Development of generalized requirements for automated electric drive of cable equipment

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Abstract. The article deals with the production of cable and wire products and the operation of cable processing equipment. The technological parameters of cable machines are analyzed by maintaining the range established by the regulatory documentation, and the main task of ensuring the efficiency of the technology is formulated. The requirements for automated electric drive of cable equipment are analyzed, considering the harsh modern operating conditions of cable products. The work of modern cable equipment with a high level of automation of the technological process and existing cable machines with a service life of more than 10 years is considered. The possibility of creating a unified automatic control system for both the entire technological process and a separate technological operation by creating a flexible control system for a separate cable machine with the further formation of a full-scale digital environment for the entire cable enterprise is analyzed. The developed generalized requirements for the automated electric drive of the cable machine made it possible to conduct research on specific cable equipment—the VSK-13 drawing machine by creating a simulation model, and the obtained results of mathematical modeling gave good results on the computational experiment of the electromechanical system of the VSK-13 drawing machine.

1 Introduction

The design of all cable products contains the basic elements that are uniform for all types of cables and wires: a cable conductor, core, insulation, shield, and protective cover/shell. At the same time, various cable machines and aggregates are used in all technological operations, performing a technological cycle based on a certain technology (drawing; annealing; twisting; extrusion; pressing, melting, rolling), and operating conditions. However, for all types of cable machines used, one common feature is characteristic—the presence of an object (cable billet) that connects all working nodes (Fig. 1). The technological operation determines the type of cable machine, as a result of which the object (cable billet) changes its appearance, changing from copper or aluminum wire rod to drawn wire, then into the twisted cable conductor (CC), followed by applying an insulation layer, twisting the CC into the core or finished cable product. Ensuring the high quality of...
2 Objects and methods of research
and the diameter of the wire/cable product; ensuring high reliability of electrical equipment; stabilization of the wire diameter and its residual deformations, exclusion of eccentricity; fixed drawing for a given diameter of the finished product, compliance with the drawing route, kinking and breakage, smooth start and braking, as well as the inclusion of emergency shutdown mode of the entire cable line as a whole; sensitivity to changes in the composition of the material and its properties.

Modern operating conditions of cable lines define strict requirements for the design and technological execution of cable and wire products at all stages of its production without exception. Compliance with these conditions, respectively, determine the requirements for the AED CPE, on which the principles of CM control and options for building more flexible electric drive control systems (FEDCS) are based.

The modern cable equipment manufactured has a high level of automation and a wide range of control parameters, which ensures speed and reliability in changing the settings of the EDCS CM to new technological conditions that take into account both the properties of the cable billet, material, and changing external influences and climatic features of the region, technology features, vibration and temperature background of the equipment operating nearby (at a small distance) installed on neighboring production areas, the human factor, which is determined by the level of training and qualification of the service personnel.

To date, cable plants have a large fleet of installed processing equipment, the service life of which lies in a wide range (Table 1), which does not allow the engineering and technical service to create a unified control system (ECS) not only for the technological process of manufacturing cable and wire products as a whole, but also for a separate technological operation, because 65% of all CPE have a CS that does not meet the requirements of digital transformation of an industrial enterprise (Table 2), and the formation of a full-scale digital environment in all production and management structural divisions of a cable enterprise [5, 6].

Table 1. Introduction of digital technologies at Uzbek cable enterprises in 2020, % of respondents

<table>
<thead>
<tr>
<th>№</th>
<th>Item Description</th>
<th>Implemented</th>
<th>Planned to Implement</th>
<th>Not Implemented and Not Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Electronic document management</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Advanced accounting systems (CRM, SAP and etc.)</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>General Service Center</td>
<td>2</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>Full automation of a separate production and business process</td>
<td>13</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Full automation of the technological chain and business process</td>
<td>5</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Full automation of the technological operation and technological process</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Machine intelligence</td>
<td>-</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td>8</td>
<td>Video analytics and machine vision</td>
<td>-</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td>9</td>
<td>Robotization of production and business processes</td>
<td>-</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>Augmented or virtual reality</td>
<td>-</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>11</td>
<td>Smart production</td>
<td>-</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>12</td>
<td>Machine-to-machine communication, IoT technologies</td>
<td>-</td>
<td>1</td>
<td>14</td>
</tr>
</tbody>
</table>
The "flexibility of technological modes" refers to adapting the working technology to the raw materials and materials used in the CM technology. Thus, the main stage in the development of generalized requirements for CM automated electric drive is the creation of a unified database of parameters of processing equipment (Fig. 2).

The development of a block diagram for a generalized technological operation for the manufacture of cable and wire products, taking into account the parameters and external influences exerted on the CM, is carried out to optimize existing technologies involved in the technological process of manufacturing cable and wire products.

The generalized requirements of the FEDCS shall include the design features of the CM and take into account the design and technological features for its subsequent modernization. The main purpose of the modernization of the CPE is the installation of an additional unit that provides stabilization of the speed of movement of the cable billet along the entire length of the CM passing through all working units and mechanisms (Fig. 1).

This is achieved by synchronizing the operation of electric motors of all working mechanisms and coordinating the parameters of technology regulation, and maintaining the tension and drawing of the cable billet in the range established by the technological documentation. The functional scheme of the FEDCS of the generalized technological operation performed on the CM is shown in Fig. 3.
Fig. 3. Functional diagram of the FEDCS generalized technological operation performed on CM:

1 is intermediate block; 2 is gear-box; 3 is electric motor; 4 is converter (power amplifier); 5 is process parameter control system; 6 is sensor system; 7 is auxiliary device system.

The flexible system of the automated electric drive of the CM shall provide control and management of the main technological parameters of the generalized technological operation (Fig. 2) of drawing: length \( l_n \), wire diameter \( d_n \), tension \( \mu \), pulling force \( P_n \), properties of processed raw materials and materials \( k_n \).

At the same time, it is necessary to coordinate the operation of the additional node and the main working mechanism of the CM, as well as the receiving mechanism, taking into account compliance with all technological modes of the technology.

The role of a power amplifier in the control system of an automated electric drive (AED) of the CM is performed by thyristor/transistor converters. The system's sensors depend on the type of the FEDCS CM: the number of controlled coordinates, the type of signal being captured, and the accuracy requirement. The construction of the AED CM is provided by the control of the main technological parameters of the technological process and control through the tension of the cable billet on the subsequent pulling, working mechanism: the length of the cable billet and diameter, circumferential and linear speeds and the number of winding turns (if this parameter is present).

The coordination of the speeds of working mechanisms and the exclusion of overstretching are performed by operators (tension sensors). They make it possible to reduce the system's sensitivity to the elasticity of the cable billet. The signal received from the tension sensor evaluates the tension values and allows the system to quickly control the tension and identify other technology parameters inaccessible to direct measurement.

The process of winding the cable billet onto the take-up block is carried out by devices with contact and non-contact measurement of the winding radius (direct and indirect methods). At the same time, the contact method cannot provide high accuracy of measurements of the current winding radius (the eccentricity of the take-up block); therefore, devices implementing non-contact methods of measuring the radius are preferred (indirect estimation of the ratio of the linear speed of the take-up block to the circumferential, measuring the radius of the take-up block as the length of the wound wire when the take-up block is rotated by an angle equal to one radian). The composition of the device: pulse sensors of the winding shaft speed. The length of the wound cable billet is determined by the number of voltage pulses at the sensor's output with sufficiently high accuracy of measuring the radius of the take-up block. It is supplemented by a system that allows it to start measuring from an arbitrary coordinate.

The tension of the cable billet, as the main coordinate, determines its properties [3, 4].

The tension control system is implemented on indirect and direct regulation principles. Automation and operational control of technological modes of equipment operation are generally implemented by the control system of the CM twin-motor electric drive using dual-circuit systems of subordinate control of the rotation speed of the CM motors and the receiver.

Proportional-integral controllers (PI controllers) make it possible to compensate...
3 Results and discussions

Fig. 4. Drawing process diagram (calculated): 1 - intermediate block; 2 - technological tool (drawing); 3 - wire; 4 - winding device (take-up block).

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The efficiency of the drawing process depends on many technological factors determined by the technical condition of the DM, the quality of the cable billet material, the properties of the technological tool, and technological lubrication. The main technological parameters of drawing include (Fig. 4): the drawing speed ($v$), the angular velocity of the pulling washers ($\omega$), the back force ($N$), and the drawing force ($P$), as well as the diameter of the pulling washer ($D$) and the input-output diameters of the wire ($d$), and the total and technological drawing ($\mu$).

Fig. 5. Results of mathematical modeling of the automatic control system of the drawing machine. A computational experiment, carried out using a simulation model allowed to obtain a transient process of operation of an electromechanical system of the drawing machine (Fig. 5). The main purpose of the research work carried out was to verify the correctness of the choice of generalized requirements for the automated electric drive of the drawing machine, and accordingly, the adequacy of the calculation system (mathematical and simulation models of DM operation), as the interconnected operation of the nodes and elements of the electromechanical system (EM S), taking into account the qualitative parameters of the drawn wire.
4 Conclusion

The developed generalized requirements for the automated control system of the drawing machine allowed the creation of a DM simulation model (Fig. 5) with flexible, energy-efficient wire drawing while increasing productivity, reducing capital and operating costs, and improving the quality of output products.

The analysis of the DM operation in the mode of simulation of technological modes allowed to conclude that the correctly generalized requirements for the automated electric drive of the DM allowed to calculate the correct version of the FEDCS of the DM to increase the operational characteristics of DM VSK-13 by 10% compared to the existing ones, and the quality of finished products and the operational parameters of the drawn wire will remain at the same level. At the same time, significant copper savings will be achieved by reducing the number of emergency shutdowns, reducing entering ends, and, as a result, introducing a resource and energy saving program into the main production of cable and wire products.

References
