**Application of information and computing technologies for monitoring and managing the technical condition of cable equipment in order to improve its reliability and operational efficiency**

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**Abstract.** This article discusses the integration of information on the technical condition of cable equipment through the use of information and computing methods for monitoring and control. Information on the age composition of processing equipment installed at cable enterprises in Uzbekistan is presented. Using the example of cable enterprises in the Republic of Uzbekistan, the practical feasibility of applying information and computing technologies to solve production and technological problems related to the manufacture of finished cable products is analyzed. The results of the functioning of the developed Comprehensive Technological Platform for the implementation of the technological process are presented, which is an integration system that combines various information and computing resources of cable equipment and related production processes.

**INTRODUCTION**

Ensuring and maintaining the technological stability of the cabling and wiring products (CWPs) manufacturing process is a crucial condition for the engineering and production services of a cable company, whose main function is to ensure and maintain the required level of reliability and stability of cable manufacturing technology. Achieving these goals becomes possible through the rational allocation of production, time, technological and labor resources. Achieving the reliability and sustainability of the production process involves the introduction of a specialized IT infrastructure with a transparent technological stack that ensures the continuity of the technological cycle, including in the event of malfunctions of the main production equipment.

**TABLE 1.** Analysis of cable machines by operating time at cable plants in Uzbekistan

| **Name of cable equipment** | **Service life, years** | | |
| --- | --- | --- | --- |
| 5 | 10 | 20 or more |
| Drawing machine | 15% | 30% | 55% |
| Extrusion line | 10% | 45% | 45% |
| Stranding machine | 15% | 50% | 35% |
| Winding machine | 10% | 20% | 70% |

The issues of cable production modernization are usually solved through the use of modern technological lines, which significantly increase the efficiency and reliability of the production process for the CWPs manufacture. At the same time, not all enterprises of the cable industry have the opportunity to carry out a complete replacement of the processing equipment fleet with limited financial and resource capabilities. The analysis of the technical condition of cable machines (CMs) installed at the production sites of cable plants in the Republic of Uzbekistan showed that over 50% of the equipment has a service life of more than 10 years, which indicates its great functional and moral depreciation (Table 1).

Based on the analysis of the technical condition of the equipment (Table 1), it was found that the cable machines (CMs) in operation have an uneven degree of physical depreciation. At the same time, the level of depreciation of working mechanisms is determined by a combination of several factors: the degree of production load of the equipment, the duration and intensity of operation (including work in three shifts), the conditions of the production environment, the level of qualification of maintenance personnel, as well as the regularity and quality of maintenance. The decrease in quality indicators and values of CM’s technical parameters in comparison with the passport data directly depends on the increase in service life.

The solution to the issue of increasing the reliability and technological stability of the CWPs manufacturing process is possible through the introduction of the Unified Information System (UIS), the main purpose of which is to combine all digital management tools, monitoring and optimization of production and technological processes used at the cable factory. The implementation of this system will ensure comprehensive control over the parameters of the technological cycle, improve the safety and reliability of the production environment, as well as implement intelligent methods for predicting the technical condition of equipment and key performance indicators. The UIS shall facilitate the transition to digitally managed technology, both at the level of individual process operations (production areas) and the entire production process as a whole.

The potential for a decrease in the performance of an individual CM can negatively impact production plan fulfillment, resulting in increased equipment downtime, missed order deadlines, increased production and process waste, excess consumption of raw materials and supplies, and an increased number of defective products. A single equipment stoppage, especially in a continuous process, can disrupt the production chain, causing a shortage of interoperational (transitional, unfinished) products throughout the entire production line.

A comprehensive assessment of the reliability of CM operation and the efficiency of the entire technological process is determined by the Integrated Reliability Indicator (IRI) of Electromechanical Systems (EMS) [12], which reflects the overall condition of the equipment according to key parameters: mean time between failures (Тf), average overhaul life (Taol), designated full rotor service life (Trsl), designated full service life (Tfsl), technical utilization coefficient (Ktu), mean storage time (Tmst) characterizing a certain aspect of the reliability and technical maintenance of the equipment.

The integration of the UIS into the production process shall take into account a number of factors: the current technical condition of all cable equipment involved in technological processes; compliance with established technological regimes and regulations; as well as the need to process data from various subsystems and quality control of manufactured cable products.

A technical audit of the RS 1+6+12+24+30/630 stranding machine, conducted in 2022, manufactured by Jiangsu Jiacheng Technology Co., Ltd. (China) and installed at the YUQORICHIRCHIQ ENERGY SYSTEMS JV LLC (Uzbekistan), revealed significant deviations between the rated specifications and actual operating parameters. Specifically, the line's productivity and speed reached only 50% of the stated values, indicating a significant reduction in the operational efficiency of this type of equipment (Table 2).

**TABLE 2.** Technical condition of the RS 1+6+12+24+30/630 stranding machine

| **Working unit** | **Quantity, pcs** | **Total maximum power, kW** | | **Operating speed, m/s** | |
| --- | --- | --- | --- | --- | --- |
| passport | actual | passport | actual |
| Work light | 4 | 300 | 350 | 120 | 90 |
| Receiver | 1 | 15 | 20 | 25 | 10 |
| Wheel-type pulling mechanism | 1 | 110 | 100 | 25 | 10 |
| **Total:** |  | **425** | **470** | **20** | **10** |

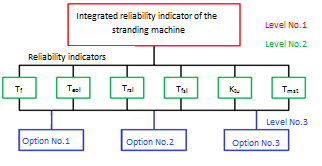
Analysis of the technical condition assessment results for the RS 1+6+12+24+30/630 stranding machine (Table 2) confirmed a significant reduction in its performance characteristics compared to the nominal specifications, due to the equipment's long service life (over 10 years). It should be noted that throughout its entire service life, a comprehensive set of maintenance measures was implemented for the CM, including scheduled preventive maintenance and emergency repairs, the primary purpose of which is to eliminate failures, malfunctions, and faults.

The results of the technical diagnostics showed that a significant part of the components and the element base were replaced with new ones, while only 10-20% of the components, mechanisms and structural elements remained original (basic), the rest were replaced during maintenance and repairs. The assessment of the operability and reliability of the stranding machine was based on actual performance indicators (Table 3).

**TABLE 3.** Reliability indicators of the options for the RS 1+6+12+24+30/630 stranding machine

| **Option** | **Reliability indicators** | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| (Тf) | (Taol) | (Trsl) | (Tfsl) | Ktu | Tmst |
| **1** | 8,5 | 20 | 43 | 10 | 0,9 | 24 |
| **2** | 11 | 23 | 43 | 8 | 0,87 | 24 |
| **3** | 9 | 21,5 | 41 | 12 | 0,89 | 36 |

The development of the basic process for calculating the integrated reliability indicator of electromechanical system for a cable machine (Fig. 1) was based on an assessment of the reliability options for processing equipment (Table 4).



**FIGURE 1.** Basic process for calculating the integrated reliability indicator of electromechanical system for a cable machine

Cable processing equipment with a service life of less than 10 years retains the ability to ensure the required level of reliability of technological operations within the required technology and production process. At the same time, CMs shall be considered as a complex, multifunctional system equipped with an Integrated Control System (ICS) capable of processing significant amounts of production, technological and technical information (Big Data). However, not all CMs can be considered as an informatization object (IO) when designing a Unified Control System (UCS), since a significant part of the equipment with a service life of more than 10 years has obsolete system and software. The introduction of this equipment into the Automated Process Control System (APCS) without prior modernization and adaptation of control systems is technically difficult or even impossible.

The efficiency of the APCS in an operating enterprise is largely determined by the number of cable machines integrated into the production process with the possibility of digital control. Currently, there are about 58 cable plants operating in the Republic of Uzbekistan, of which 15 belong to large industrial enterprises that provide about 95% of domestic demand for CWPs. At the same time, an analysis of the level of implementation of digital solutions at the Republic's cable enterprises revealed a significant lag in the field of digitalization of both production equipment and technological processes in general.

**EXPERIMENTAL RESEARCH**

The solution to the issue of improving the reliability of cable technologies is directly related to the introduction of systems capable of real-time monitoring and control of CM technological parameters as part of the production process. This task can be solved by developing a specialized Automated Control and Monitoring System (ACMS), which has an additional information layer that ensures constant monitoring of the equipment's technical condition. The implementation of this system will allow maintaining a stable level of reliability and operational efficiency for all process units within the cable assembly.

The accuracy of assessing the reliability of processing equipment (PE) depends on the enterprise's level of digital maturity. Various digital transformation methodologies are used globally for this purpose, including: MIT Center for Digital Business, Capgemini Consulting, Digital Maturity Model, Digital Transformation Index, Digital Business Aptitude (DBA), Global Center for Digital Business Transformation, Acatech, and others [2, 3, 4].

The integration of modern technical solutions, within the framework of the APCS with advanced capabilities, for the cable industry relies on the capabilities of the enterprise as part of a range of works aimed at increasing the level of digitalization of both individual pieces of equipment and the entire production and technological process. The result of this work shall be to increase the efficiency, stability and predictability of the CWP manufacturing processes, as well as to improve the quality and operational reliability.

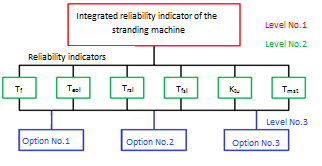
The use of information and computing technologies, both at the scale of individual CMs and at the level of the entire technology, is a relevant research topic. The implementation of a network of intelligent (SMART) measuring sensors that continuously monitor technological processes and equipment conditions opens up vast opportunities for automating production and technological operations and solving a range of problems related to production optimization and the reduction of production losses.

When considering a generalized CM with the required level of reliability, it can be conceptualized as a complex automated control system capable of ensuring the uninterrupted operation of working units and mechanisms by monitoring established modes and technical parameters under the probable occurrence of various production and process uncertainties. A CM control system (CS) integrated into the APCS shall maintain the synchronization of all equipment units without exception (according to the process flow) during production order fulfillment, ensuring quality control (input, interoperational, and output) of finished products, forecasting CM maintenance and repair schedules, etc.

The cable production management process is a technically complex and multi-parameter task, the solution of which, in the conditions of the current technology at the enterprise, is assigned to the production service. The effectiveness and timeliness of management decisions largely depend on the level of professional training and practical experience of the specialists of this service. In this context, there is a high probability of delays in responding to production deviations, as well as making ineffective or erroneous decisions due to subjective factors, lack of competence or the influence of the human factor [5].

**RESEARCH RESULTS**

Modern CM is a high-tech and multilevel system that includes a complex of interconnected subsystems, the coordinated functioning of which is aimed at ensuring the quality requirements of products, as well as the reliability of technological processes and equipment in general. Maintaining stable CM characteristics requires strict adherence to established modes and parameters. A decrease in the reliability and operability of an individual cable equipment may be due to a number of factors, including: uneven distribution of the production load, deviations in technological modes that occur during operation, as well as the influence of the external environment and operating conditions.



**FIGURE 2.** Functional diagram of the additional control level system (main data flow processes)

The occurrence of abnormal shutdowns in CM operation can lead to disruption of the stability of the Automatic Control System (ACS) and the technological process as a whole. Such failures have a negative impact on the entire production system, as they cause disruptions in the flow of information, disrupting the integrity of input, output, control and disturbing signals. In addition, this may lead to malfunctions in the operation of the software of the control modules of the equipment.

To ensure the required level of reliability and stability of the production process, it is proposed to implement an additional control system (Fig. 2) designed for comprehensive monitoring of engineering, process, and production parameters. The system's capabilities include: analysis of current process conditions, the formation of informed management decisions with confirmation of their adequacy, and an assessment of the feasibility of proposed corrective actions.

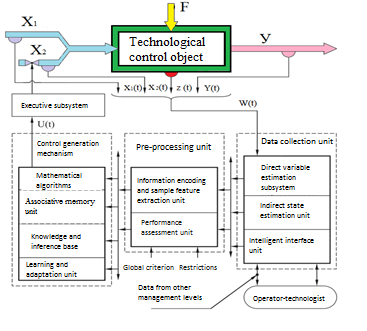
The Integrated Control System (ICS) of the CM, equipped with expanded functionality, shall be capable of interaction at the level of intersystem integration, which will enable its inclusion in the Unified Process Control System (UPCS) for the CWPs manufacture, representing an important step towards the digitalization and intellectualization of cable production.

The Unified Process Control System (UPCS) for the CWPs manufacture is a centralized intelligent platform consisting of many built-in subsystems – the Integrated Control System (ICS), whose main task is to ensure stability, reliability and high production efficiency within the framework of the entire technological cycle, including the main and auxiliary technological routes, as well as interoperational (transitional) processes [5, 6].

At its core, the UPCS is an Intelligent Control System (ICS), whose functionality includes strict control over the design parameters of cable products (CPs), CM operating modes, and production order fulfillment deadlines. Furthermore, the system is designed to maintain a high degree of reliability and adaptive stability of the processing equipment under various types of production uncertainty. This ensures high response rates, operational stability, and overall system operability in dynamically changing production conditions [7].

The development of the UPCS was carried out on the basis of the current functional computer control scheme (Fig. 3), using the Embarcadero RAD Studio XE3 programming environment [4] in the conditions of a specific manufacturing enterprise in the cable industry. The architecture of the intelligent control system (model) presented in Fig. 3 has the following explanation: X₁, X₂ - input signals characterizing the properties and parameters of the raw materials and materials determined by the design of the final product; F - disturbances and interference of external and internal nature; Y — output signal reflecting the key quality parameters of the finished cable product (e.g., construction length, geometry, strength characteristics, etc.).

The process of designing the ICS involves developing an algorithm for processing data in numerical, multi-valued (fuzzy), or symbolic representation. These algorithms form the basis for constructing a mathematical model that ensures the operational processing of information flows and the implementation of adaptive control based on the results of corresponding numerical calculations [5, 6, 7].

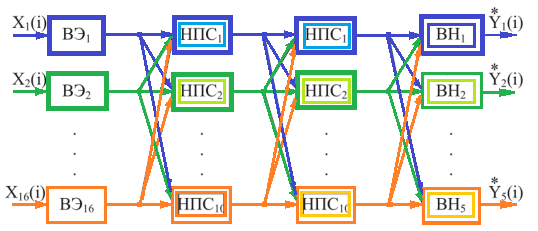


**FIGURE 3.** The ICS structure: Х1, Х2 – input signals; F - disturbances and interference;

У- output signal

The Intelligent Process Control System (IPCS) operates using a developed mathematical model that enables the efficient processing and analysis of information flows received through data transmission channels. Processing is accomplished through an analysis of the system's structural elements, such as accumulated knowledge, generalized and current data, using developed control algorithms and methods for estimating the numerical values of dynamic parameters. These parameters are retrieved from a database containing production and technological base values [8, 9, 10, 11].

A key element of the IPCS architecture is a functional structure built on the principles of interaction with a multilayer Artificial Neural Network (ANN), which ensures the adaptability and learning ability of the control system in a complex and changing production environment (Fig. 4). The use of ANN allows not only for processing large volumes of heterogeneous information but also for generating informed control actions based on predictive assessments of the state of control objects.

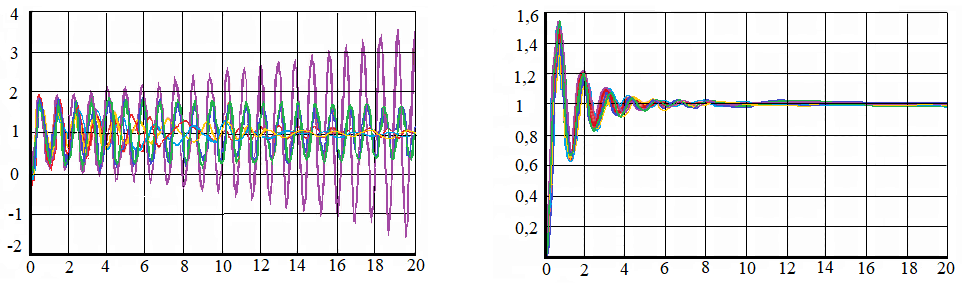


**FIGURE 4.** The IPCS functional structure: IE1, …. IE16 – input elements (normalizing and distributing converters); ILN1, … ILN10 - intermediate layer neurons; ON1, … ON5 – output neurons

Mathematical modeling of a technological process based on the IPCS is a multi-component task encompassing various operational modes of the processing equipment during CWPs manufacture. This study examines two structural organization options for the production process (see Fig. 5):

a) a fully coupled dynamic system in which all production stages are tightly interconnected;

b) an optimized structure with a complex yet flexible architecture, ensuring increased adaptability and resilience.



|  |  |
| --- | --- |
| а) | b) |

**FIGURE 5.** Results of mathematical modeling of the IPCS for VVG ng 4x16 cable production: dynamic structure (a), optimized structure (b).

Random values of the process operation parameters for VVG ng 4×16 cable manufacturing (Fig. 5) were selected as the initial data for the modeling. These values correspond to the current production flow at the enterprise, which includes: drawing (shown in Fig. 6 in blue), conductor stranding (green), insulation application (yellow), core formation by stranding (blue), protective sheath application (purple), and finished cable rewinding (red). The total production cycle time for this flow is 20 hours, during which the cable product passes through all process stages. Modeling, taking these parameters into account, allows for a more accurate assessment of the IPCS performance under various architectural organization options for the production process.

The results of mathematical modeling shown in Fig.5 are based on the application of a special evaluation criterion - the reproducibility index (coefficient of statistical stability of the process) Срk [12], obtained during the analytical analysis of experimental data.

The following conclusions were reached based on the modeling:

The dynamic structure (Fig. 5, a) is characterized by low stability and is the result of fragmented interactions between uncoordinated subsystems – CMs, operating in isolation. Their operation is locally adapted to current production conditions, taking into account the redistribution of available production resources. The lack of system coordination and mutual synchronization leads to high sensitivity of the entire structure to changes in the external environment and internal fluctuations in the technological process.

The optimized system (Fig. 5, b), on the other hand, is a flexible, multi-level architecture integrated into the overall production process. Its development is based on an analysis of the current equipment load and an assessment of the technical condition of the CM, enabling dynamic adaptation of the process flow to achieve an optimal balance between production efficiency and reliability.

As a result of this optimization, the production system shows signs of stable functioning, manifested in the stabilization of key indicators over time. This is achieved due to the synergetic effect that occurs in the context of deep integration of all components within the Comprehensive Technological Platform that functions as a single information space of a cable company.

The proposed solution provides an increase in the reliability of the cable equipment operation and the efficiency of the CWPs manufacturing process.

The achievement of these goals is ensured through monitoring and analysis of data coming from integrated information and computing technologies. This approach makes it possible to maintain the stability of technological operations (Fig. 5, b), reduce the number of unscheduled equipment failures, as well as optimize the route of product passage through technological stages and increase the efficiency of CM.

The approbation of the proposed model and its implementation into production practice made it possible to effectively solve the problems of analyzing and evaluating the reliability and stability of both individual units of equipment and the production process as a whole. This integrated approach enabled the development of predictive process routes for fulfilling production orders, taking into account the current technical condition of the equipment and its distribution within the company's existing fleet of processing equipment.

**CONCLUSIONS**

The study demonstrates that ensuring the reliability and operational efficiency of cable manufacturing equipment with a high degree of physical and moral wear requires the integration of information and computing technologies into production processes. Traditional maintenance approaches are insufficient to maintain technological stability under modern operating conditions.

The analysis of cable enterprises in the Republic of Uzbekistan revealed that a significant share of processing equipment has exceeded its normative service life, resulting in reduced productivity and increased failure risks. In this context, the implementation of a Unified Process Control System based on integrated monitoring and control principles is technically justified.

The use of an integrated reliability indicator of electromechanical systems provides an objective assessment of the technical condition of cable machines, enabling informed maintenance planning and modernization prioritization. The proposed Intelligent Process Control System ensures continuous monitoring, real-time data processing, and adaptive control through the application of intelligent algorithms and artificial neural networks.

Mathematical modeling confirmed that an optimized, flexible production architecture significantly improves process stability, reduces sensitivity to disturbances, and increases overall manufacturing efficiency. Industrial approbation of the developed model demonstrated its practical applicability for predictive production planning, rational equipment load distribution, and improvement of product quality.

Overall, the proposed approach forms a methodological basis for the digital transformation of cable manufacturing, ensuring a sustainable increase in reliability, technological stability, and operational efficiency of production systems.

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