Cable conductor of cabling and wiring products based on composite materials for transport systems

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Abstract. The article deals with the issues of working out the technology of manufacturing cabling and wiring products that are used in railway transport systems. A cable conductor for a cable product, made on the basis of composite materials, was adopted as the object of research. The technology of production of composite billets and wire for cable products for subsequent drawing, as well as ways of obtaining them, is covered in detail. Special attention is paid to the problems of operation in railway transport, power transmission systems, which confirms the relevance of the research. The increase in the cost of the finished product is due to the violation of the technology, which is associated with the structural diversity of the layers of the composite long-length billet, determines the need to maintain the constancy of its plastic properties along the entire length. By means of a generalized mathematical model of the drawing process and on the basis of reference data, calculated parmeters of technological extracts were obtained for the layers of the composite billet to be drawn. The results of the research work made it possible to develop a methodology for calculating the technological modes of operation of the drawing machine and to determine the optimal technological parameters of the technological equipment.

1 Introduction

The work of modern railway transport systems is inextricably linked with the use of cabling and wiring products. One of the main tasks that arises during the operation of railway transport is electromagnetic compatibility [1] determined by the reliability of electrical equipment installed on traction electric vehicles (tools, devices, apparatuses) in an electromagnetic environment and the creation of conditions for the inadmissibility of their influence.

The degree of influence of the transmission line on adjacent networks is determined by the voltage level of the cable line and the currents flowing through it, as well as the degree of symmetry. Therefore, the issues of identifying patterns that interfere with the interaction of jointly working technical means will help determine the sources of electromagnetic emission both affecting the system and affected by them.

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Electric traction railway transport and traction network have cabling and wiring products in their composition, and cable lines and power transmission lines generally consist of it by 100%. Therefore, the study of the issue of improving the properties of the current-carrying part of the cable products in the systems under consideration: electric rolling stock; contact and rail wires, is relevant and will allow to form recommendations to achieve this goal.

Kryukov A.V. and Lyubchenko I.A. [2], A.M. Kozina and D.I. Seliverov [3], Tikhonova M.Yu., Kiyatkina M.P., Alayev K.R. [4], Khalikov A.A., Kolesnikov I.K., Kurbanov J.F. [5] were engaged in the study of the quality of cable lines in railway transport. However, they did not consider ways to improve the quality of the cable conductor.

The solution to this issue can be found in the use of composite materials (composites) in electric railway transport, which are used in the form of long-length electrical conductors for the production of cabling and wiring products (CWP). Cable products for these systems can be made on the basis of copper, aluminum and steel. The main advantage of the above-mentioned CWP is the development of designs of current-carrying parts with predetermined properties [6]:

- high performance in terms of production efficiency, structural weight and manufacturability;
- the possibility of obtaining materials with qualitatively new properties that not only increase the performance characteristics of existing structures, but also allow to create fundamentally new types that are not available when using traditional materials.

The technological process of manufacturing a cable conductor (CC) for a cable product that has special requirements for electromagnetic compatibility is very complex. This is due to the fact that the components included in the composite material, from which the CC to be made, shall be mutually compatible, i.e. they shall not interact with each other (not dissolve or otherwise absorb each other). All these parameters affect the quality of the CC made on the basis of composites, determining the technological and operational properties, which depend on the properties of the components of its constituent material and the level of their interaction [7]. The composition of composite wires from which CC is made shall also include filler, the quantitative composition and type of which determines a variety of physical and mechanical characteristics for it [8]. Based on the above, the following statement of the issue can be formulated: the component composition of the composite CC shall have complementary properties, which allows achieving high strength and fracture toughness characteristics in combination with at least high conductive properties.

2 Objects and methods of research

To date, with various methods of production of composite materials, powder metallurgy is often encountered; sintering in a vacuum furnace or in a dry hydrogen medium (for refractory compounds having high mechanical properties). In the case when a strengthening non-metallic element is introduced into the structure of the CC, the effect of an electric current is used, which accelerates the sintering process, and ultimately a cable product with high mechanical properties and reduced cost is obtained. The electric pulse and electric contact sintering method allows combining two advantages of the CC: a unique combination of materials and the physical and mechanical properties of the CWP established by the operating conditions [8-11]. In addition, composite CC can be made by molding products, consisting of open (contact molding, spraying, winding, centrifugal molding) and closed (pressing, injection molding, as well as pulling, drawing) methods [10, 11]. Axisymmetric layered composite wire (bi- and trimetallic electrical conductors) are drawn and is considered the most effective technology for manufacturing CC [11].

 https://doi.org/10.1051/e3sconf/202340103036

Modern scientists Arkulisa G.E., Belov M.I., Boyarshinov M.I., Belalov Kh.M., Zalazinskiy A.G., Eylman L.S. and others deeply investigated the issues of the process of deformation of cable billets based on composite materials by drawing technology [11].

The revised requirements for the operational characteristics of the CWP used in electrified electric road transport and traction systems have also determined new conditions for the technological process of production of composite CC, namely the use of modern technological cable equipment [12, 13]. The complexity of the manufacturing technology of CC, structured from layered electrical conductors, is caused by the need to produce a construction length equal to 1 km and strict control of the technology requirements with the provision of structural limitations: the continuity of the core coating and the constancy of the wire diameter [11].

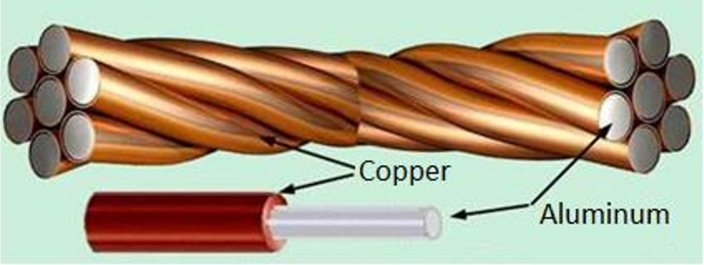

Fig. 1. Composite wires made of aluminum copper

As an example, consider a composite aluminum wire coated with copper having a brittle intermetallic phase between the aluminum core and the copper coating (Fig.1). As a result of multi-pass drawing of the cable billet, we obtain wires with an output diameter ($d_{output} = 0.1 \div 0.7\ mm$), a construction length - a single segment - ($l_{constr.} = 3 \div 30\ km$). At the same time, the main design parameter – the strict geometry of the multi-core composite, shall correspond to the absence of overclamping, breaks, foreign inclusions, high uniformity of superconducting fibers. In this regard, the technological process of production of the finished cable product (composite wire drawing) is the longest of all existing technologies.

In addition, multi-pass drawing has the ability to provide deformation of the cable billet without breaks, as a result of which a composite long-length billet with a structural variety of layers allows to maintain plasticity along the entire length of the drawn wire, while ensuring continuity. This indicator is especially important for fine drawing, which has a high cost of the billet.

In this regard, the relevance of the set production task increases significantly, because it becomes possible to organize and technologically debug the production of long composite products that meet high operational requirements - the absence of defects along the entire length. This can be achieved by implementing measures to work out technological modes and improve technological equipment [11, 12], developing new methods for recalculating the drawing route [13, 14].

The most developed, in terms of the technology, is the method of production of bi- and trimetallic round-section electrical conductors, the structure of which is a core and one or two shells (Fig. 2) [11].

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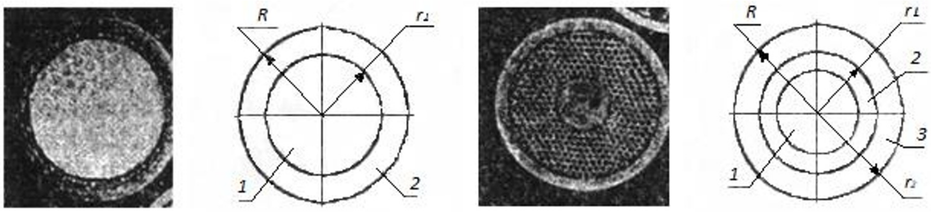

Fig. 2. Cross section of composite billet for wire drawing: 1 - core; 2, 3- shell.

The drawing technology under consideration makes it possible to produce a CC with a critical value of the magnetic field strength, temperature and current density (j_c), determined by the percentage composition and structural parameters of the metals or alloy included in its composition [7-9].

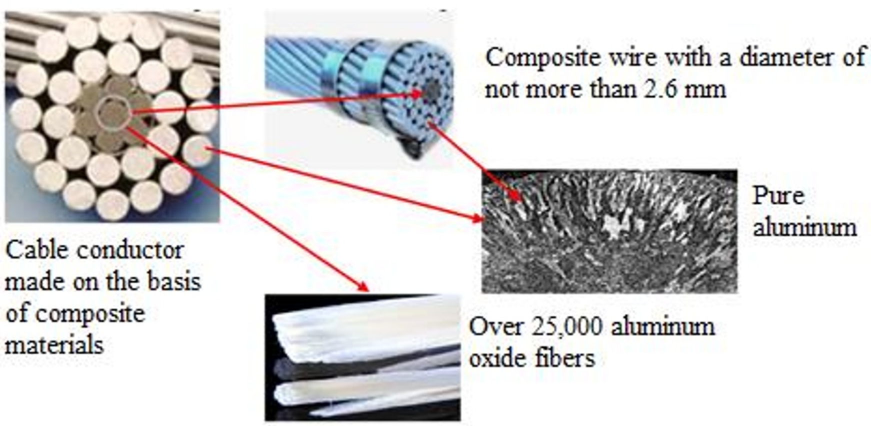

Fig. 3. Construction of bare non-insulated wire made on the basis of composite materials

Consider possible versions of the composite used for the cable billet (Fig. 3), bi- or trimetall, having an intermediate layer or core made on a composite basis, consisting of superconducting fibers (*NbTi* alloy or *Nb* compounds (($\sim 10^1$-10^4 *pcs*), which are matrices (copper or high-tin bronze [9, 10].

3 Results and their discussion

The qualitative parameters of a heterogeneous system (a composite material having components that are not miscible with each other) provide the required set of CC properties for electrified railway transport and traction network. At the same time, the nomenclature range of composite wires has different operational and technical parameters, are manufactured under different technological conditions and on different cable machines (CM), the choice of which is determined by the technological capabilities of the cable enterprise, as well as a variety of chemical composition.

The drawn wire is the basis for the manufacture of the conductive part of the cable. Accordingly, the proven technological operation - drawing, will allow to obtain a finished product with high performance characteristics and low cost of production, due to the reduction of production waste, namely: breaks and technological defects [10, 11].

The analysis of existing technologies allowed to identify two ways to solve the issue:

https://doi.org/10.1051/e3sconf/202340103036

• practical - increasing the durability of the finishing (diamond) die of the drawing process tool [12-14],

• mathematical - improvement of drawing technology (development of a mathematical model of drawing a composite billet and a methodology for calculating the minimum and maximum values of one-time deformation determined by the unevenness of deformation of a composite billet (heterogeneous composition) [11].

The peculiarity of the billet for composite CC is the layering structure and composition (differing physical and mechanical characteristics) [16], which means that the elemental composition of the material has different extraction coefficients, as well as the strength and speed of drawing (Fig. 4).

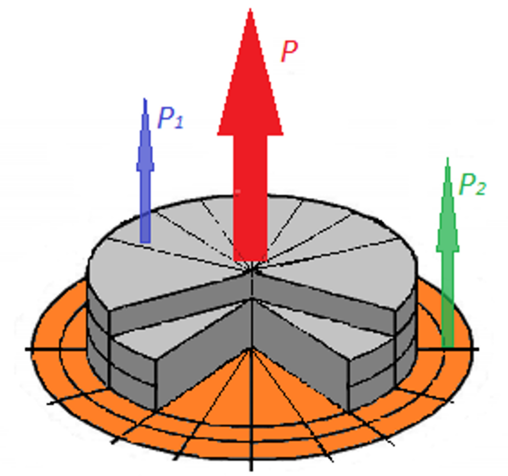

Fig. 4. Model of the distribution of drawing forces across layers of composite wire: P – drawing force; P_1 – drawing force acting on the core; P_2 – drawing force acting on the shell

The basic model of the distribution of drawing forces across layers of composite wire (Fig. 4) is developed on the basis of a generalized mathematical model for a drawing machine [11].

$$P = P_1 + P_2 \tag{1}$$

The heterogeneity of the chemical composition of the initial billet determines the different values of the wire drawing, due to the degree of deformation of the layers. At the same time, the critical point in the drawn wire is the transition of layers (material composition), which occurs due to the presence in this area of the initial stage of the drawing and, as a consequence, of a significant compaction of the material structure resulting from interlayer friction, when the drawing force formed between the inner layers of the material structure is applied. The cross-section of the billet is considered a dangerous cross-section if the drawing force acts on the plane (1).

The generalized mathematical model (2) allows the technology of wire drawing based on composite material and to calculate the operating modes of a direct-flow drawbench. At the same time, the optimal multiplicity of the drawing process was determined with the provision of energy efficiency of the technology as a whole for the composite billet [11, 12].

$$\mathrm{M}_{din_n}(p) = M_{dv\,n}(p) - P_n(p)\frac{R_{b\,n}^{in}}{j_{red\,n}} + Q_{(n-1)}(p)\frac{R_{b\,n}^{out}}{j_{red\,n}} - \mathrm{M}_{\mathrm{xx}\,n}(p)$$
$$\omega_{dv\,n}(p) = M_{dv\,n}(p)\frac{1}{J_{\Sigma n}\,p};$$
$$v_{b_n}^{in}(p) = \omega_{dv\,n}(p)\frac{R_{b\,n}^{in}}{j_{red\,n}};$$
$$v_{b_n}^{out}(p) = \omega_{dv_n}(p)\frac{R_{b\,n}^{out}}{j_{red\,n}}; \qquad (2)$$
$$P_i(p) = (v_{b\,n}^{in} - v_{v\,n}^{out})\frac{EF_n}{L_{p\,n}p}$$
$$v_{v_n}^{out} = v_{v_n}^{out}\mu$$
$$v_{\text{в}_n}^{in} = Q_i(p)\frac{L_{Q_n}p}{EF_{(n-1)}} + v_{\text{б}(n-1)}^{out}$$
$$Q_n(p) = P_n(p) - N_n(p)$$

The results of modeling the drawing process are presented in Fig.5, which allowed obtaining optimal values of technological drawing (Fig. 5) [11].

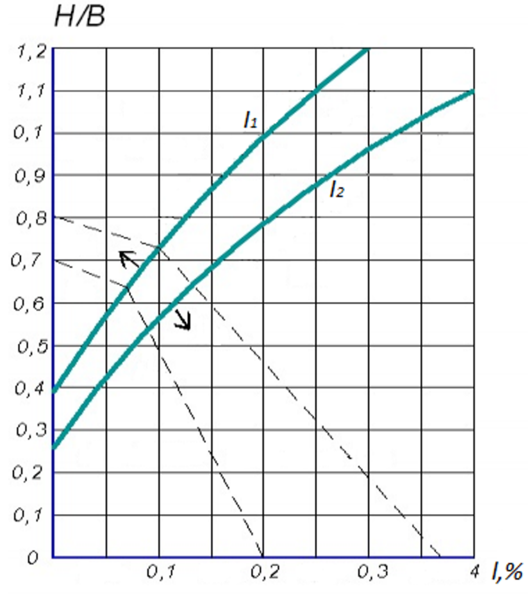

Fig. 5. Parameters of technological drawing for composite billet, where I_1 – core; I_2 - shell

4 Conclusions

The study of electromagnetic compatibility issues is relevant for electric railway transport. In this regard, the improvement of the CC design will improve the quality performance of the entire electrical system as a whole. This is achieved through the introduction of CC, made on the basis of composite materials. The solution of the task is impossible without improving the drawing technology. At the same time, it should be noted that the technological processes of drawing wires, made on the basis of traditional materials and composite materials, require constant development and improvement of manufacturing technology, because they differ significantly from the production of standard cables and wires. In addition, the efficiency of the drawing technology depends on the features of the composite wire structure. The research work carried out and the corresponding calculations, by means of a generalized mathematical model of the drawing process, allowed to obtain data on refined technological characteristics. The application of the results of research work will make it possible to reduce the percentage of waste associated with the breakage and culling of expensive products, which will make it possible to work out the technological mode and correctly calculate the drawing route.

As a result of the research work carried out, a methodology has been developed with the help of which it is possible to calculate the technological modes of operation of the drawing machine, and determine the optimal technological parameters of the processing equipment. The operation of cable products, the design of which contains a composite current-carrying part, is a very progressive direction, not only for railway transport, but also for the national economy as a whole. However, recycling of waste and dismantled cable, which is subject to replacement, as out of order has not been solved, and requires new technological solutions and research in this direction.

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