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METHOD OF EVALUATION THE EFFICIENCY OF FIBER-OPTIC CABLES MODELS WITH MULTI-MODULAR DESIGN BASED ON MASS AND DIMENSIONAL INDICATORS

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ABSTRACT

Context. Today, the leading cable production plants in many countries of the world manufacture single- and multi-module designs of fiber-optic cables (FOC) with different protective covers and the number of fibers. This creates a wide range of possible FOC models for different consumer (buyer) requirements. However, the lack of openness of prices for FOC for the consumer, in particular for the project organization, and the desire of the manufacturer to save on production creates a need for the development and research of a method for evaluating the effectiveness of FOC of a multi-module design. In the work, it is proposed to do this by analyzing a number of optical cable models according to parameters-criteria – the compactness coefficient and the economic efficiency coefficient of the FOC by diameter.

Objective. To develop a method of evaluation the efficiency of fiber-optic cables models with multi-modular design based on mass-dimensional indicators, which will allow to quickly choose an appropriate model of the FOC with the given initial data.

Method. A method of evaluating the efficiency of the FOC modular design has been developed and proposed. It is based on the comparison of cable models and the selection of the most appropriate of them at given initial data. The paper proposed and introduced parameters-criteria for this – the compactness coefficient υ and the efficiency coefficient according to the diameter of the cable E_0 – which show the connection of the design characteristics of the FOC to a certain parameter of its structure. At the same time, the most effective model (design) of the FOC compared to the basic models in terms of technical conditions, both from the point of view of the manufacturer and the customer, consists in lower material costs for its production while simultaneously ensuring the specified requirements for the cable (first of all, number of fibers and mechanical strength). This will allow, at the stage of cable design, to make an appropriate choice of its model with given initial parameters and to develop such a design of the FOC, which will allow to minimize the dimensions (and therefore the material capacity and cost) of the model without losing its quantitative and qualitative characteristics.

Results. The paper presents the results of the development and research of the method of evaluating the efficiency of the FOC with multi-module structure based on mass and dimensional indicators. For example, using the developed method, it is shown that it is possible to choose a FOC model with a diameter smaller by 10.9% and save 15.5% of the cable cost for each kilometer of the fiber optic communication line while ensuring the initial requirements for the cable.

Conclusions. The scientific novelty of the work results is that, method of evaluation the efficiency of a modular FOC design has been first developed, which allows at the cable design stage to compare the model with the cable design according to the technical conditions (TC) and the appropriate choice of this model with the given initial parameters. The practical significance lies in the possibility of using this method to make an accelerated selection of the cable model at the stage of its design, while simultaneously providing the necessary capacity of the FOC with optical fibers and minimizing the cost of its materials and dimensions.

KEYWORDS: fiber-optic cable, cable design, geometric dimensions, mass-dimensional indicators, cost of cable materials.

ABBREVIATIONS

AON is an all optical network
FOC is a fiber optic cable;
FOCL is a fiber-optic communication line;
FE is a filling element;
FTTB is a Fiber To The Build;
FTTH is a Fiber To The Home;
HF is a hydrophobic filler;
OM is an optical module;
OF is an optical fiber;
CSE is a central strength element;
PSE is a peripheral strength element.

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NOMENCLATURE

υ is a coefficient of FOC compactness;

E_0 is a coefficient of economic efficiency of the FOC by diameter;

d_{OM} is a diameter of the optical module tube;

D_c is an outer diameter of the cable;

n is a number of twisted elements in the cable core;

θ is an angle of spiral twisting of the elements in the cable core;

m is a number of layers in the cable core;

Δt_{wb} is a radial thickness of the water-blocking tape;

Δt_{ph} is a radial thickness of protective hose;

V_c is a the volume of fiber optic cable;

P_c is a mass of fiber optic cable;

P_{OF} is a mass of optical fiber;

P_{CSE} is a mass of the central strength element;

P_{OM} is an optical module mass;

P_{hf1} is a mass of hydrophobic filler inside optical module;

P_{hf2} is a mass of hydrophobic filler between optical modules;

P_{ph} is a mass of the protective hose;

P_{wb} is a mass of water-blocking tape;

P_{PSE} is a mass of the peripheral strength element;

d is a diameter of solid element;

D_{av} is an average diameter of the tubular element, mm;

δ is a wall thickness of the tubular element, mm;

l is a length of the element of the cable, km;

γ is a density of the material of structural element;

K is a structural or technological coefficients (twising, helicity, corrugation, etc.);

E_0 is a parameter-criterion of the economic efficiency of the cable, UAH/(km·mm);

C_c is a full cost of materials of cable, UAH/km;

N is a number of cable design elements.

C_{el} is a cost of the cable element, UAH/km;

C_1 is a cost of one kilometer or unit of cable element material, UAH/kg;

M is a mass of the volume element of the FOC, kg/km;

K_w is a rate of waste in the manufacture of the FOC element, %;

LD is a linear density of aramid threads, dtex;

n_{at} is a number of aramid threads in PSE layer;

P_{ha} is a mass of hydrophobic aggregate in all OM, kg;

D_{inOM} is an inner diameter of the tube OM, mm;

d_{OF} is a diameter of one OF, mm;

K_h is a coefficient of helical stacking of fiber;

n_{OF} is a number of fiber in one module tube;

γ_{gz} is a material density of hydrophobic aggregate, kg/mm^3;

K_{OM} is a constructive and technological coefficient that takes into account the spiral stacking of OM around the CSE;

n_{OM} is a number of OM in the core of the OC;

d_{out} is an outer diameter of the tubular element of the FOC, mm;

d_{in} is an inner diameter of the tubular element of the FOC, mm.

INTRODUCTION

Modern society in the conditions of rapid technical progress requires providing the increasing number of telecommunication services and services, the implementation of which occurs due to the use of various means of telecommunications. The steady increasing the number of users of telecommunication services and their requirements leads to an increase in the volume of information transmitted in the communication network. And it determines the expansion of the transport telecommunications network and the subscriber access network. In addition, one of the main trends is the introduction of 5th generation (5G) mobile communication networks, which provide high data transfer rates and low delay. Future mobile communication networks place high demands not only on quality characteristics, but also on the efficiency of the infrastructure on which communication provision is based [1]. In this context, the design of optical cables becomes a main element, providing an extremely important foundation for the transmission of data in huge volumes.

In many countries of the world, the communication network today has a two-level hierarchical structure (transport telecommunication network and subscriber access network) using both copper and fiber optic communication cables. High-speed mutual exchange of information (audio, video, various types of data) between the devices of nodes of the transport telecommunication network is carried out exclusively on the basis of fiber-optic cables of various designs. On the subscriber access networks the FOCs are increasingly being replaced the traditional electrical cables with copper cores due to the possibility of simultaneously receiving integrated services of the Internet, television and telephony, which will also ensure a certain network energy independence during the provision of services. This is achieved by the creation of appropriate constructions of FOC and the building of new high-speed fiber optic communication lines. For this purpose, factories are actively working in cable production (PJSC "Odeskabel", PJSC "Zavod 'Pivdenkabel'" and others).

Factories producing cable products, guided by their own scientific developments, design and manufacture an increasingly large and wide range of FOC of various designs for certain operating conditions (in soil, cable ducts, underwater, for suspension, in mines, subchannels, collectors, etc.). At the same time, in order to achieve significant profitability of production and ensure the technical efficiency of the cable, cable production plants try to choose the appropriate design of the FOC (size and number of structural elements, their materials, manufacturing technology, weight and cost of the cable) according to the criterion "technical ability/cost of the cable". At the same time, the organization (customer) that performs the design and/or building of FOCL needs such a brand of cable for certain laying conditions, which would at the same time ensure minimum costs for its purchase and compliance with the requirements for the technical ability of the ca-

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ble. That is, the customer of cable products chooses the FOC brand on the basis of requirements from: the specified number of optical fibers and the operating conditions of the cable, which determines the type of its protective coatings, mechanical strength, mass, dimensions, etc. That is why the manufacturing plants provide a wide range of cable products for the needs of the customer. Such a task of choosing the optimal cable laying for the given conditions is very large in scope of work and duration in time. Therefore, the cable production plant designs, calculates, develops and tests only the basic prototypes of FOC brands. And variations of the basic FOC model create a wide range of brands of this cable. The task of choosing an effective (expedient) sample of the FOC during the design falls on the manufacturer, and during the construction of the FOC – on the design organization.

Currently, there is no publicly available regulatory documentation on the development of FOC, and known sources provide only individual details about the calculation of their structures. Therefore, it requires the creation of new, improvement of existing methods of design, calculation and development, evaluation of cable structures for given operating conditions.

Today, the leading cable production plants mostly manufacture single- and multi-module FOC designs with different protective covers and number of fibers. At the same time, within the framework of one brand of cable, the same FOC design has a different number of OF. This leads to the complication of choosing an appropriate design of the FOC, and sometimes to its impracticality in certain operating conditions, reducing its technical capability. And the development of a method for evaluating the effectiveness of FOC models based on mass-dimensional indicators will allow to make an appropriate choice of cable design with a given number of optical fibers, as well as with the possibility of reducing the cost of materials for production.

The object of study is the evaluation of the effectiveness of models of fiber-optic cables with multi-module design by mass and dimensional indicators.

The subject of study is the model of a multi-module fiber optic cable design.

The purpose of the work is to develop a method of evaluating the efficiency of models of fiber-optic cables with multi-module design based on mass-dimensional indicators, which will allow to quickly choose an appropriate (better) model of the FOC with the given initial data. This approach is universal when creating a wide range of cable products and selecting a cable based on the "quality/price" criterion for specific operating conditions.

1 PROBLEM STATEMENT

Suppose there are *m* models of FOC with modular design, each of which has a certain number of optical fibers and other technical characteristics, which in practice depend on the technological capabilities of production. First of all, the number of optical fibers n_{OF}, the number N and the dimensions (d, Δt) of the structural elements, their materials, the mass P_c, the price C_1 and the volume V_c determine the full cost of the FOC C_c, which can be represented as a function $C_c = f(n, N, P_c, V_c, K, \gamma, C_1)$.

The task of finding an effective FOC model consists in finding such a cable model x with the minimum total cost of materials $C_x = \min[C_{c1}, C_{c2},\ldots,C_{cm}]$ and the number of fibers, which is greater than the required $N_{\text{OF}}>N_{\text{OFneed}}$.

In turn, the problem of finding an effective FOC model is to find such a set of mass-dimensional parameters of the cable design (n, N, d, P_c, V_c) in which $C_c \rightarrow \min$. For this purpose, it is proposed to introduce criteria-parameters: cable compactness coefficient υ and economic efficiency coefficient by diameter E_0.

2 REVIEW OF THE LITERATURE

Analysis of the works of well-known authors in the field of fiber-optic communication, in particular, design, development and production of FOC – Malke G., Hessing P., Kanamori H., Beyer G., Bailey D., Wright E., Bondarenko O.V ., Katok V.B. etc. [2 – 12] showed the lack of completeness of research in this direction. In particular, these works show approaches to the calculation and design of modular structures of cables according to tensile load [2, 3, 5, 7, 12], features of the use of different materials for structural elements of cables [4], consideration of metrological standards during the production of FOC [6], features of the construction of a modular type FOC [8], interrelations of the sizes of the structural elements of the FOC and methods of determining the cost of the cable [8, 10, 11]. However, the assessment of the effectiveness of modular constructions of the FOC based on mass-dimensional indicators, which would allow choosing the appropriate cable structure for the given initial data (conditions), remained out of the authors' attention.

3 MATERIALS AND METHODS

Currently, in the conditions of the market economy, there are a lot of different telecommunication companies (telecommunication operators) that are engaged the providing telecommunication needs of consumers within the limits of a settlement or district. Network construction technologies such as Fiber to the Build and Fiber to the Home, which are built on the basis of FOCL, have become especially popular for use. They make it possible to implement the AON optical information transmission technology. For this, communication operator companies use FOC with different amount of OF (for laying in the ground, cable duct, low-current channels, hanging between buildings or on network poles for various purposes).

To ensure the necessary bandwidth of communication lines and networks, FOCs with a certain number (from 4 and more) of single-mode optical fibers with low attenuation are used. In some countries, FOCs as a rule with modular design are manufactured and used on communi-

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cation networks. Modular designs of the FOC core can have a different structure, i.e. different number and sizes of twisting elements (tubes of optical modules, filling elements, layers, etc.), which determines the difference in their geometrical and dimensional parameters. Fibers in FOC are placed inside the tube of optical modules with different diameters, which are filled with hydrophobic filler. In such FOC the core contains, as a rule, from 2 to 12 OM tubes in the first layer or OM and a certain number of filling elements, which are spirally arranged around the central strength element. As a rule, the CSE is made of a fiberglass rod or a steel rope with a polyethylene sheath. The diameter of the CSE depends on the number of elements in the first layer of the cable core. The size of the CSE, in turn, is decisive when calculating the value of the maximum permissible tensile load of the FOC, the value of which is used to estimate the long-term mechanical strength of the cable and to conduct its development [2, 8, 11].

The choice of the FOC core structure, materials and sizes of the structural elements of the cable determines its technical indicators, including weight and dimensions.

Therefore, FOC designers solve the task of developing a cable design that would allow minimizing the dimensions (which means the material capacity and cost) of the models without losing their quantitative and qualitative characteristics. At the same time, the design of a certain brand of FOC can have several options for the core and the number of OF in it. This requires the selection of the optimal design of the FOC for the given operating conditions. At the same time, the effectiveness of the FOC model (construction) compared to the basic models according to the technical specifications, both from the point of view of the manufacturer and the customer, consists in lower material costs for its production while simultaneously ensuring the specified requirements for the cable (primarily, in terms of the number of fibers and mechanical strength). The choice of a modular design of the FOC with OF freely located inside determines the absence of mechanical stresses in the fibers and ensures their integrity during operation [11].

The efficiency of the FOC design in terms of mass and dimensions compared to the basic models according to the technical conditions consists in the lower material consumption of its structural elements while ensuring the proper level of its technical ability. The solution to this problem is based on the definition and study, first of all, of the FOC cores, which are difference between cable models. This will make it possible to compare FOC models with each other according to the criteria of constructive efficiency and to choose the most appropriate one of them at the given initial data.

In order to evaluate the effectiveness of fiber-optic cable models based on mass-dimensional indicators, it is necessary to introduce parameters-criteria that would show the connection of the characteristics of the FOC design to a certain parameter of its structure. Therefore, it is proposed to introduce the following parameters-criteria in the work:

– cable compactness coefficient, which shows the relationship with the volume of the FOC and its mass;

– coefficient of economic efficiency of the FOC by diameter, which characterizes the part of the cable cost per unit of its diameter.

In a general view, the structure of the core of an optical cable with a single-layer multi-module unarmored design is presented in Fig. 1 [2, 3, 6, 8, 10].

First of all, it is necessary to show the relation between the outer diameter of the FOC structure and the number of layers, the number and sizes of elements (OM or FE) in the layers, the radial thicknesses of the protective layers of the cable, etc.

Taking into account [2, 8, 9, 10], the outer diameter of the FOC of the multi-module design according to Fig. 1 can be determined by the expression:

$$D_c = d_{\text{OM}}\left(\sqrt{1+\frac{1}{\sin^2\theta}\left[\frac{1}{\sin^2 \pi/n}-1\right]}+1\right)+ \\ +2(m-1)d_{\text{OM}}+2\Delta t_{wb}+2\Delta t_{ph}. \quad (1)$$

For a generalized assessment of FOC models, we will calculate the parameters of their technical and economic group. As you know, the technical and economic group includes three main parameters, namely: product cost (UAH/km), dimensions or volume V (dm^3) and mass P_c (kg/km) [7, 13, 14].

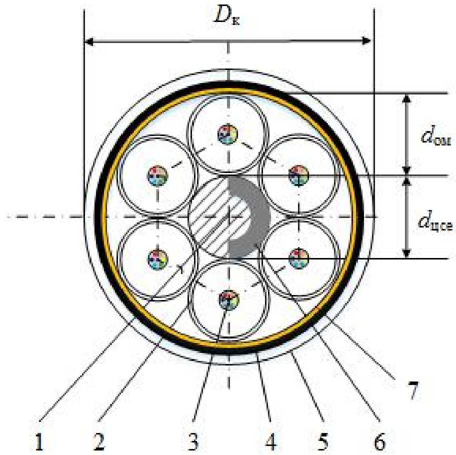

Figure 1 – Cross-section of a model of a single-layer construction of FOC: 1 – CSE; 2 – OM tube; 3 – OF; 4 – water-blocking layer; 5 – protective hose; 6 – polyethylene coating (in the case of metal TSE); 7 – peripheral strength element

According to [2], the product of the volume and mass of the cable model under investigation will allow to obtain the parameter-criterion – the compactness coefficient of the FOC υ (dm^3· kg):

$$\upsilon = V_c \cdot P_c. \quad (2)$$

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By the value of the parameter-criterion of the compactness coefficient, it is possible to compare the material consumption of the cable with the material consumption of the basic design according to the technical specifications and, thus, determine the efficiency of its model based on mass-dimensional indicators. The smaller the value of the compactness factor, the smaller its weight and material consumption.

The volume of the cable V_c is defined as the sum of the volumes of all its structural elements (solid or tubular) and their fillings. Expressions for calculating the volumes of solid and tubular structural elements of the FOC are presented as:

– for solid element $V_c = \pi d_{el}^2 \cdot l \cdot K / 4$;

– for tubular element $V_c = \pi(d_{out}^2 - d_{in}^2) \cdot l \cdot K / 4$.

The mass of the FOC is the sum of the masses of all its elements and their fillings. The mass of FOC can be calculated using the following expression:

$$P_c = \sum_{i=1}^{N} P_i = P_{\mathrm{OF}} + P_{\mathrm{CSE}} + P_{\mathrm{OM}} + P_{hf1} + P_{hf2} + P_{wb} + P_{\mathrm{PSE}} + P_{ph}. \quad (3)$$

Most cable construction elements are solid (optical fibers, CSE or PSE fiberglass rods, filling elements, etc.) or tubular (OM tube, protective hose, etc.). According to [7, 8, 10], the expressions for calculating the mass of solid and tubular structural elements of the FOC are generally presented as:

– for a solid element

$$P = \frac{\pi d^2}{4} \gamma\, l(k, K)\ ; \quad (4)$$

– for a tubular element

$$P = \pi D_{av} \delta \gamma\ l(k, K)\ . \quad (5)$$

In formulas (4) and (5), the nominal dimensions of the elements are substituted (without taking into account tolerances) and the nominal mass is calculated (without taking into account waste).

The mass of the hydrophobic filler of the OM cable tubes is determined by the expression [9]:

$$P_{hf} = \frac{\pi}{4}\left(D_{in\mathrm{OM}}^2 - d_{\mathrm{OF}}^2 K\ n_{\mathrm{OF}}\right)\gamma_{hf} l K_{\mathrm{OM}} n_{\mathrm{OM}}\ . \quad (6)$$

The mass of aramid threads, kg, can be calculated by the expression [9]:

$$P_{\mathrm{PSE}} = LD \cdot n_{at} 10^{-4}\ . \quad (7)$$

Establishing a relation between the compactness coefficient of the FOC, in particular, from its core structure (the number of OM tubes, fibers, etc.) will allow choosing a less material-consuming cable model while providing a given amount of OF.

It is possible to calculate the cost of materials of individual elements and the total cost of materials of all elements of the FOC based on the determined masses of the cable elements and the prices of their materials.

It is obvious that each model of FOC, due to its different diameter, volume (material consumption), has a corresponding cost price. Therefore, in order to quantitatively compare the efficiency of the designs of these models, in this work it is proposed to introduce a parameter-criterion of the economic efficiency of the FOC by the diameter E_0, which will characterize the cost of the cable materials per unit of its diameter, i.e.:

$$E_0 = \frac{C_c}{D_c}\ . \quad (8)$$

The total cost of materials of all elements of the FOC is determined by the expression [9]:

$$C_c = \sum_{i=1}^{N} C_{eli}\ . \quad (9)$$

The cost of materials for a separate element of the cable is calculated according to the expression [9]:

$$C_{el} = C_1 M \left(\frac{100 + K_w}{100}\right). \quad (10)$$

According to the value of the parameter-criterion – coefficient of economic efficiency of the FOC by diameter, it is possible to compare the cost of materials of different cables models and, thus, determine its more efficient design. The lower the value of the coefficient of economic efficiency of the FOC, the lower the cost of the part of the cost of the cable materials per unit of its diameter. Thus, lower costs for cable materials as a whole.

4 EXPERIMENTS

A multi-module FOC design without armor was chosen as the sample for the research (Fig. 1). It can contain several (1, 2 and 3) concentric layers of OM around the CSE. The number of elements in the first layer used in practice are in ranges from 3 to 12 [2, 5, 10, 11].

In the investigated FOC models, the following were adopted: the diameter of the OM tube (element in layer) d_{OM} = 2.3 mm with the maximum number of OF in each module N_{OF} = 12, the fiber diameter in the primary protective coating d_{OM} = 0.255 mm, the step of the spiral arrangement of the layer elements around the CSE h = 90 mm. The densities of materials and semi-finished products used in the calculations for the structural elements of the FOC and their cost are taken according to [2, 10].

In this work, the assumptions are:

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1. All elements of the layer are OM tubes with optical fibers. All OM tubes in FOC design are completely filled by fibers, that is, they contain 12 fibers in each.

2. OM tubes, which have a spiral arrangement around the CSE with a certain angle, in the cross-section of the cable were considered as circles, not an ellipse.

Calculations of data arrays of FOC models were performed in the MathCad 14 software environment using expressions (1)–(10) and known geometry formulas.

5 RESULTS

Using expression (1), calculations of the outer diameters of the intended models of the FOC were performed in the paper. At the same time, taking into account the rule of "correct twisting", at twisting the elements of the cable core in a spiral layer, their number in each subsequent layer increases by six compared to the previous one. And their variety is determined by the possible number of elements of a layer from 3 to 12 and layers from 1 to 3 [10]. The results of the calculations of the outer diameters of the FOC models are presented in the Table 1.

For a visual representation and better understanding, the results of the calculations of the outer diameters of the FOC models are presented in Fig. 2.

Table 1 – The results of the calculations of the diameters of the FOC models

Number of layers in FOC design	Number of elements in the first layer									
	3	4	5	6	7	8	9	10	11	12
	diameters of the FOC design, mm									
I	8.5	9.1	9.7	10.4	11.1	11.8	12.5	13.2	14	14.7
II	13.1	13.7	14.3	15	15.7	16.4	17.1	17.8	18.6	19.3
III	17.7	18.3	18.9	19.6	20.3	21	21.7	22.4	23.2	23.9

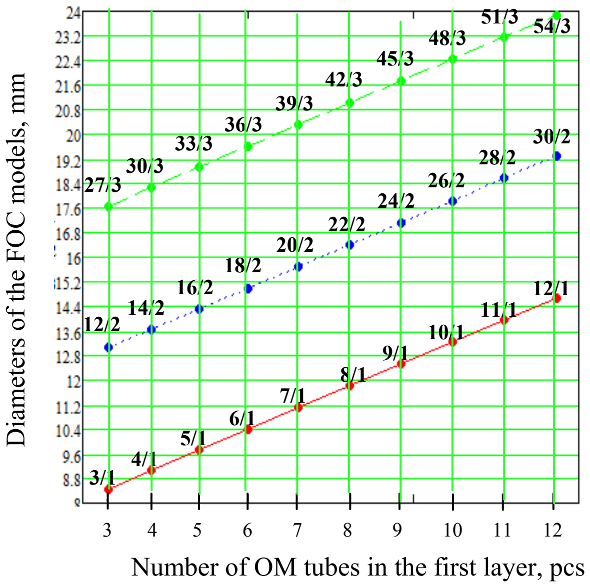

Figure 2 – Dependences of the outer diameter of FOC models on the number of OMs in the first cable layer for one-, two- and three-layers core designs (*m*/*n* FOC model number, where *m* is the total number of OMs; *n* is the number of layers)

Three dependencies are shown in Fig. 2 show the connection between the number of OM in the first, second, and third layers and the outer diameter of the FOC. Fig. 2 shows that with an increase of the number of OM in the first FOC layer from 3 to 12 in the one-, two- and three-layers structure of the cable core, its outer diameter will increase linearly. It can also be seen that some models of FOC with the same number of OM tubes can be obtained using a different number of layers and provide the same cable capacity (or even more), but with a smaller diameter. This fact makes it possible to obtain a given capacity of OF in the cable when using a larger number of layers, while achieving smaller dimensions (material consumption) of the FOC. The smaller dimensions of the FOC lead to a decrease in the material capacity of the cable and, as a result, to a decrease in the cost of its materials during manufacture.

In order to quantitatively verify this statement, it is necessary to carry out a generalized assessment of the effectiveness of each presented model of the FOC according to the criteria outlined in the work.

According to expressions (2) – (7), the calculations of the mass of structural elements of the FOC were performed. All calculations of the coefficient of compactness of the FOC models are given in the Table 2 and Fig. 3.

Fig. 3 shows that the dependencies of the compactness coefficient have a parabolic character, that is, a small increase of the number of OM in the first layer leads to a greater increase of the cable compactness coefficient. That is, obtaining a smaller value of the FOC compactness coefficient is achieved when using a smaller number of OM and layers of the cable core. This choice is limited only by the conditions for the total number of optical fibers and the value of the mechanical strength of the cable [11]. This makes it possible to choose a more compact FOC model, which is especially relevant for more efficient use of the space of cable ducts, collectors and other places of cable laying. So, for example, models 12/1 and 12/2 have the same number of OFs in FOC models (144 fibers). According to the dependencies in Fig. 3, by choosing the 12/2 model, it is possible to get a FOC with a lower cost of materials. At the same time, the diameter of the FOC model will decrease by 10.9 %.

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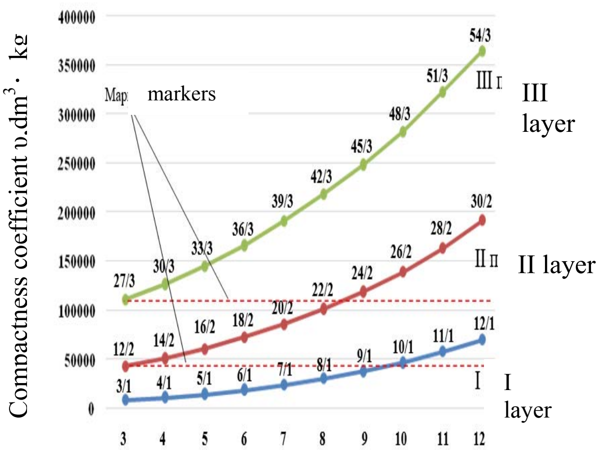
Table 2 – The results of calculations the compactness coefficient (dm^3·kg) of one-, two-, and three-layer FOC designs with different core structures

Number of OM tubes in the first layer	The number of layers of the FOC construction														
	I					II					III				
	Number of OF, N_{OF}	Diameter of FOC, mm	Volume of FOC per 1 km, dm^3	Mass of FOC per 1 km, kg	Compactness coefficient, dm^3 · kg	Number of OF, N_{OF}	Diameter of FOC, mm	Volume of FOC per 1 km, dm^3	Mass of FOC per 1 km, kg	Compactness coefficient, dm^3 · kg	Number of OF, N_{OF}	Diameter of FOC, mm	Volume of FOC per 1 km, dm^3	Mass of FOC per 1 km, kg	Compactness coefficient, dm^3 · kg
3	36	8.5	56.745	150.418	8535.5	144	13.1	134.782	317.830	42837.8	324	17.7	246.057	451.153	111009.4
4	48	9.1	65.039	170.605	11096	168	13.7	147.411	345.018	50859.4	360	18.3	263.022	481.645	126683.2
5	60	9.7	73.898	193.635	14309.2	192	14.3	160.606	375.193	60258.2	396	18.9	280.552	515.222	144546.6
6	72	10.4	84.949	218.876	18593.3	216	15.0	176.715	407.717	72049.7	432	19.6	301.719	551.235	166318.1
7	84	11.1	96.769	246.096	23814.5	240	15.7	193.593	442.363	85638.4	468	20.3	323.655	589.453	190779.4
8	96	11.8	109.359	275.173	30092.6	264	16.4	211.241	479.010	101186.6	504	21.0	346.361	629.756	218122.9
9	108	12.5	122.718	306.163	37571.7	288	17.1	229.658	517.725	118899.7	540	21.7	369.836	672.215	248609.3
10	120	13.2	136.848	338.953	46385	312	17.8	248.846	558.396	138954.6	576	22.4	394.081	716.718	282444.9
11	132	14.0	153.938	373.568	57506.3	336	18.6	271.716	601.055	163316.3	612	23.2	422.733	763.300	322672.1
12	144	14.7	169.717	410.133	69606.5	360	19.3	292.553	645.838	191574.8	648	23.9	448.627	812.103	364331.3



Number of OM tubes in the first

Figure 3 – Dependencies of the compactness coefficient of FOC models on the number of OM in layers (*m*/*n* FOC model number, where *m* is the total number of OM; *n* is the number of layers)

Using expressions (9), (10), the full cost of FOC materials C_c (Table 3) for one-, two-, and three-layers cable designs were determined in the work. Fig. 4 makes it possible to establish a visual connection between the cost of materials of the model FOC and the diameter of the cable. This dependence will make it possible to determine the parameter-criterion of economic efficiency of FOC models by diameter.

Fig. 4 shows the dependence of the total cost price of FOC materials on its diameter with different numbers of layers and elements in them. From Fig. 4 and Table 3 it can be seen that some of FOC models have approximately the same cost of materials in the overlapping parts of the graphs. This indicates that it is possible to choose such a FOC model, which at the same cost of materials will have better indicators of economic efficiency.

It was established that the increase of the cost of FOC materials due to the increase of the number of OM tubes (and therefore the total capacity of the OF inside the cable) from 3 to 12 in the first layer in a single-layer core of the cable is 66.8 %, in a two-layers – 86.6 %, in a three-layers – 87 %. The specified results of the calculation of the increase of the cost price of FOC materials in percent mean that the models of single-layer cables have the smallest cost variation.

According to the expression (8), the parameter-criterion of the economic efficiency of the FOC design by the diameter E_0 is determined. The results of the calculation of E_0 are presented in the Table 4 and Fig. 5.

From the Table 4 and Fig. 5, it can be seen that using more than one layer in the cable core, the value of the parameter-criterion of the coefficient of economic efficiency of the FOC decreases, that is, the expediency of the three-layer design is higher than the others if a large number of OF is needed. But at the same time, it can be seen that in the overlapping parts of the graphs, some FOC models have approximately the same values of the E_0 coefficient. That is, with approximately the same cost of materials of these FOC models, it is advisable to choose the one with a larger number of layers, as this gives a larger number of optical fibers. So, for example, from Fig. 5 models 10/1 and 12/2 have almost identical values of the parameter-criterion of economic efficiency E_0. However, by choosing the 12/2 model, it will allow us to get a FOC with more optical fibers (144 vs. 120).

On the other hand, for example, the models 12/1 and 12/2 have the same number of optical fibers, but different prices. By choosing the model 12/2 according to the results of this method, it will save 15.5 % of the cost of the cable for each kilometer of FOCL.

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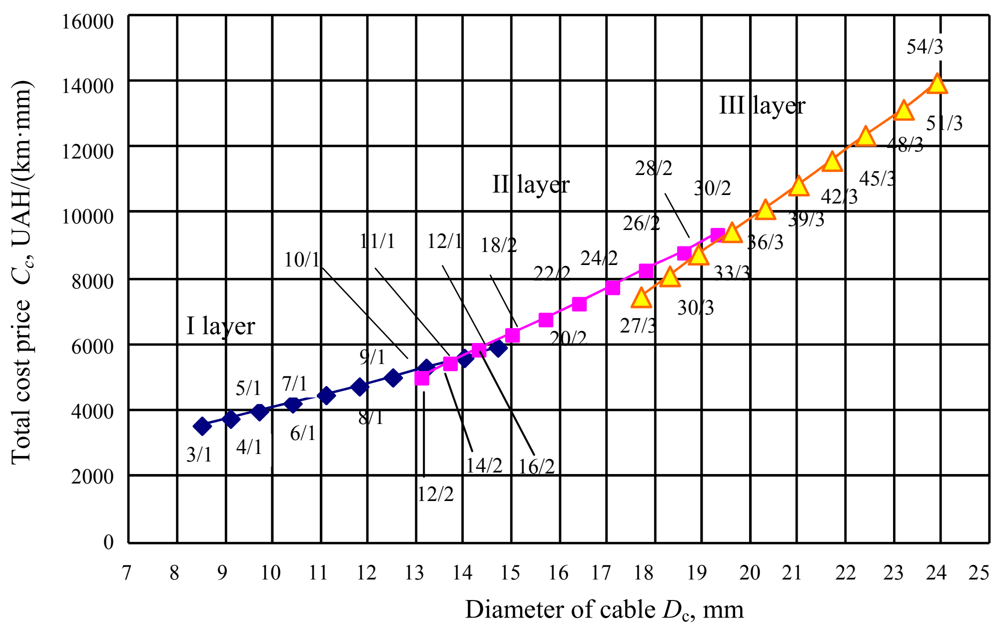

Figure 4 – Dependence of the total cost price of materials of the FOC on its diameter for one-, two- and three-layer designs (*m*/*n* FOC model number, where *m* is the total number of OMs; *n* is the number of layers)

Table 4 – Results of the calculation of the parameter-criterion of the economic efficiency of the FOC design by diameter

Parameter-criterion of the economic efficiency of the FOC design										
Number of layers in cable core	Number of OM in the first layer									
	3	4	5	6	7	8	9	10	11	12
I	0.416	0.339	0.279	0.227	0.188	0.158	0.134	0.114	0.097	0.085
II	0.117	0.107	0.097	0.088	0.079	0.072	0.065	0.059	0.054	0.049
III	0.067	0.064	0.061	0.057	0.053	0.050	0.047	0.044	0.041	0.038

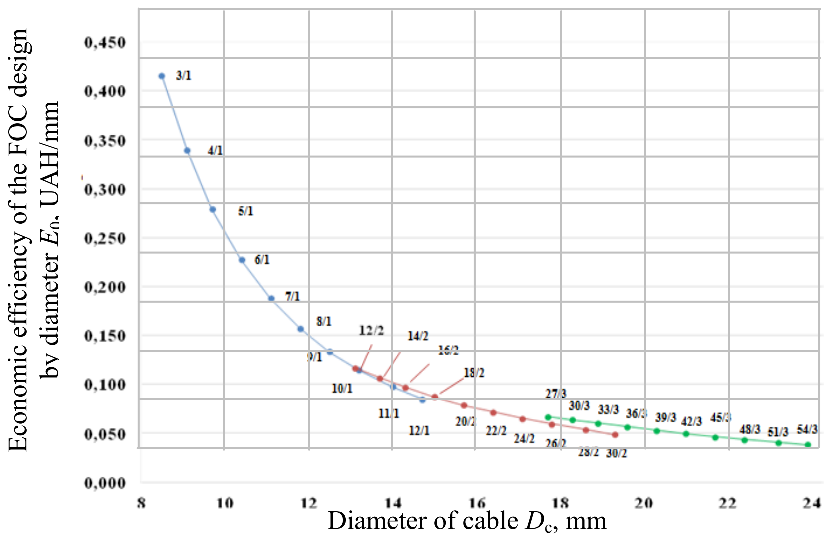

Figure 5 – Dependence of the parameter-criterion of the economic efficiency of the FOK design by the cable diameter (*m*/*n* FOC model number, where *m* is the total number of OMs; *n* is the number of layers)

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6 DISCUSSION

The proposed method of evaluating the efficiency of the FOC with a modular design will allow during the cable designing stage to make an appropriate choice of its model with the given initial parameters. The researches presented in this work show a large number of possible models of FOC. This is also confirmed by the variety of cable models that are presented on the official websites of the manufacturers' factories, for example PJSC "Odeskabel" and PJSC "Zavod 'Pivdenkabel'" [13, 14]. Thus, manufacturing plants provide a wide range of cables of the same brand, which differ in the structure of the core and the number of fibers. The consumer, based on his needs, chooses the necessary capacity of the cable. Moreover, a very important point at this stage is the lack of transparency of prices for FOC for the consumer. And the manufacturing plant seeks to save on the cost price of production of the FOC and to reach an agreement on the price through discussion with the buyer. Therefore, this method of evaluating the effectiveness of modular FOC design will allow manufacturing plants to systematize the expediency of manufacturing FOC models, and consumers – without prices, to orient themselves in the expediency of choosing a certain cable model.

The approaches to the creation of multi-layer FOC presented in this work are confirmed by the capabilities of the manufacturing plants according to their prices for cable products [13, 14].

The use of a larger number of layers in a multi-module FOC for reducing the costs of materials is confirmed by the results of work [11].

CONCLUSIONS

The researches in this work of the effectiveness of the modular FOC design based on mass and dimensional indicators allowed us to do the following conclusions:

1. In the work the method of evaluating the efficiency of the multi-module FOC design based on mass-dimensional indicators by applying to the intended range of cable models the criteria parameters – the cable compactness coefficient and the economic efficiency of the cable by to the diameter E_0 is developed and researched.

2. In the course of researches of FOC models, according to the accepted parameters-criteria, it was established that:

– by changing the number of layer elements and layers, a wide range of FOC models can be obtained to ensure the diversity of cables in terms of the total number of optical fibers;

– the use of the parameter-criterion of compactness is the ability to choose a model of the FOC with a smaller diameter (dimensions) while providing the same amount of OF. In the work, for example, it is shown that using this approach it is possible to choose a FOC model with a diameter smaller by 10.9 %.

– the increase of the cost of the FOC materials due to the increase of the number of OM tubes (and therefore the total capacity of the OF in the cable) from 3 to 12 in the first layer with a single-layer core of the cable is 66.8 %, with a double-layer – 86.6 %, with a three-layer – 87 %.

– the use of a cable with maximally filled by OM tubes in layers with one- and two-layers core is impractical, since the transition to a larger number of layers with a smaller number of OMs will allow to obtain a more compact cable design while simultaneously providing a given number of OFs. Therefore, for example, it is shown in the work that, by selecting the FOC model according to the approaches proposed in the method, it is possible to save 15.5 % of the cost of the cable for each kilometer of the FOCL.

3. The method, results, established facts and statements obtained in this work can be recommended for usage in the process of accelerated selection of a cable model at the stage of its designing, with the simultaneous provision of the necessary capacity of the FOC with optical fibers and the minimization of the cost of its materials and dimensions.

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МЕТОД ОЦІНКИ ЕФЕКТИВНОСТІ МОДЕЛЕЙ ВОЛОКОННО-ОПТИЧНИХ КАБЕЛІВ БАГАТОМОДУЛЬНОЇ КОНСТРУКЦІЇ ЗА МАСО-ГАБАРИТНИМИ ПОКАЗНИКАМИ

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АНОТАЦІЯ

Актуальність. На сьогодні заводи-лідери виробництва кабельної продукції в багатьох країнах світу виготовляють одно- та багатомодульні конструкції волоконно-оптичних кабелів (ВОК) з різними захисними покривами та кількістю волокон. Це створює широкий ряд можливих моделей ВОК для різних вимог споживача (покупця). Проте відсутність відкритості цін на ВОК для споживача, зокрема для проєктної організації, і прагнення виробника зекономити на виробництві створює необхідність в розробці та дослідженні методу оцінки ефективності ВОК багатомодульної конструкції. В роботі запропоновано зробити це шляхом аналізу низки моделей оптичних кабелів за параметрами-критеріями – коефіцієнтом компактності та коефіцієнтом економічної ефективності ВОК за діаметром.

Мета. Розробити метод оцінки ефективності моделей волоконно-оптичних кабелів багатомодульної конструкції за масо-габаритними показниками, що дозволить прискорено вибирати доцільну модель ВОК із заданими вихідними даними.

Метод. Розроблено і запропоновано метод оцінки ефективності ВОК модульної конструкції, який базується на порівнянні моделей кабелів і виборі найбільш доцільної з них при заданих вихідних даних. В роботі запропоновано та введено для цього параметри-критерії – коефіцієнт компактності υ та коефіцієнт ефективності за діаметром кабелю E_0 – які показують зв’язок характеристики конструкції ВОК до певного параметру його структури. При цьому найбільш ефективна модель (конструкція) ВОК порівняно з базовими моделями по технічним умовам, як з точки зору виробника і замовника, полягає в менших матеріаловитратах на його виробництво при одночасному забезпеченні заданих вимог до кабелю (в першу чергу, по кількості волокон та механічній міцності). Це дозволить на етапі проектування кабелю здійснити доцільний вибір його моделі з заданими вихідними параметрами та розробити таку конструкцію ВОК, яка дозволить мінімізувати габарити (а значить матеріалоємність і собівартість) моделі без втрати її кількісних та якісних характеристик.

Результати. В роботі приведено результати розробки та дослідження методу оцінки ефективності ВОК багатомодульної конструкції за масо-габаритними показниками. Для прикладу, використовуючи розроблений метод, показано, що можна обрати модель ВОК з діаметром меншим на 10,9 % і зекономити 15,5 % вартості кабелю на кожен кілометр ВОЛЗ при забезпеченні вихідних вимог до кабелю.

Висновки. Наукова новизна результатів роботи полягає в тому, що вперше розроблено метод оцінки ефективності ВОК модульної конструкції, який дозволяє на етапі проєктування кабелю здійснити порівняння моделі з конструкцією кабелю по технічним умовам (ТУ) та доцільний вибір цієї моделі з заданими вихідними параметрами. Практична значущість полягає в можливості за допомогою даного методу здійснювати прискорений вибір моделі кабелю на етапі його проєктування з одночасним забезпеченням необхідної ємності ВОК оптичними волокнами та мінімізації собівартості його матеріалів та габаритів.

КЛЮЧОВІ СЛОВА: волоконно-оптичний кабель, конструкція кабелю, геометричні розміри, масо-габаритні показники, собівартість матеріалів кабелю.

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