Ensuring reliable operation of stranding machine for cable production through the use of intelligent technologies

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Abstract. The article discusses the reliability of cable manufacturing equipment by diagnosing its technical condition. The solution of this issue is provided by the use of intelligent systems with expert assessment and prediction of probable failures in operation. The built-in working environment for the management of cable manufacturing equipment makes it possible to solve the issues posed by the reliability of cable making machines with a long service life by integrating artificial intelligence elements into a system with limited resources. The implementation of the solution to the problem is carried out on the stranding machine for cable production, on the example of which the options are considered that provide the necessary level of not only the reliability of the equipment in the manufacturing technology, but also the reliability in operation of the finished cable product.

Introduction

The use of artificial intelligence in the operation of technological systems is an urgent task focused on centralized management of production processes provided with modern high-tech equipment.

Like any modern technological process, cable production is a flexible technology aimed at the production of finished cable products of various nomenclature, which is determined by the volume of the production order, depending on the contracts concluded by the sales service for the supply of cable or wire to consumers.

The main purpose of the production service is to ensure the preparation of production (PP) for the frequent changeability of the nomenclature of cable and wire products (CWP), taking into account the high productivity of the technological equipment involved. This is achieved by purchasing highly efficient in-line cable lines built on modern information technologies capable of providing the necessary level of automation of the entire production technology as a whole. However, the cable industry contains a large fleet of obsolete technological equipment that has been put into operation for more than 10 years (Table -1), which is not able to meet the requirements of technology: to maintain complex mechanization and automation at the proper level both for modern cable production and for a single technological process of manufacturing a single production order for a cable product. The new, modern technological equipment has input *x(t)* and output *y(t)* control signals focused on working in a single (centralized) control system for the production process of manufacturing finished products, which ensures the smooth introduction of digital technologies into the cable industry.

The cable company today is a production process of mastering new types of high-quality CWP, having a high level of operational reliability, with minimizing the set deadlines for both the PP and the manufacture of the finished product, ensuring the seriality of the products with a reduced level of labor intensity of the technological process and reducing the cost of the CWP. The task set by the production workers is solved by the acquisition of modern, high-tech production complexes, which include several cable lines that perform technological operations sequentially and are linked to a single automated system with numerical control. The peculiarity of modern cable making machines is that they freely adapt to a single automated process control system (APCS) within the entire cable plant, providing accurate and maximally predictable control of the manufacturing technology of the finished cable product in the context of the fulfillment of the general production order received from the sales service. Thus, the modern production of the CWP, oriented to new technological equipment, capable of providing complex mechanization and creating an efficiently functioning production structure with unconditional provision for rapid change of the manufactured range of cable products. All this is achievable only with the availability of a high technical level of the manufacturing technology used, which is equipped with new cable manufacturing equipment that provides the finished cable product at all stages of production: high quality, operational reliability, as well as energy and resource saving in general for the considered technological cycle of production.

However, the engineering services of cable companies do not seek to dismantle cable manufacturing equipment that has a long service life for several reasons: economic (lack of financial opportunity to upgrade the entire fleet of cable making

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machines at a time) and industrial (the technical condition of the equipment allows to fulfill a production order, even with zero automation). In this regard, the issue of increasing the efficiency of operation of previously installed technological equipment located at a cable company with a long operational life is particularly acute (Table-1).

Table 1. The service life structure of cable manufacturing equipment in the context of the JV OJSC "Uzkabel" (Uzbekistan, Tashkent)

Service life group	Type of cable manufacturing equipment							
	Continuous casting and rolling line	Wire-drawing machine	Extruding machine	Stranding machine	Winding machine	Inclined vulcanization line	Other equipment (auxiliary)	Total:
Up to 5 years	-	40	20	20	20	-	50	21,4
From 5 to 10 years	-	35	15	40	40	-	50	25,7
From 10 to 20 years	-	5	-	-	-	-	-	0,71
More than 20 years	100	20	65	40	40	100	-	52,1
Total:	100	100	100	100	100	100	100	100

It should be noted that the analysis of the state of the technological equipment fleet of cable companies of the Republic of Uzbekistan has a similar situation (Table-2) in terms of technical security of the production cycle.

Table 2. The share of cable manufacturing equipment installed at cable companies of the Republic of Uzbekistan having different service life.

Name of the cable company	Service life structure of the cable manufacturing equipment fleet, by year of commissioning, %			
	up to 5 years	from 5 to 10 years	from 10 to 20 years	more than 20 years
JV OJSC "Uzkabel"	21,4	25,7	0,71	52,1
“Andijan Kabel”	10	14,3	35,6	40,1
Yuqorichirchik metal invest	5	10	85	-

Table-1 demonstrates that the analysis of the technological equipment fleet of JV OJSC "Uzkabel" (Uzbekistan, Tashkent) showed that 58.8% of the cable making machines involved in the production process of the CWP manufacturing has a service life of more than 10 years and requires modernization not only of the EMC but also of the automated control system, and therefore the implementation of measures for the introduction of automated control systems is ineffective on the production areas under consideration. A similar situation is developing at other cable companies in Uzbekistan with extensive production experience in the CWP manufacture. The work on the introduction of full automation of cable production is effective only if measures are taken to improve not only the EMC of the above-mentioned technological equipment, but also its control system as a whole. Against the background of rapidly developing cable technologies, such machines belong to systems with limited resources, because they work within the framework of a separate technological operation and lose greatly in terms of productivity, energy efficiency, energy and resource conservation, which causes great production difficulties in fulfilling the established production task and meeting its deadlines. An individually designed built-in control environment for each technological unit will allow achieving the solution of the task by ensuring the reliability of cable making machines with a long service life, due to the integration of artificial intelligence elements into a system with limited resources. All of the above forms one common production problem – the creation of a single production process that coordinates the operation of the entire fleet of installed cable making machines with different commissioning dates and greatly differing in technological, technical and production parameters: the volume of production, production time of cable product manufacturing, estimated machine time, etc. The solution of the task is possible not only through the introduction of intelligent control systems (ICS) focused on the expert assessment of the technological parameters of each unit of cable making machines, but also ensuring the regulation of operating parameters in combination with the ability of independent analysis, as well as the learning process based on the prediction of probable failures in the operation of technological equipment, its EMC and possible failures of installed technological modes. All of the above confirms the relevance of the chosen research direction for the production process of the CWP manufacturing. At the same time, it is necessary to develop an individual system for a cable making machine that has a long service life and ensures its unconditional integration into a single production system on a par with modern cable manufacturing equipment, through its modernization.

Research methods

To date, there are a large number of directions for the implementation of intelligent systems for various types of technological objects. The most realistic, in terms of improvement and modernization of technological equipment with a long service life, is the development and implementation of a control system using artificial neural networks of technological parameters for a single cable making machine.

The cable making machine, which has a long service life, is focused on one technology (drawing, stranding, extrusion, etc.), which is carried out through the interaction of several units consisting of complex, interconnected mechanisms. During the entire period of operation for this group of machines, repair services carried out repeated, partial replacement of components and assemblies, which leads to a deterioration in the performance characteristics of the machine compared to the passport ones (Table - 3). During the technical diagnostics of the equipment (stranding machine of general stranding 630C 1-6-12-18-24), a discrepancy between the passport data and real indicators - output parameters was revealed. It should be noted that for the

other units of cable making machines, the same similar situation develops.

Table 3. The results of the technical diagnostics of the operating parameters of the 630C 1-6-12-18-24 stranding machine installed at JV OJSC "Uzkabel" (Tashkent, Republic of Uzbekistan)

Name of the parameter	Unit of measurement	Technical data	
		passport	actual
Linear speed of wire movement	m/min	30-55	20-35
Kinematic extraction	%	1,3÷1,25	1,15
Maximum rotation speed of the carriage	rpm	132	80-95

Solving the issues of modernization of cable making machines with a long service life is complicated by the fact that the existing element base corresponds to modern technologies, and therefore, obtaining performance characteristics close to the passport data for the machine in question is a complex engineering task. It is possible to carry out post-repair configuration of such equipment, as well as to maintain technological modes in conditions of strict compliance with technical regulations (regulatory and technical documentation) and production relationships only by developing an expert control system - an intelligent neural network (INN) operating for a specific cable making machine.

The considered type of INN refers to the RBF network, which has a target learning function focused on decision-making and technology management by approximating and predicting the technological parameters of both the EMC and the cable facility.

The creation of a digitalization system for cable manufacturing equipment is impossible without the development of a mathematical model that shall include a large array of input *x(t)* and output *y(t)* parameters linked to the production and technological indicators of not only the upgraded machine, but the input and output parameters of other cable making machines that are interfaced in the production chain as part of the overall production order – *"end-to-end vision"* of production technology. Thus, the mathematical model shall be based not only on the input and output parameters of the technological process, but also on the analytical data of equipment operation and technology execution in previous periods of operation (hour, shift, quarter, year), as well as disturbing signals *z(t)* - changes in external conditions (ambient temperature, humidity, dustiness, vibration), which is especially important for regions with elevated ambient temperatures, especially for Uzbekistan in the summer, when the temperature in the sun reaches 55-60°C).

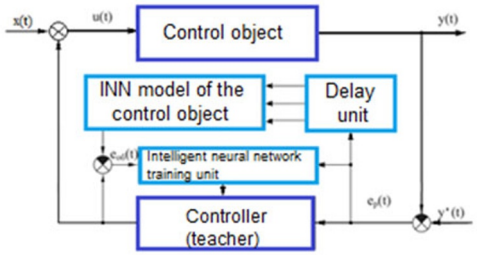

Fig.1. Block diagram of a generalized version of the INN: *x(t)* - input signal; $e_{06}(t)$- learning error, which is the difference between the output value and the control actions *u(t)*; *y(t)* - output action of the object.

A lot of research has been devoted to solving the problem under consideration on approaches to the formation of the INN, namely the inverse-direct (D. Psaltis) [1-4] and inverse-indirect (M. Kawato) [1-4] neural network model of the control object. The main task of integrating the INN into the control system (CS) of a technological object is to adjust for optimal control of the technological process through regulation of the main operating parameters of cable manufacturing equipment, followed by setting up the system for independent control of the entire technology of cable product manufacturing [5, 6], including the transition to a new production order. In a generalized version, the INN is an automatic control system with negative feedback, developed on the basis of a controller with a "teacher" function. Fig. 1 presents a block diagram of the learning process in the process of technology implementation by cable manufacturing equipment.

The implementation of the solution to the issue has been carried out using the example of stranding machine for cable production, within which it is necessary to consider options that ensure a given level of not only the reliability of the equipment in the manufacturing technology, but also the reliability in operation of the finished cable product.

As the object of the study, a rigid stranding machine (SM) of the disc type of cable production has been selected, which strands the conductive core (CC) of a cable product from a variety of previously cast (copper or aluminum) wires stranded according to the stranding system: *1+6+12+18+24+36.*

The developed mathematical model is presented as a system of differential equations in operator form, which describes the operation of the SM EMC with maintaining the tension of the cable billet, with the specified control parameters:

$$\left.\begin{aligned}
&M_{\text{дин}_i}(p)=M_{\text{дв}_i}(p)-P_i(p)\frac{R_{\text{б}_i}^{\text{вх}}}{j_{\text{ред}_i}}+Q_{(i+1)}(p)\frac{R_{\text{б}_i}^{\text{вых}}}{j_{\text{ред}_i}}-M_{\text{хх}_i}(p);\\
&\omega_{\text{дв}_i}(p)=M_{\text{дин}_i}(p)\frac{1}{J_{\Sigma_i}p};\\
&V_{\text{б}_i}^{\text{вх}}(p)=\omega_{\text{дв}_i}(p)\frac{R_{\text{б}_i}^{\text{вх}}}{j_{\text{ред}_i}};\\
&V_{\text{б}_i}^{\text{вых}}(p)=\omega_{\text{дв}_i}(p)\frac{R_{\text{б}_i}^{\text{вых}}}{j_{\text{ред}_i}};\\
&P_i(p)=\left(V_{\text{б}_i}^{\text{вх}}-V_{\text{в}_i}^{\text{вых}}\right)\frac{EF_i}{L_{P_i}p};\\
&V_{\text{в}_i}^{\text{вых}}=V_{\text{в}_i}^{\text{вх}}\mu;\\
&V_{\text{в}_i}^{\text{вх}}=Q_i(p)\frac{L_{Q_i}p}{EF_{(i-1)}}+V_{\text{б}(i-1)}^{\text{вых}};\\
&Q_i(p)=P_i(p)-N_i(p).
\end{aligned}\right\}\quad(1)$$

where, M - the moment acting in the system under consideration; ω - the angular velocity of carriage rotation, v - the linear velocity of workpiece movement; P - pulling force; Q - tension.

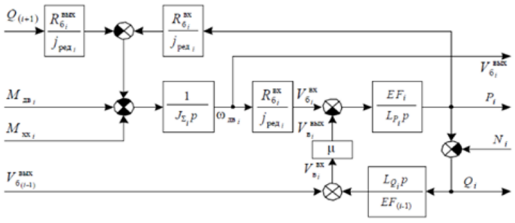

Fig.2. Block diagram of the mathematical model of stranding machine that provides tension maintenance.

The block diagram of the mathematical model, compiled in accordance with (2) is shown in Fig.2, reflects the essence of the process of forming forces during CC stranding, causing tension of the cable billet, as one of the main adjustable parameters in cable production.

The integrated INN in the SM EMC shall be maximally adapted in terms of the technological and production features of the technological operation "CC stranding" [7, 8]. Functionally, it is a multi-level control system that is built both on optimization and regulation of critical technological parameters (step and multiplicity of stranding, stranding ratio, compaction ratio, linear speed of the workpiece, rotation speed of the carriage, pulling force, tension, etc.), and on the forecast model - a recommendation service that works in real time (24/7). So in the real operating mode, the number of controlled system parameters is 125 pcs., each of which is considered important for the operation of the equipment, because it has a tightly controlled control range, which ultimately determines the quality of the technology performed. Therefore, the main intellectual load developed by the ICS is an expert assessment of the correctness of maintaining the technology, in order to fulfill the final production task – the manufacture of high-quality cable products.

All existing expert systems (ES) are based on computer programs, realize the main goal - to exclude the human factor (the opinion of the technologist) in making decisions in technology, as a separate (narrow) area of tasks (Fig. 3).

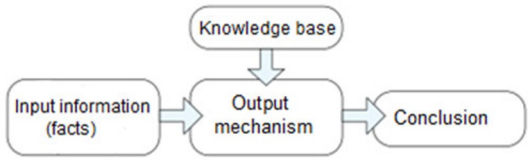

Fig. 3. Block diagram of the ICS ES.

The introduction of the ICS ES into the operation of the SM EMC will increase the speed of the SM operation by increasing the operating speeds, the correct selection of equipment operating modes, the amount of technological information processed, as well as the correct choice of solutions for extreme operating modes of equipment and the exclusion of the *"human factor"*.

The results obtained

The production process of CWP manufacturing is considered as a system mechanism that has a very tight time frame limited by the timing of the production order, and this complicates the task of performing the operation of the CC stranding due to time constraints associated with the execution of the production order.

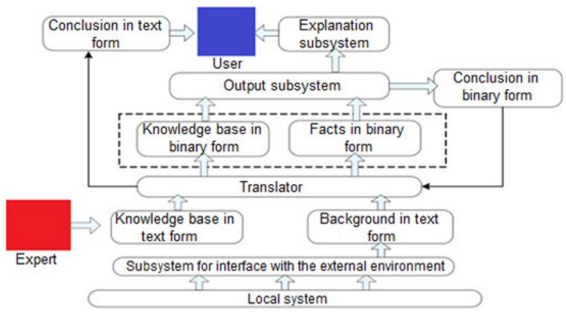

Fig. 4. Block diagram of the SM integrated control system.

Thus, the development of an algorithm for real-time ICS EC is a more complex task than the description of an automated control system having a static structure of equipment operation. Embedded and integrated into the general system, the ICS shall have many subsystems that are functionally connected and interfaced into a single system of interaction in terms of decision-making time and have strict limits on the amount of allocated memory, as well as execution time [8, 10-12]. At the same time, the integrated system shall also make the necessary edits independently and coordinate the calculation time of the control signal.

In addition, the SM ICS shall be adapted to work in a common network, i.e. it is compatible with other units of equipment included in the technological process of manufacturing a cable product, both within the production area, as well as the workshop and the company [7-12]. The block diagram of the integrated control system is shown in Fig. 4.

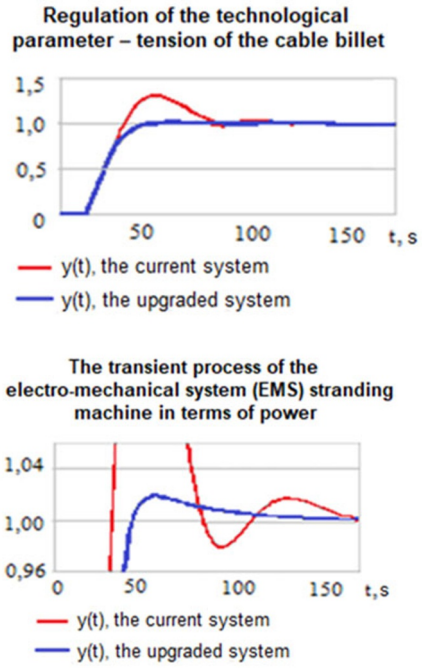

Fig. 5. The results of modeling the transition process in the current and upgraded system: *y(t)* - the output parameter of the system.

The results of mathematical modeling made it possible to test the operating and technological modes of cable manufacturing equipment – stranding machine, model "630C 1-6-12-18-24". The results of modeling the transition process in the current and upgraded system are shown in Fig. 5, both for systems in various situations and controlled by conditionally defined (selected) parameters.

Conclusion

Thus, the result of the research work done is to obtain, by mathematical modeling, the calculated characteristics of the operation of the technological equipment - the stranding machine, which allowed to conclude that the developed built–in INN is able to ensure the reliability of the stranding machine for cable production through the use of intelligent technologies. The implementation of the proposal was carried out at a specific stranding machine for cable production, and the necessary level of reliability of the technological equipment was obtained, but also the reliability of the finished cable product was increased.

References

1.Omatu S. Neuro-control and its applications / S. Omatu, M. Khalid, R. Yusof - London: Springer-Verlag, 1996. – p. 272.

2. Terekhov V.A. Neural network control systems / V.A. Terekhov, D.V. Efimov, I.Yu. Tyukin - M.: Higher School, 2002. – p. 183.

3. Modern applied management theory. New classes of technical system regulators. / Edited by A.A. Kolesnikov - Taganrog: TRTU, 2000. – p. 656.

4. Method of resource saving of cable production recyclables. Victoria Tsypkina and Daniyar Madrakhimov. E3S Web Conf.,139 01058 (2019) DOI: 10.1051/e3sconf/201913901058.

5. Improving the reliability of power supply to active consumers by improving the technology for manufacturing cable product, Vera Pavlovna Ivanova, Victoria Vyacheslavovna Tsypkina, E3S Web of Conf. 216 01152 (2020), DOI: 10.1051/e3sconf/202021601152

6. Improving the reliability of cable lines operation in hot climates, Daniyar Bakhtiyarovich Madrakhimov, Vera Pavlovna Ivanova, Victoria Vyacheslavovna Tsypkina, E3S Web of Conf. 216 01151 (2020), DOI: 10.1051/e3sconf/202021601151

7. Modeling of a resource-saving method of drawing, Victoria Tsypkina, Veronica Ivanova, E3S Web Conf. 139 01073 (2019), DOI: 10.1051/e3sconf/201913901073

8. Cable conductor of cabling and wiring products based on composite materials for transport systems, V.V. Tsypkina, V.P. Ivanova, K.K. Jurayeva, E3S Web of Conf. 401 03036 (2023), DOI: 10.1051/e3sconf/202340103036

9. Tsypkina, V., Ivanova, V., & Jurayeva, K. (2022). MATHEMATICAL MODELING OF THE CONVEYOR MOVEMENT FOR THE CABLE WASTE CRUSHING LINE. *Вестник КазАТК*, *122*(3), 255–261. https://doi.org/10.52167/1609-1817-2022-122-3-255-261.

10. Development of generalized requirements for automated electric drive of cable equipment, V.V. Tsypkina, V.P. Ivanova, D.N. Isamukhamedov, A.U. Turabekov, R.F. Atamukhamedova, E3S Web of Conf. 401 02045 (2023), DOI: 10.1051/e3sconf/202340102045

11. Improvement of the multifilament wire lager for cable production, Olimjon Toirov, Vera Ivanova, Viktoriya Tsypkina, Dilnoza Jumaeva, Dilnoza Abdullaeva, E3S Web Conf. 411 01041 (2023), DOI: 10.1051/e3sconf/202341101041.