E3S Web of Conferences **401**, 02045 (2023) https://doi.org/10.1051/e3sconf/202340102045
CONMECHYDRO - 2023

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

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cable and wire products is achieved by observing the established modes and norms in the operation of processing equipment, the main of which is the regulation of the tension of the object (cable billet) in the required ranges except for kinking and overstretching.

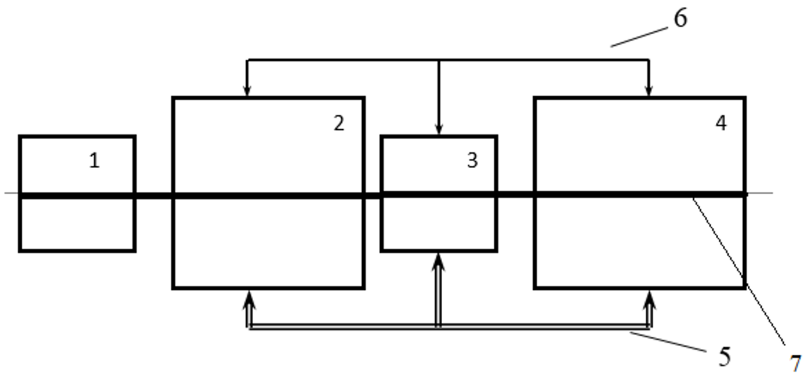

Fig. 1. The main components of the cable machine: 1 is pay-off stand; 2 is working unit; 3 is draw-out equipment; 4 is receiver, 5 is electrical connection; 6 is mechanical connection; 7 is object (cable billet).

Each cable processing equipment (CPE) has individual technological parameters, the maintenance of which ensures high quality of cable and wire products manufacturing, starting from the stage - the manufacture of copper or aluminum wire rod and ending with the finished cable product. The main task of ensuring the efficiency of the technological process is to maintain the values of the parameters of the cable machine in the required range, which shall not exceed the maximum tension determined by the tensile strength of the processed material and taking into account the minimization of the relative elongation of the entire cable billet as a whole.

Many scientists working in the cable industry, such as I.B. Peshkov, G.I. Meshchanov, A.K. Bulkhin, Yu.T. Larin [1, 2, 3], as well as cable enterprises of the CIS countries, were engaged in solving the issues of optimizing technology and maintaining the established technological parameters of equipment in the operation of cable machines: JSC "Elektrokabel" (Moscow), JSC "Samarakabel" (Samara), SPE "Spetskabel" (Moscow), LLC "Tatkabel Plant" (Stolyuishche village, Kazan), who conducted extensive research and practical work in the field of developing requirements for the operation of processing equipment. However, the analysis of scientific and practical works showed that they considered certain types of cable machines (CM), and a unified approach to the issue of deep automation of the technological process has not been developed. In this regard, and taking into account the growing requirements for modern cable products, it is an urgent solution to the problem of developing generalized requirements for automated electric drive of cable equipment technologies that take into account the parameters of systems and conditions for ensuring the quality of regulation of technological and operating parameters.

2 Objects and methods of research

The technological process of manufacturing cable and wire products and the features of the execution of cable equipment (CE) determine the requirements for an automated electric drive (AED) [3, 4]: coordination of the movement of the CM working parts, start and shutdown; regulation of the operating speed in a given range; regulation of the tension of the cable billet and stabilization of the uniformity of recoil and layout; regulation of tension 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, determines 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

№	Item description	Implemented	Planned to implement	Not implemented and not planned
1	Electronic document management	10	3	2
2	Advanced accounting systems (*CRM, SAP and etc.*)	10	3	2
3	General Service Center	2	5	8
4	Full automation of a separate production and business process	13	1	1
5	Full automation of the technological chain and business process	5	8	2
6	Full automation of the technological operation and technological process	10	3	2
7	Machine intelligence	-	-	15
8	Video analytics and machine vision	-	-	15
9	Robotization of production and business processes	-	5	10
10	Augmented or virtual reality	-	1	14
11	Smart-production	-	1	14
12	Machine-to-machine communication, IoT technologies	-	1	14

One of the ways to solve this problem is the introduction of measures to modernize existing cable processing equipment with a service life of more than 10 years (table 1) by automating it - the development of the FEDCS that meets modern requirements of the technological process and provides productivity growth, high energy efficiency of both the entire technology as a whole and maximum *flexibility of technological modes* equipment. 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).

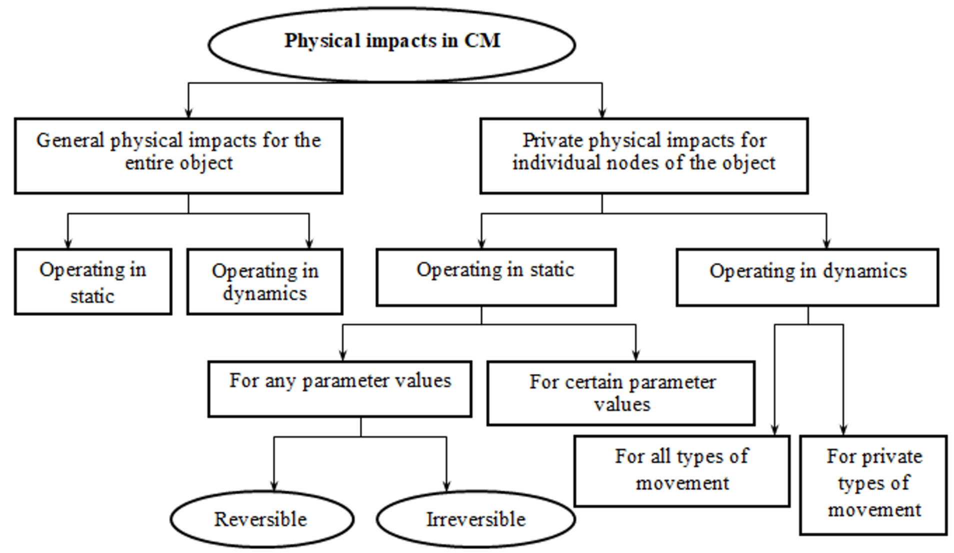

Fig. 2. Classification of CM parameters

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.

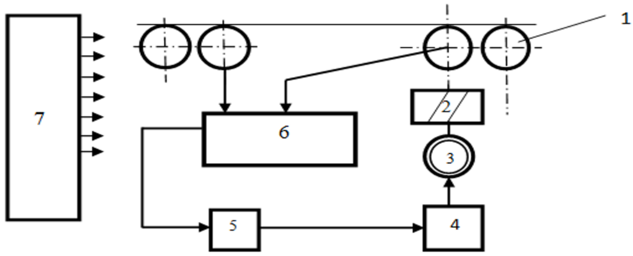

Fig. 3. Functional diagram of the FEDCS generalized technological operation performed on CM: 1 is intermediate block; 2 is gear-box; 3 is electric motor; 4 is converter (power amplifier); 5 is process parameter control system; 6 is sensor system; 7 is auxiliary device system

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 (μ), 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 loopers (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 for the inertia of the power circuit in the internal current loop of the CM motors and the receiver and form a transient process in the current loop to ensure a faster increase in the armature current in the absence of over-regulation with the necessary limitation of the current and speed of the motors during overloads and fluctuations in the mains voltage (the choice is made from the condition of ensuring minimal static errors in the speed of the CM driving motor). The receiver motor has a PI controller for speed and wire tension. The drawing machine is controlled as a signal generated either at the output of the take-up block radius meter or as a function of the length of the wire being wound. The operation of the device is based on the method of controlling the winding density (Archimedean spiral) [7], forming, following the law of regulation, the tension of the cable billet as a function of the signal of the difference between the actual and theoretical winding radii, which is fed through the integrator to the input of the tension device. The signals of operational control of the winding speed, the length of the cable billet, its tension, the uniformity of the layout, the radius of the pulling devices, and the number of turns enter the control device and provide current information about the progress of the technological process, and form a command to automatically stop when the specified parameters are reached (the length of the wire and the radius of the working area of the pulling device).

When choosing an option for constructing a control system for a generalized technological process [4, 8, 11], it is necessary to take into account the dynamic characteristics of the control object and the tension control circuit to the winding density control circuit; tension control, reducing the sensitivity of dynamic characteristics to the natural inertia of working mechanisms and the static torque of the drive motor; to build a system at the level of the control loop for changing the diameter of the cable billet, which is explained by the high requirements for the accuracy of measuring the linear parameters of the moving billet, the winding radius, tension and rotation speed of the intermediate blocks, the need to use sensors to control the process of winding the cable billet; in the case of installing a low-flow tension sensor in conditions of parametric and external disturbances, use reversible converters to power the drive motors and ensure the necessary speed and accuracy of regulation in all CM operating modes.

The developed block diagram of the generalized technological operation of the technological process of manufacturing cable and wire products (Fig. 2) includes technological parameters (Fig. 1), which are the basis for formulating generalized requirements for automated electric drive of cable equipment. The work done makes it possible to use the functional scheme of the FEDCS as a generalized technological operation performed on the CM (Fig. 3).

3 Results and discussions

A drawing machine (DM) of the VSK-13 brand, the service life of which exceeds 20 years, has been chosen as the research object. The technological operation of the drawing (Fig. 4) is determined by the amount of drawing of the cable billet (3) obtained due to the difference in the rotation speeds of the intermediate blocks (1) [11-14].

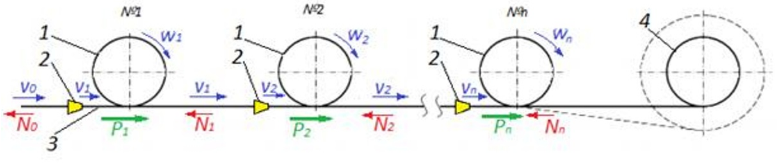

Fig. 4. Drawing process diagram (calculated): 1- intermediate block; 2 - technological tool (drawing); 3- wire; 4- winding device (take-up block)

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 (ω), 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 (μ).

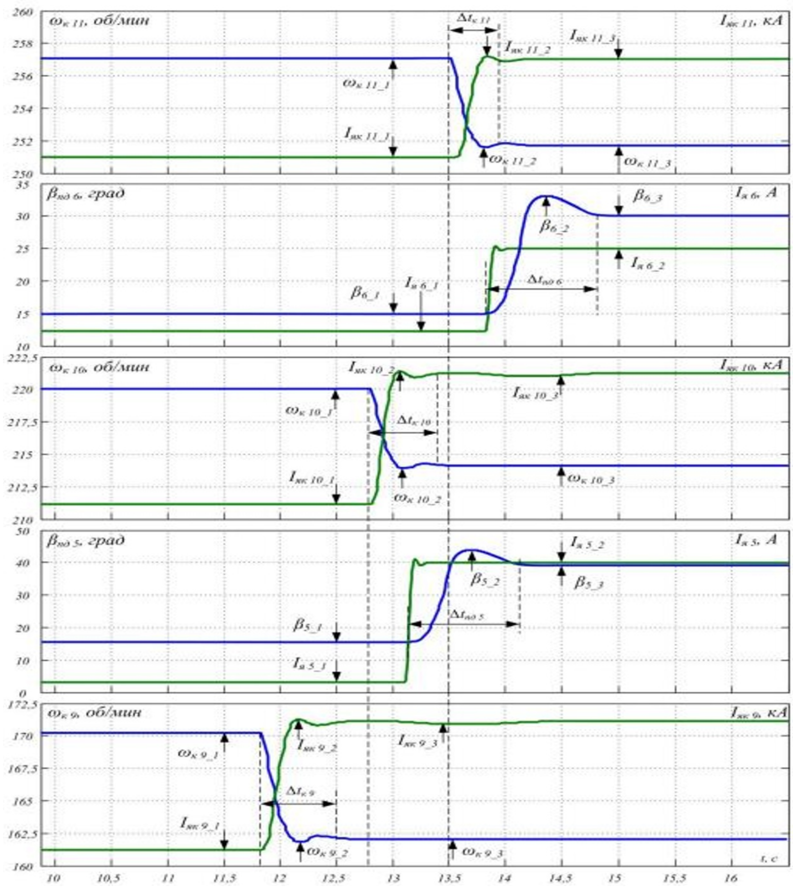

Fig. 5. Results of mathematical modeling of the automatic control system of the drawing machine

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 (EMS), 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 of 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

1. Peshkov I.B., Cables and wires. Fundamentals of cable technology, Moscow, (2009).
2. Meshchanov G.I., Kamenskiy M.K., Frik A.A. Development of production and expansion of application areas of new types of fireproof cables in Russia. Cables and wires, No. 4 (305), p. 5-9. (2007).
3. Bulkhin A.K., Kidyaev V.F., Kijayev S.A. Electric drive and automation of drawing equipment. (2002).
4. Bulkhin A.K., Kidyaev V.F., Kijayev S.A. Automation and adjustment of cable equipment. pp. 175-185. (2001).
5. Pirmatov, N. B., Madrakhimov, D. B., Ivanova, V. P., Tsypkina, V. V., Ortikova, M. J., and Atamukhamedova, R. F. Determination of the degree of digitalization at the cable enterprise level. In AIP Conference Proceedings, Vol. 2552, No. 1, p. 070009. (2023).
6. Pirmatov, N. B., Ivanova, V. P., Tsypkina, V. V., Nazrullaeva, O. A., and Ramatov, A. N. U. Issues of digital transformation of the cable enterprise. Universum: Engineering Sciences, Vol. 6-4(87), pp. 71-75. (2021).
7. Bystrov A.M. Multi-motor automated electric drives of production lines of the textile industry / Bystrov A.M., Glazunov V.F. -M.: Light industry, 1977. - p.225-263.
8. Bergmann J. P., Petzoldt F., Schürer R., and Schneider, S. Solid-state welding of aluminum to copper-case studies. Welding in the World, Vol. 57, pp.541-550. (2013).
9. Glazunov V.F. Principles of subordinate regulation in the construction of a high-speed production line electric drive, pp. 75-86. (1980).
10. V.P. Tsypkina, A.A. Khashimov, V.V. Tsypkina, Automation and modernization of technological drawing processes that ensure resource saving. Tomsk
11. V.P. Ivanova, V.V. Tsypkina, O.U. Turabekov, Kh.A. Muminov, S.M. Khayitmuradova. Issues of development of an improved automatic control system for a drawing machine with a long service life. Universum: Technical Sciences. No. 5-5 (86). (2021).
12. Tsypkina, V., and Ivanova, V. Modeling of a resource-saving method of drawing. In E3S Web of Conferences, Vol. 139, p. 01073. (2019).

13. Madrakhimov, D. B., Ivanova, V. P., and Tsypkina, V. V. Improving the reliability of cable lines operation in hot climates. In E3S Web of Conferences, Vol. 216, p. 01151. (2020).
14. Tsypkina, V. V., Ivanova, V. P., Isamukhamedov, D. N., Turabekov, A. U., and Hayitmuradova, S. M. Ways to solve the system technical and economic issue-digital transformation of the technological process of manufacturing cable products. In AIP Conference Proceedings, Vol. 2552, No. 1, p. 070010. (2023).