operation of cables laid, for example, in the soil, in cable ducts, etc., is the effect on them of dynamic mechanical, physical and climatic loads. As noted earlier, these loads cause a change in the length of the cable in the span between the line supports and the appearance of its mechanical tensile (compression) of stresses. The last makes it necessary to determine the cable sag in the span and the tensile load to which it corresponds.

The conditions for hanging the DSOC and its mechanical state during operation are determined by the values of: cable mechanical stress (σ_{cx}), relative elongations of the cable and its optical fiber (ε_{cx}, $\varepsilon_{\mathrm{OF}x}$), span length ($L_{sx}$), sag ($f_x$) and tensile load (TL) of the cable (F_{tl}), which is caused by the longitudinal deformation ε. At the same time, under any operating conditions, it is necessary to ensure that the tensile force of the cable F_{tlx} is less than its maximum permissible tensile load F_{mtl} (MPTL), which is indicated in the technical conditions, i.e. $F_{tlx} \leq (0.65...0.70) \cdot F_{mtl}$. In turn, the tensile loads acting on the structure of the DSOC will make it possible to determine the mechanical state of the OF in the core of the cable and its changes.

According to, for example, [11] hanging and installation of communication network cables can be carried out at temperatures from minus 5 ºC to plus 50 ºC, and operation – from minus 40 ºC to plus 70 ºC. In addition, different designs of DSOC provide different values of the maximum allowable tensile loads due to central and peripheral strength elements or their combination. This is due to the difference in the conditions of their suspension and operation (length of span, climatic conditions, etc.).

In the absence or effect of external physical and climatic loads (hoarfrost weight, ice weight) on the cable, in addition to when it is affected by its own weight and the temperature of the environment, it is possible to evaluate the mechanical state of the DSOC structure by the of sag arrow in the line span during operation. In order to control the mechanical state of the optical fiber, it is necessary to perform calculations of the sag arrow f_x for an extended temperature range (–5...+70) ºC. It is possible to estimate the results of the f_x calculations based on the data of its measurements using special equipment. In addition, the measured values of f_x make it possible to find out about the value of the actual mechanical stress σ_{ax} (or longitudinal deformation ε_{ax}) in it and to determine the actual tensile load acting at this moment. This will make it possible

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to monitor changes in the mechanical characteristics of the cable over time to prevent the appearance of excessive TL and breakage of optical fibers.

In order to solve the given problem, it is possible to choose the following modular constructions of DSOC as a research subject, which contain:

– CSE and PSE from fiberglass rods (FR);

– CSE from fiberglass rods and PSE from winding aramid threads (AT).

Since the ways of assessing the mechanical state of these cable structures are the same, and the results will differ only due to the values of their equivalent temperature coefficient of linear expansion and Young's modulus of the cable, the second structure of the DSOC was chosen for research.

At the same time, the following assumptions are accepted in the work:

– fiberglass rods work within the limits of elastic deformation;

– the relative longitudinal elongation of aramid threads creep is not taken into account in the calculation of the PSE tensile load;

– the cable suspension points on the overhead line are at the same height.

As an example, let's solve the given problem for a cable produced by PJSC "Odeskabel" (Fig. 1), which is suspended on a OFOCL located in the conditions of the Odesa climate zone.

In this work, the following expressions are used to estimate the specific loads of the DSOC and its mechanical characteristics during operation.

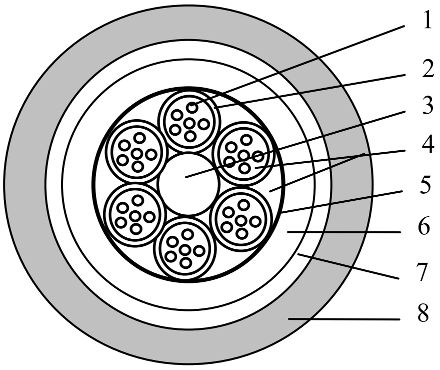

Figure 1 – Design of DSOC with strength elements from FR and AT: 1 – optical fiber; 2 – optical module tube (OM); 3 – CSE (fiberglass rod); 4 – filling compounds; 5 – fastening element; 6 – intermediate shell; 7 – PSE (winding of aramid threads); 8 – outer shell

The equivalent mechanical stress σ_1, which appears in the cable due to its suspension and the action only the self-weight of the DSOC, can be determined using the transformed formula for determining the sag arrow [11]:

$$\sigma_1 = \frac{L_s^2 \gamma_1}{8f} . \tag{1}$$

The last expression is valid with sufficient accuracy for engineering calculations when the cable is suspended at the same heights.

The specific loads on the DSOC ($\gamma_1 ... \gamma_7$) characterize the physical and climatic loads on the cable under operating conditions and include the load from its own weight, wind pressure, the weight of hoarfrost and ice.

The specific load from the self-weight of the DSOC can be determined by the expression [11]:

$$\gamma_1 = \frac{P_c}{S} n . \tag{2}$$

It is possible to determine the equivalent mechanical stress in the DSOC σ_x under the influence of physical and climatic loads using the equation of state of the suspended cable in the span under the condition of the equality of the suspension points (Fig. 2) [11]:

$$A\sigma_x^3 + B\sigma_x^2 + C = 0 . \tag{3}$$

here $A = \left(1 + \alpha_{\mathrm{OC}}(t_x - t)\right)\left(1 + \frac{L_s^2 \gamma_1^2}{24\sigma_1^2}\right)$;

$$B = \left(1 + \alpha_{\mathrm{OC}}(t_x - t)\right)\left(\frac{L_s^2 \gamma_1^2 E_{eq}}{24\sigma_1^2} - \frac{L_s^2 \gamma_1^2}{24\sigma_1} - \sigma_1\right) +$$

$$+ \alpha_{\mathrm{OC}} E_{eq}(t_x - t); \; C = \frac{-L_s^2 \gamma_x^2 E_{eq}}{24} .$$

It is possible to solve equation (3) to find the values of the equivalent mechanical stress in the presence and absence of external climatic loads using the Cardano formula.

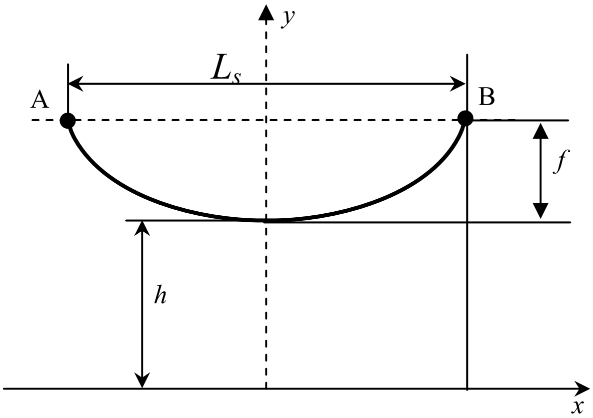

Figure 2 – The sag of the DSOC in the span of the OFOCL with the same height of the suspension points A and B (L_s – the length of the span, f – the arrow of the cable sag, h – the dimensions of the OFOCL in the span)

The magnitude of the sag of the DSOC f_x on the length of the span L_s with the known equivalent mechanical stress under certain external climatic influences σ_x and the specific load γ_x can be determined by the expression [11]:

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$$f_x = \frac{L_s^2 \gamma_x}{8\sigma_x}. \qquad (4)$$

Based on the obtained value of the equivalent mechanical stress σ_x in the suspended DSOC, which is under the influence of certain mechanical and physical-climatic loads, it is possible to determine the value of the tensile load of the cable F_{tlx} of the cable according to the expression [11]:

$$F_{tlx} = \sigma_x \cdot S_{SE} \cdot g. \qquad (5)$$

The last makes it possible to check the correspondence of the F_{tlx} value to the MPTL value of the cable.

According to [5, 11], the permissible equivalent mechanical stress in the DSOC acquires its maximum value under the action of the cable's own weight and the highest or lowest temperature, depending on the type of design of the DSOC. Thus, the construction of the DSOC, which is shown in Fig. 1, has the greatest value of permissible equivalent mechanical stress at the minimum temperature, and the cable design with strength elements made of fiberglass rods – at the maximum.

In the DSOC selected for research, this is due to the presence in the design of elements with different temperature coefficients of linear expansion of materials. Due to the presence of PSE from aramid threads, a tensile stress appears in it at negative temperature, which compensates for the total mechanical compressive stress of all other elements of the cable. In the design of the DSOC with strength elements made of fiberglass rods, the TCLE of the materials of all elements is positive, which explains the change in the equivalent stress of the cable in proportion to the operating temperature.

Since the compatible elements in the design of the DSOC are in close contact with each other, its mechanical properties can be equated to the mechanical properties of a continuous linear element. Then, with relative elongation/compression (deformation), the equivalent mechanical stress of the cable, according to Hooke's law, will be equal to:

$$\sigma_x = \varepsilon_{pcx} \cdot E_{eq}. \qquad (6)$$

Thus, with the help of (6), it is possible to calculate ε_{pcx} and evaluate the deformation processes in the cable and the mechanical state of the OF in it. Therefore, ε_{pcx}, which characterizes the processes of elongation/compression, allows us to estimate the permissible change in the length of the DSOC when acting on it by a longitudinal mechanical force. At the same time, the main task of the OC design is to ensure during operation that no mechanical stress is applied to the optical fibers located in the core of the cable. That is why the DSOC designs with loose tube cable have gained the greatest use in the world. These designs of the cable allow to ensure its permissible relative elongation. It provides additional fiber length in the tube of the optical module before it begins to stretch under the action of tensile forces.

Therefore, the maximum allowable relative elongation of such a cable (MPC) ε_{mpc} is determined by its design features and the arrangement of OF in it. According to [2], it can be determined by the expression:

$$\varepsilon_{mpc} = \varepsilon_{pc} + \varepsilon_{ex\mathrm{OF}} + \varepsilon_{p\mathrm{OF}}. \qquad (7)$$

The permissible relative elongation of the cable ε_{pc} is determined by the expression given, for example, in [2, 5]:

$$\varepsilon_{pc} = -1 + \sqrt{1 + \frac{4 \cdot \pi^2 \cdot R^2}{h_s^2} \cdot \left(\frac{2\Delta R}{R} - \frac{\Delta R^2}{R^2} \right)}. \qquad (8)$$

Permissible relative elongation of OF $\varepsilon_{p\mathrm{OF}}$ is allowed within the limits of up to 0.25 % for the entire period of operation [2]. As a rule, in practice, during the development of OC $\varepsilon_{ex\mathrm{OF}}$ is taken equal to 0 in order to obtain a technological reserve for the permissible elongation of the cable.

Additional relative elongation of the cable under certain climatic conditions can be calculated based on expression (6):

$$\varepsilon_{pcx} = \frac{\sigma_x}{E_{eq}}. \qquad (9)$$

The actual additional relative elongation of the cable ε_{apcx}, suspended under certain climatic conditions on the OFOCL, can also be determined based on expression (6):

$$\varepsilon_{apcx} = \frac{\sigma_{ax}}{E_{eq}}. \qquad (10)$$

The measurement of the actual sag of the DSOC in the span of the OFOCL (f_{ax}) during the operation of the line makes it possible to determine the value of its actual mechanical characteristics. Thus, the actual mechanical tension of the cable, based on expression (1), can be determined by the formula:

$$\sigma_{ax} = \frac{L_s^2 \cdot \gamma_1}{8 \cdot f_{ax}}. \qquad (11)$$

In turn, the actual tensile load of the cable under certain climatic conditions can be determined by analogy to expression (5) using the formula:

$$F_{atlx} = \sigma_{ax} \cdot S_{\mathrm{SE}} \cdot g. \qquad (12)$$

The value of these mechanical characteristics of the OC will make it possible to estimate the actual elongation

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of the cable and the mechanical state of the optical fiber in it under certain climatic conditions.

Evaluation of the mechanical characteristics of the DSOC and control of the mechanical state of the OF along the length of the span of the OFOCL in the conditions of the given climatic zone require a number of reference data. These data include:

– cable brand and specifications;

– cable design characteristics (cable diameter D_c, weight of the cable P_c, equivalent temperature coefficient of linear expansion of the cable α_{OC} and Young's modulus of the cable E_{eq}, number and type of aramid threads and fiberglass rods from their TCLE, permissible relative elongation of OF in the cable $\varepsilon_{p\text{OF}}$ according to the data of the manufacturer's factory);

– the span length of the OFOCL and the value of the sag boom of the DSOC during installation at t °C;

– physical and climatic characteristics of the area of cable operation (wind speed during hoarfrost and ice υ, maximum radial thicknesses of hoarfrost and ice walls Δt_h and Δt_i, maximum and minimum temperatures of the climatic area of cable operation);

– corresponding specific loads and mechanical characteristics of DSOC.

In the absence of data from the DSOC developer on α_{OC} and E_{eq}, their values are determined according to [12], and the value of $\varepsilon_{p\text{OF}}$ is taken as 0.25 %.

Determination of specific loads on DSOC is performed according to [11].

In this work, it is proposed to evaluate the mechanical state of the DSOC during operation by two ways:

– calculating according to expressions (1), (3)–(5) and (9);

– measuring and calculating according to:

a) the results of the measurement of the DSOC sag in the span of the OFOCL (f_{ax}) under the influence of $t = -5$ ºC, hoarfrost and ice without wind and its calculation (f_{axc}) at the temperature $t = -5$ ºC, hoarfrost and ice with wind;

b) calculation of its mechanical characteristics (ε_{apcx}, σ_{ac} and F_{atlx}) according to expressions (10)–(12).

When implementing the methods, the specific load γ_x is taken according to reference data of the OFOCL operator.

The last method can be implemented based on the results of the f_{ax} measurement during the maintenance of the OFOCL. Currently, some methods of its measurement using various equipment, including drones and unmanned aerial vehicles, are used.

According to the measured value of f_{ax}, there is the actual mechanical stress of the DSOC in the span of the line under the influence of temperature of minus 5 ºC, hoarfrost and ice without wind, and the calculated value of f_{axc} under the influence of temperature of minus 5 ºC and ice with wind. The value of the actual mechanical stress of the cable is found by the expression transformed from expression (4):

$$\sigma_{ax,axc} = \frac{L_s^2 \gamma_x}{8 f_{ax,axc}}. \tag{13}$$

Determination of the permissible relative elongation of the cable is carried out according to expression (10), and its tensile load – by (5).

Thus, the results of the evaluation of the mechanical characteristics of the DSOC during operation, obtained by the first way, should be considered as reference for the technical personnel of the OFOCL operator.

The results of the assessment of the mechanical characteristics of the DSOC obtained by the second way should be considered as actual, that is, those that must be used to monitor the mechanical state of the optical fiber.

This way was developed on the basis of an assessment of the actual mechanical characteristics of the DSOC during operation and the results of experimental studies:

– measurement of the actual cable sag in the span of the OFOCL and calculation of its value when the cable is affected by the temperature of $t = -5$ ºC, the weight of ice with wind pressure;

– calculation of the actual mechanical stress, additional elongation and tensile load of the cable at different span lengths.

The last made it possible to determine and establish the presence/absence of excessive tensile forces on the optical fiber in the cable.

According to the results of the calculation of the maximum permissible elongation of the cable (7), its permissible relative elongation – expression (8) – with the values of the permissible elongation of the OF and its excess length in the OM tube, according to the data of the developer of DSOC, it is possible to assess the mechanical state of the OF in the researched cable of the brand OKL-3-D2A14. Therefore, at the determined value of ε_{mpc}, a limit is obtained, i.e., the maximum elongation of the DSOC, the value of which, when compared with the elongation of the cable under certain mechanical and physical-climatic conditions, makes it possible to control the mechanical state of the optical fiber.

Therefore, the values of ε_{mpc} and ε_{apcx} obtained during the operation of DSOC create the possibility of control the mechanical state of both cable and optical fibers. The last makes it possible to monitor them and take preventive measures at the OFOCL to ensure its service life.

The value of the cable sag in the span of the OFOCL under the influence of the temperature of minus 5 ºC, ice with wind (f_{7i}) is calculated according to the parabolic curve of the dependence of f_{ax}, f_{axc} on the specific loads (γ_{3h}, γ_{3i} and γ_{7h}) of the OFOCL. An example of calculation f_{7i} is given in next chapter. Studies of the theoretical foundations of the method of control the mechanical state of OF were carried out with the help of software implementation in the Python environment in accordance with the graphic model presented in Fig. 3.

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4 EXPERIMENTS

Control of the mechanical state of OF and DSOC under the influence of current mechanical, physical and climatic conditions of operation requires:

1. Calculation of specific loads to DSOC.
2. Calculation of the equivalent mechanical stress of DSOC.

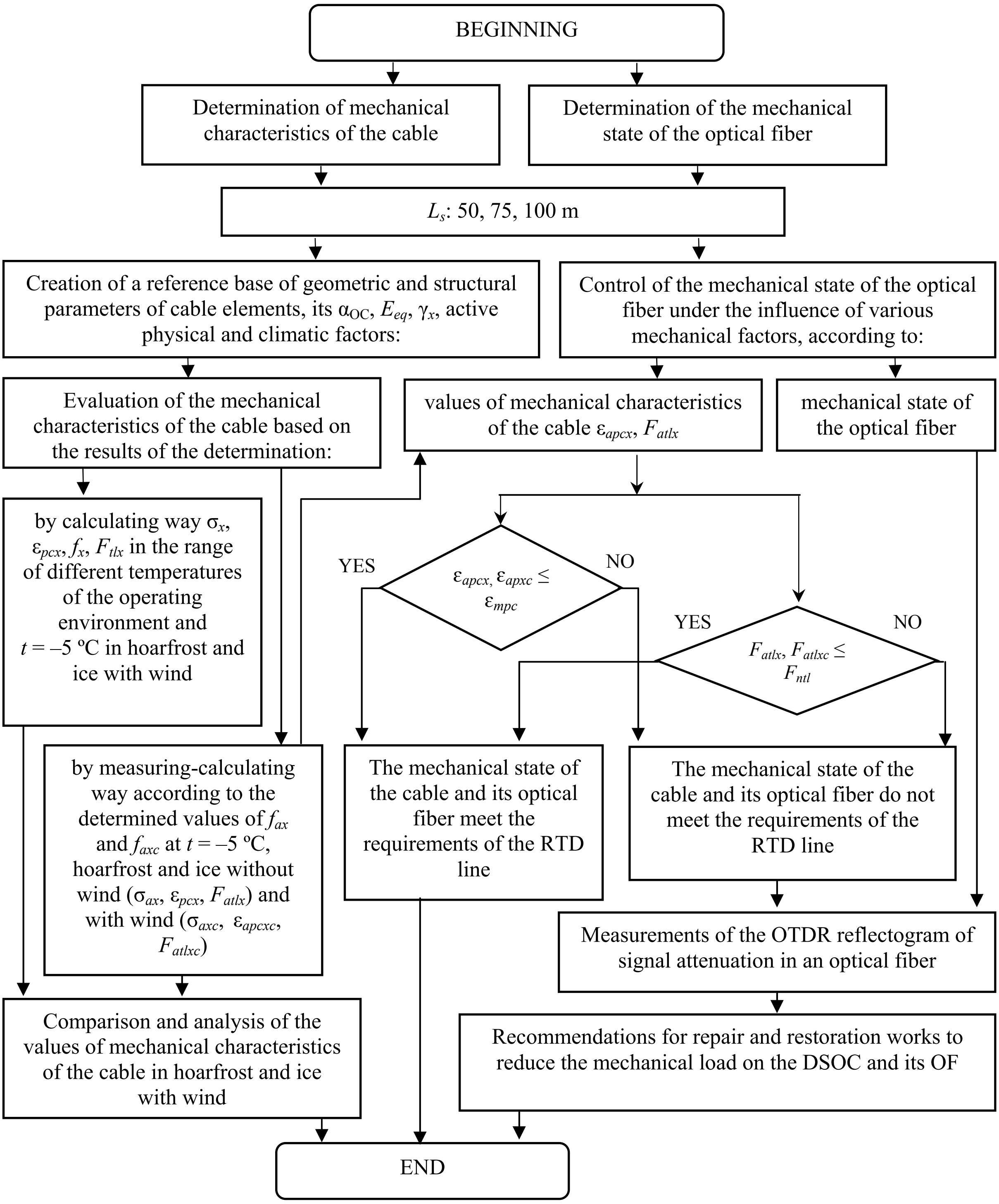

Figure 3 – Graphic model of the study by the method of control the mechanical state of the optical fiber depending on the cable brand and the climatic zone of operation

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3. Determination of the arrow sag of the DSOC in the span. Comparison of the obtained value f_x with the measured actual cable sag. In the case of a difference in results, make an appropriate analysis of the reasons for the change in cable sag from the expected value and foresee the possibility of implementing preventive measures.

4. Determination of the tensile load acting on the cable and its comparison with the value of MPTL of DSOC, which is specified in its technical characteristics (or technical conditions for the cable). In case of exaggeration (65...70) % of the MPTL, make an appropriate analysis of the reasons for cable overload in order to ensure its mechanical integrity and foresee the possibility of implementing preventive measures.

5. Determination of the actual effective relative elongation of the cable (ε_{apc}) and its value according to expression (11) to estimate the mechanical state of the fiber.

As an example, in this paper, the specific loads from mechanical and physical-climatic influences and the corresponding mechanical characteristics of the DSOC type OKL-3-D2A14 made by PJSC “Odeskabel” were determined based on the ways of evaluating the mechanical characteristics of the DSOC during operation. In the calculations it was assumed: the diameter of the cable D_c = = 13.6 mm, the specific weight of the cable P_c = = 155 kg/km, the equivalent TCLE of the cable α_{OC} = = $6.226 \cdot 10^{-6}$ K^{-1}, the equivalent Young’s modulus of the entire cable (E_{eq} = 20010 N/mm^2, determined according to [12]), the conditions of the Odesa climate zone (Black Sea region) – wind speed during hoarfrost and ice V = = 28.3 m/s, the maximum radial thickness of the hoarfrost wall on the cable Δt_h = 0.5 mm and the ice wall Δt_i = = 28 mm, the initial sag of the DSOC at the temperature of 20 ºC is equal to 1 % of the span length, the span length of the OFOCL 50 m, 75 m and 100 m. As PSE in the calculations aramid threads of the type “Twaron D1052 8050” with TCLE $\alpha_{at} = -3 \cdot 10^{-6}$ 1º K^{-1} and a fiberglass rod of the type “Polystal P20” with TCLE α_{fr} = =$6.6 \cdot 10^{-6}$ 1º K^{-1} are used.

Determination of the reference data of OFOCL was carried out in accordance with the theoretical foundations of the method and ways of assessing the mechanical characteristics of DSOC in the Odesa climatic zone (chapter 3).

In Odesa climate zone, the air temperature varies from maximum of plus 37 °C to minimum of minus 28 °C. Due to the fact that the cable has a black sheath, the maximum temperature was assumed to be plus 50 °C in the calculations of its specific load and mechanical characteristics.

Let’s perform the evaluation of mechanical characteristics of DSOC by calculating method.

The results of the calculation of the specific loads on the cable and its mechanical characteristics during operation in the Odesa climatic zone according to this way of assessment for different span lengths and the effect of mechanical and various physical and climatic factors are given in the Table 1.

The results of calculating the values of the mechanical characteristics of DSOC, which are given in Table 1, shown that they increase, primarily, from a change in temperature from plus 50 °C to minus 28 °C. Their worst values appear at $t = -5$ °C during hoarfrost and ice. In turn, changes in the values of the mechanical characteristics of DSOC brand OKL-3-D2A14 in absolute value (Table 1) are given in Table 2. These characteristics were calculated for three values of the length of the line span: 50 m, 75 m and 100 m.

Let’s perform the evaluation of mechanical characteristics of DSOC by measuring-calculating way.

The results of determining the mechanical characteristics of DSOC during operation in the selected climatic zone by the measuring-calculating way are given in Table 3. At the same time, the values of the arrow sag f_x were taken based on the results of two measurements at the temperature $t = -5$ °C and the effect of hoarfrost and ice without wind on span lengths 50 m, 75 m and 100 m. The value of the cable arrow sag at the temperature $t = -5$ ° C, hoarfrost and ice with wind were calculated according to the parabolic curve of dependence of f_{ax}, f_{axc} on the specific loads of the cable: $\gamma_{3\mathrm{h}}$ – hoarfrost, γ_{3i} – ice and γ_{7h} – hoarfrost. The value of f_x at γ_{7h} was found according to the data in the Table 1. The dependence of the cable sag arrow of the brand OKL-3-D2A14 at L_s = 100 m on the specific loads of the OFOCL are shown in Fig. 4.

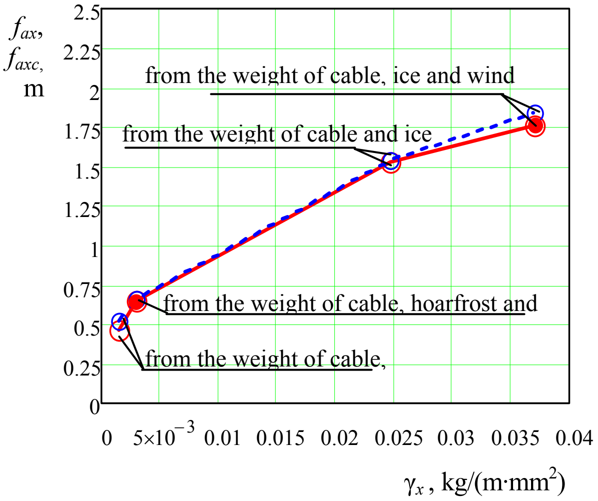

Figure 4 – Dependence of the cable arrow sag at L_s = 100 m on the specific loads of OFOCL, obtained by —— calculating and – – measuring-calculating ways (• – f_{ax} , ○ – f_{axc})

Table 3 shows the results of determining the mechanical characteristics of the DSOC (σ_{ax}, ε_{apcx}, F_{atlx}), measurements and calculations of the cable sag in spans with different lengths (f_{ax}, f_{axc}) during its operation in the selected climatic zone when acting on the OFOCL hoarfrost and ice without wind.

As noted earlier, this way of assessing the mechanical characteristics of DSOC gives their actual values under the conditions of the location of the line under the influence of hoarfrost, ice without wind. Therefore, in order to

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compare the results of determining the mechanical characteristics of the cable according to the first and second ways, an analysis of the data in the Table 1 and Table 3 was carried out. This analysis shown that the difference in the values of mechanical characteristics obtained by these ways is from 3.98 % to 4.50 %.

Let's perform the evaluation of the method of control the mechanical state of the optical fiber.

As noted earlier, certain physical and climatic loads on the DSOC cause its longitudinal deformations, which lead to the elongation of only the cable structure and/or its elongation together with the optical fiber. Excessive elongation of DSOC can lead to decreasing the size of the line and exceeding the norms of the cable parameters according to the Technical Specifications. The last, with a significant and long-term effect of influential factors, leads to a difference between F_{atlx} and F_{mtl}, which can cause a breakage of the OF and a complete failure of the cable. Thus, the work establishes a clear mathematical toolkit, which allows to control the mechanical state of the optical fiber and the mechanical characteristics of the cable as a whole under the influence of physical and climatic influences of the operating environment.

As an example, in the study of the method of control the mechanical state of an optical fiber, the values of the actual effective elongation of the fiber and the actual tensile load on the cable were determined using expressions (10) – (12). The values of ε_{apcx} and F_{atlx} were obtained when the temperature changed from plus 20 °C to minus 5 °C, hoarfrost and ice according to chapter 3. When studying these mechanical characteristics at $t = +20$ °C, the cable's own weight was taken into account, and at $t = -5$ °C its own weight, the weight of hoarfrost and ice, and the wind pressure. For the analysis of the mechanical state of OF under the above conditions, ε_{mpcx} was calculated according to the reference data. At the same time, using expression (8), it was determined that for the studied design of the DSOC, the permissible relative elongation of the cable is 0.34 %. Then ε_{mpc} according to (7) with $\varepsilon_{exOF} = 0$ and $\varepsilon_{pOF} = 0.25$ % is 0.59 %.

Table 1 – The value of the specific loads γ_x on the cable brand OKL-3-D2A14 and its mechanical characteristics, obtained by the calculating way

№	γ_x, kg/(m·mm^2), in the Odesa climate zone under the influence of various factors	L_{sx}, m	Mechanical characteristics of DSOC along the length of the line span			
			σ_x, kg/mm^2	ε_{pcx}, %	f_x, m	F_{tlx}, N
1	weight of cable, $t = +50$ °C, $\gamma_1 = 0.00130$	50	0.675	0.033	0.602	181.8
		75	1.040	0.051	0.879	280.1
		100	1.416	0.069	1.147	381.4
2	weight of cable, $t = +20$ °C, $\gamma_1 = 0.00130$	50	0.813	0.040	0.500	218.8
		75	1.219	0.060	0.750	328.2
		100	1.625	0.080	1.000	437.6
3	weight of cable, $t = -28$ °C, $\gamma_1 = 0.00130$	50	1.150	0.056	0.353	309.6
		75	1.600	0.078	0.571	430.9
		100	2.037	0.100	0.798	548.5
4	weight of cable and hoarfrost, $t = -5$ °C, $\gamma_{3h} = 0.00145$	50	1.018	0.050	0.445	274.0
		75	1.462	0.072	0.697	393.8
		100	1.896	0.093	0.956	510.5
5	wind pressure at hoarfrost, $t = -5$ °C, $\gamma_{5h} = 0.00147$	50	1.024	0.050	0.449	275.7
		75	1.470	0.072	0.703	395.9
		100	1.905	0.093	0.965	512.9
6	weight of cable, hoarfrost and wind pressure, $t = -5$ °C, $\gamma_{7h} = 0.00290$	50	1.444	0.071	0.628	388.7
		75	1.999	0.098	1.020	538.2
		100	2.522	0.124	1.437	679.2
7	weight of cable and ice, $t = -5$ °C, $\gamma_{3i} = 0.02464$	50	5.260	0.258	1.465	1415.0
		75	6.970	0.342	2.486	1877.0
		100	8.520	0.417	3.617	2293.0
8	weight of cable, ice and wind pressure, $t = -5$ °C, $\gamma_{7i} = 0.03700$	50	6.827	0.335	1.694	1838.0
		75	9.026	0.442	2.882	2430.0
		100	11.005	0.540	4.203	2963.0

Table 2 – Changes of the values σ_x. ε_{pcx}. f_x and F_{tlx} DSOC in absolute value at the temperature $t = +50$ °C relative to their values at $t = -5$ °C in hoarfrost and ice with wind obtained by the calculating way

№	L_{sx}, m	Changing the values of the mechanical characteristics of the cable							
		characteristic name							
		σ_x, kg/mm^2, at:		ε_{pcx}, %. at:		f_x, m, at:		F_{tlx}, kN, at:	
		hoarfrost	ice	hoarfrost	ice	hoarfrost	ice	hoarfrost	ice
1	50	0.769	6.152	0.038	0.302	0.026	1.092	0.207	1.656
2	75	0.959	7.986	0.047	0.391	0.141	2.003	0.258	2.150
3	100	1.106	9.589	0.055	0.471	0.290	3.056	0.298	2.581

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Table 3 – Values of the mechanical characteristics of OKL-3-D2A14 DSOC, obtained by the measuring-calculating way under the influence of the weight of the cable, hoarfrost, ice without wind pressure and temperature $t = -5$ °C

№	L_s, m	f_{ax}, m, at:		Values of the mechanical characteristics of the cable					
				σ_{ax}, kg/mm², at:		ε_{ax}, %, at:		F_{atlx}, N, at:	
		hoarfrost	ice	hoarfrost	ice	hoarfrost	ice	hoarfrost	ice
1	50	0.463	1.524	0.979	5.052	0.048	0.248	263.5	1361
2	75	0.725	2.585	1.406	6.702	0.069	0.329	378.7	1805
3	100	0.994	3.762	1.823	8.187	0.089	0.401	491.0	2205

In addition, an analysis of the mechanical state of the optical fiber is provided (Table 4) for line span lengths of 50, 75, and 100 m.

The results of the analysis of the mechanical state of the optical fiber in the investigated structure of the DSOC under the influence of physical and climatic influences of the operating environment are given in Table 4, Fig. 5 and Fig. 6.

Data analysis (Table 4) shown that when:

– the maximum permissible relative elongation of the DSOC ε_{mpc} = 0.59 % on all lengths of the span, the additional relative elongation of the cable is less than this value;

– the length of the span of the overhead line 100 m, the actual tensile load of the cable F_{atlxc} = 2.722 kN is greater than the norm of its permissible tensile load according to [7] F_{ntl} = 2.600 kN.

Therefore, the cable brand OKL-3-D2A14 in the Odesa climate zone at L_s = 100 m cannot be used on the OFOCL.

Table 4 – Results of the analysis of the mechanical state of the optical fiber in DSOK OKL-3-D2A14 under the influence of physical and climatic influences at different lengths of span at the temperature of plus 20 °C and minus 5 °C

№	γ_x, kg/(m·mm²), in the Odesa climate zone under the influence of various factors	Mechanical characteristics of DSOC on the length of the span														
		ε_{apc}, ε_{apcxc}, %, at span lengths of the OFOCL, m						F_{atl}, F_{atlxc}, N, at span lengths of the OFOCL, m						Mechanical state of the OF at the span length of the OFOCL, m		
		50		75		100		50		75		100		50	75	100
		ε_{apc}, ε_{apcxc}	ε_{pc}	ε_{apc}, ε_{apcxc}	ε_{pc}	ε_{apc}, ε_{apcxc}	ε_{pc}	F_{atl}, F_{atlxc}	F_{ntl}	F_{atl}, F_{atlxc}	F_{ntl}	F_{atl}, F_{atlxc}	F_{ntl}			
1	$t = 20$ °C and cable weight, $\gamma_1 = 0{,}00130$	0.040 <	0.340	0.060 <	0.340	0.080 <	0.340	218.80<	2600.0	328.20 <	2600.0	437.60 <	2600.0	OF straightens in the core and is not subject to longitudinal elongation		
2	$t = -5$ °C, weight of cable and hoarfrost, $\gamma_{3h} = 0{,}00145$	0.048 <	0.340	0.069 <	0.340	0.089 <	0.340	263.50 <	2600.0	378.70 <	2600.0	491.00 <	2600.0	OF straightens in the core and is not subject to longitudinal elongation		
3	$t = -5$ °C, wind pressure at hoarfrost, $\gamma_{5h} = 0{,}00147$	0.050 <	0.340	0.072 <	0.340	0.093 <	0.340	275.70 <	2600.0	395.90 <	2600.0	512.90 <	2600.0	OF straightens in the core and is not subject to longitudinal elongation		
4	$t = -5$ °C, cable weight, hoarfrost, wind, $\gamma_{7h} = 0{,}00290$	0.068 <	0.340	0.097 <	0.340	0.125 <	0.340	370.90 <	2600.0	531.50 <	2600.0	685.00 <	2600.0	OF straightens in the core and is not subject to longitudinal elongation		
5	$t = -5$ °C, weight of cable and ice, $\gamma_{3i} = 0{,}02464$	0.248 <	0.340	0.329 <	0.340	0.401 >	0.340	1361.0 <	2600.0	1805.0 <	2600.0	2205.0 <	2600.0	OF straightens in the core and is not subject to longitudinal elongation		OF is subject to elongation by 0.06 %
6	$t = -5$ °C, weight of cable and ice, wind pressure, $\gamma_{7i} = 0{,}03700$	0.31 <	0.340	0.418 >	0.340	0.496 >	0.340	1702.0 <	2600.0	2298.0 <	2600.0	2722.0 >	2600.0	OF straightens in the core	OF is subject to elongation by 0.08 %	OF is subject to elongation by 0.16 %

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5 RESULTS

In the work, the method of control the mechanical state of the optical fiber of DSOC during operation was created. Based on the developed theoretical basis of the method, experimental studies were performed to evaluate the mechanical characteristics of the cable OKL-3-D2A14 at three span lengths of the line located in the Odesa climatic zone and the mechanical state of its fiber. On the basis of the developed reference data of the method and measurements and calculations of the cable arrow sag, an analysis of the results of the study of ways for evaluating the mechanical characteristics of cables was carried out. These results proved the possibility of using the measuring-calculating way at controlling the mechanical state of the optical fiber during the operation of the OFOCL.

The results of a comparison of the measured values of the sag of the DSOC (Table 3) and those calculated under the influence of the weight of the cable, the weight of hoarfrost and ice without wind pressure (Table 1) shown that the measured values are greater than the calculated values by up to 4 % both in hoarfrost and in ice at all span lengths.

The analysis of the obtained values of mechanical characteristics of DSOC by these methods shown that their difference is also up to 4 %.

The obtained values of the actual sag of the cable in the worst operating conditions during icing with wind (Table 4) allow us to determine the dimensions of the line and the value of the tensile load of the DSOC.

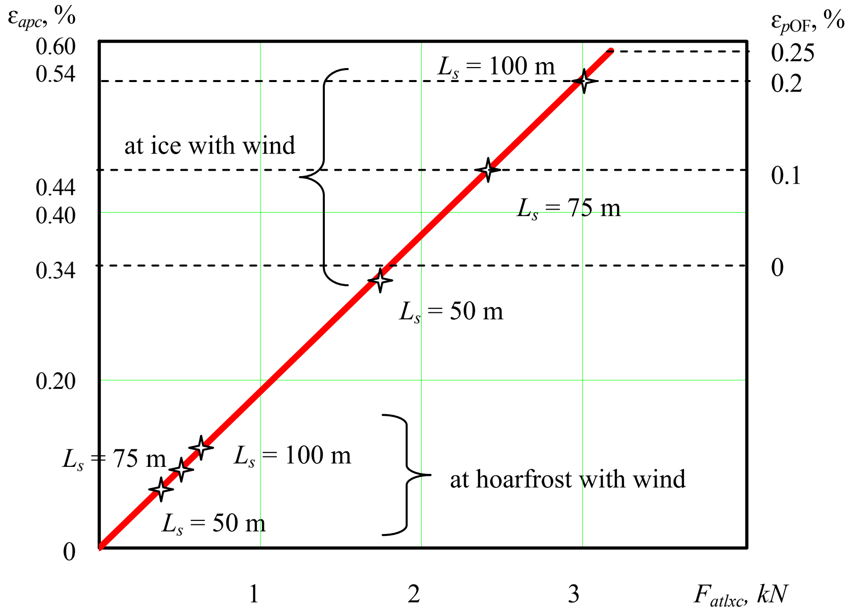

Figure 5 – Assessment of the mechanical state of OF under the influence of physical and climatic influences

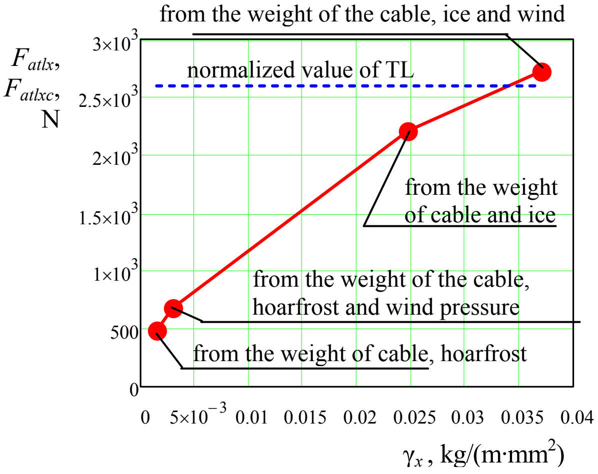

Figure 6 – Dependence of the tensile load of the cable on the specific loads of the OFOCL on the length of the span of 100 m

The developed method of control the mechanical state of OF shown that:

a) for all span lengths and temperatures from plus 20 °C to minus 5 °C during hoarfrost with wind, the optical fiber is not subject to longitudinal elongation;

b) at temperature t = –5 °C:

– and at ice without wind, the optical fiber is straightened in the tube of the optical module at L_s = 50 m, 75 m, and at L_s = 100 m it is subject to elongation by 0.06 %;

– and ice with wind, the optical fiber is straightened in the tube of the optical module at L_s = 50 m, and at L_s = 75 m it is subject to elongation by 0.08 % and at L_s = 100 m – by 0.16 %.

So, the research results proved that the cable brand OKL-3-D2A14 in the Odesa climate zone on lines with a span length of 100 m or more is inadmissible for operation.

6 DISCUSSION

The approaches presented in the work in the created method are confirmed by their necessity, given in the international and Ukrainian regulatory and technical documentation for the building and operation of the OFOCL.

The method is cheap and easily accessible to operators of overhead communication lines. Therefore, its use improves the monitoring of the mechanical state of the pipeline and leads to a reduction in the costs of its operation.

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The proposed method of control the mechanical state of the optical fiber in DSOC allows:

– choose the brand of cable when designing the OFOCL for hanging on various engineering structures in the given climatic zone and the length of the span with the same height of the cable suspension points;

– monitor the technical state of the line based on the results of the assessment of the mechanical characteristics of the cable and control of the mechanical state of the optical fiber and measurements of its attenuation coefficient;

– the studies carried out in the work allow to ensure the specified service life of the lines with proper maintenance or repair and restoration works of DSOC. This is confirmed by the results of the experiment performed in the work. Therefore, the method will help the service personnel of the lines to take timely measures to eliminate problems in the mechanical states of the cable and its fiber.

CONCLUSIONS

The research carried out in this work made it possible to draw the following conclusions:

1. The international and domestic regulatory and technical documentations of the OFOCL and a number of scientific works regulate the control of the mechanical characteristics of the optical cable during operation, but the control of the technical state of the fiber in full to ensure the quality and reliability of the line during the specified service life is not provided.

2. In this work, the method of control the mechanical state of the optical fiber of dielectric self-supporting optical cables during operation has been developed due to the developed ways of evaluating the mechanical characteristics of the cable along the length of the span under the influence of mechanical, physical and climatic factors of the area where the line is located.

3. With the help of the developed method, the determination of mechanical stresses and the study of additional relative elongations of the cable and its tensile loads in the span of the line during operation on the OFOCL under the conditions of various mechanical and physical-climatic loads (ice, wind pressure, the affect of temperature and their combination) of the Odesa climatic zones at three span length values. It was established that changes in mechanical and physical-climatic loads of operating conditions cause different magnitudes of longitudinal deformations of DSOC and OF as a whole. Using this method, it was established that the cable brand OKL-3-D2A14 with the specified design parameters at a span length of 100 m under the worst climatic conditions ensures the mechanical integrity of the OF with an additional relative elongation of 0.16 %, but in terms of actual tensile strength, it does not meet the norm – 2.6 kN.

As the mechanical state of cable and optical fiber deteriorates over time, it is very important to monitor them to prevent fiber breakage.

4. The proposed method of control the mechanical state of the optical fiber on the suspended DSOC on the OFOCL allows monitoring changes in the mechanical state of optical fibers and the cable as a whole to prevent the additional appearance of unacceptable tensile forces and failure of the communication line. This method can be used for application by the relevant departments for the technical operation of telecommunication lines on communication networks based on suspended optical cables.

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МЕТОД КОНТРОЛЮ МЕХАНІЧНОГО СТАНУ ОПТИЧНОГО ВОЛОКНА ДІЕЛЕКТРИЧНОГО САМОУТРИМНОГО ОПТИЧНОГО КАБЕЛЮ ПРИ ЕКСПЛУАТАЦІЇ

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АНОТАЦІЯ

Актуальність. Нормативно-технічна документація для волоконно-оптичних ліній зв’язку (ВОЛЗ) регламентує контроль механічного стану оптичного кабелю (ОК) під час експлуатації, але контроль механічного стану волокна в повній мірі для забезпечення якості та надійності лінії протягом заданого терміну служби не передбачає.

Як відомо, що для забезпечення надійності оптичного кабелю, як правило, допустиме видовження оптичного волокна (ОВ) складає $\varepsilon_{\text{дОВ}}$ < (0,2…0,25) %, прийняте при конструюванні кабелю. Але при експлуатації в волокнах можлива поява багаторазових надлишкових видовжень, що перевищують ці значення.

Таким чином, розробка та обґрунтування способів оцінки механічних характеристик діелектричного самоутримного оптичного кабелю (ДСОК) та методу повного контролю механічного стану оптичного волокна являється необхідним. Останнє може привести до дострокового виходу із ладу оптичного волокна.

Мета. Розробка та обґрунтування методу контролю механічного стану оптичних волокон підвісних ДСОК, а також оцінка умов деформації оптичних волокон в їх осерді з появою поздовжніх розтягувальних/стискальних навантажень при експлуатації.

Метод. Розроблено та запропоновано два способи оцінки механічних характеристик ДСОК та метод контролю механічного стану його волокна. Для цього в роботі прийняті такі характеристики кабелю та волокна: відносне видовження кабелю та волокна ($\varepsilon_{\text{к}x}$, $\varepsilon_{\text{ОВ}x}$), довжина прольоту ($L_{\text{пр}x}$) лінії, стріла провисання кабелю в прольоті (f_x) та розтягувальне навантаження (РН) кабелю ($F_{\text{рн}x}$), що обумовлює поздовжню деформацію ε. При цьому в методі запропоновано контроль механічного стану оптичного волокна при експлуатації ДСОК виконувати за рахунок визначення його діючого відносного видовження за механічними та фізико-кліматичними умовами розташування лінії.

В роботі запропоновано, завдяки розробленим довідковим даним для вибору типу кабелю та кліматичної зони розташування лінії, вимірювальному обладнанню та математичному інструментарію, вимірювати та розраховувати такі механічні характеристики:

- еквівалентну механічну напругу в ДСОК;
- розрахункову та фактичну стріли провисання кабелю в прольоті;
- фактично діюче відносне видовження кабелю;
- фактичне розтягувальне навантаження, що діє на кабель.

Приведені в роботі способи та метод дозволяють при експлуатації ДСОК здійснювати повну оцінку механічних характеристик кабелю та контроль механічного стану оптичного волокна. Це створює можливість моніторингу їх змін для недопущення появи надмірних навантажень при експлуатації та виходу з ладу волоконно-оптичної лінії зв’язку.

Даний метод можливо рекомендувати для застосування відповідними підрозділами з технічної експлуатації телекомунікаційних ліній та мереж зв’язку на базі підвісних оптичних кабелів.

Результати. В роботі приведені результати розробки та обґрунтування методу контролю механічного стану оптичних волокон діелектричних самоутримних оптичних кабелів при експлуатації. Для прикладу, використовуючи розроблений метод, показано, що в кабелі марки ОКЛ-3-Д2А14 виробництва ПАТ «Одескабель» в умовах Одеської кліматичної зони (Причорноморського регіону) оптичні волокна при довжині прольоту лінії 100 м підлягають видовженню на 0,16 %, а ДСОК підлягає фактичному розтягувальному зусиллю – 2,722 кН. Цей результат контролю механічного стану ОВ встановив, що такий прольот лінії забезпечує його механічну цілісність у межах допустимої деформації 0,25 %, прийнятої при конструюванні кабелю, але перевищує його допустиме розтягувальне навантаження 2,6 кН.

Висновки. Наукова новизна результатів роботи полягає в тому, що вперше розроблено способи повної оцінки механічних характеристик ДСОК при експлуатації та метод повного контролю механічного стану його оптичного волокна. Він дозволяє виконувати моніторинг змін механічного стану оптичного волокна кабелю.

КЛЮЧОВІ СЛОВА: відносне видовження, діелектричний самоутримний оптичний кабель, оптичні волокна, поздовжнє розтягувальне навантаження, фізико-кліматичні навантаження.

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