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Production machines maintenance based on digitalization*

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Техническое обслуживание технологических машин на базе цифровизации***

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Introduction. Digital data and analytics transform the role of the production equipment maintenance. Analytical information of sensors placed on the product allows continuous monitoring of the production machines operation and their timely servicing. Thus, defects in technical equipment are identified, the analysis of which enables to develop algorithms for monitoring and forecasting, and to prevent equipment from overshooting the limits of the safe operation.
Materials and Methods. Basic digitalization principles and the digital images structure are presented. A mathematical method is used to describe the digital image vector and the control system algorithm.
Research Results. The achievements of the known systems of maintenance and digitalization of various machines are summarized. The application of a dynamic digital image made it possible to determine the desired levels of the production facilities maintenance. An optional version of monitoring the equipment state within the framework of the production digitalization concept is shown. It is based on the proposed algorithm for an autonomous control of the process state.
Discussion and Conclusions. The construction of machine digital images in accordance with the main stages of its life cycle is described. The task of automated maintenance of machine tools based on digitalization is considered.

Keywords: monitoring, digitalization, autonomous control, maintenance, digital image.

Введение. Цифровые данные и аналитика преобразуют роль технического обслуживания производственного оборудования. Аналитическая информация датчиков, размещенных на изделии, позволяет непрерывно наблюдать функционирование технологических машин и своевременно обслуживать их. Так, выявляются дефекты технического оснащения, анализ которых позволяет разрабатывать алгоритмы мониторинга, прогнозирования и предупреждать выход оборудования за пределы надежной работы.
Материалы и методы. Представлены основные принципы цифровизации и структура построения цифровых образов. Используется математический метод описания вектора цифровых образов и алгоритмизации системы управления.
Результаты исследования. Обобщены достижения известных систем технического обслуживания и цифровизации различных машин. Использование динамического цифрового образа позволило определить необходимые уровни для поддержания работоспособности технологических объектов. Показан возможный вариант мониторинга состояния оборудования в рамках концепции цифровизации производства. Он основан на предложенном алгоритме автономного управления технологическим состоянием.
Обсуждение и заключение. Описано построение цифровых образов станка в соответствии с основными стадиями его жизненного цикла. Рассмотрена задача автоматизированного поддержания работоспособности станков на базе цифровизации.

Ключевые слова: мониторинг, цифровизация, автономное управление, обслуживание, цифровой образ.

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Introduction. At the present stage of development of engineering and technology, issues of the production digitalization, in particular, the life-cycle management of production machines, the independent management of their operation and maintenance, are particularly sensitive. According to K. Schwab, Head of the World Economic Forum, digital data and analytics transform the role of servicing [1]. We are talking about the analytical information of sensors placed on the product. It helps to conduct continuous monitoring, and to study equipment operation and its maintenance. Thus, defects in the equipment are identified, the analysis of which enables to develop monitoring algorithms, to make forecasts, and to prevent equipment from going beyond the limits of reliable operation. This approach generally improves the efficiency of production processes. Description of the product operation based on digitalization allows for the creation of digital twins of machines for various purposes. The concept of "digital twin" includes a temporal information copy of an object, artificial intelligence, information technologies, and software. All these components are involved in the creation and support of intelligent digital models (DM) of complex technical products.

Publications devoted to this topic represent research in the field of intellectual monitoring and control of the technical condition of machines and machine tool systems [2–14].

Metal-cutting machines are provided with new properties that allow them to meet the growing demands for speed and accuracy of cutting, reliability and safety of operation under the conditions of fast-speed processes. As in mechatronics in general, in machine tools, a number of organizational and technology principles related to digitalization is implemented. Some of them are listed below.

Openness and controllability. A machine is an open, self-controlled system connected with the outdoor environment. Information on the state of the equipment, the outdoor environment is used for control, and the object behavior is simulated.

Originality of properties of the entire machine system. The characteristic of a system object extends further than a sum of features of its components. The system obtains properties that none of its components possesses. In other words, the functions of the components can synthesize new properties of the system.

Self-sufficiency of the system. The system and its elements can function independently of external systems.

Intelligent management. Procedures for controlling an object (machine) are based on an analysis of its states and manufacturing situations using information technologies and knowledge processing mechanisms.

Information and intellectual support of the machine operation includes procedures for maintenance and repair. The development of digital automated diagnostic and control systems involves the creation of specific software for information processing integrated with an external network communication environment.

Main Part. In the presented paper, the digital embodiment of an object will be called its digital image (DI).

The machine DI corresponds to various methods of constructing digital models (Digital model). The model selection is determined by the object life cycle stage – from design to disposal (Fig. 1).

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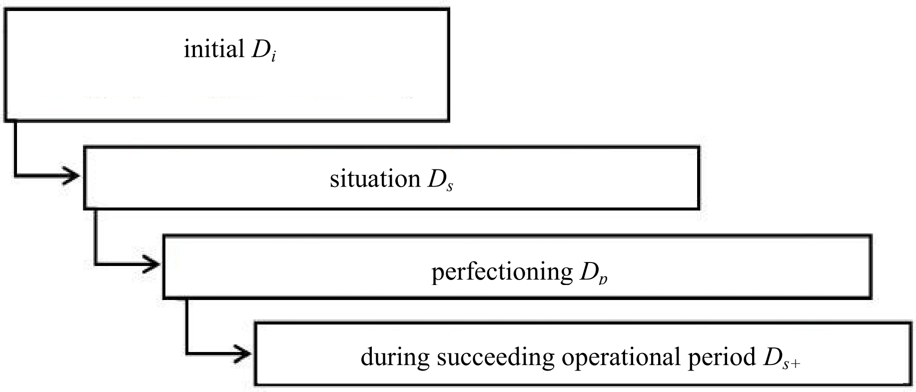

Fig. 1. Stages of representation of machine digital images

According to the notation of Fig. 1 and considering the sequence of transformations, an ordered set of digital models of the machine state during the life cycle is as follows:

$$D_m = (D_i, D_s, D_p, D_{s+}).$$

According to the standard rules and test methods, the work on creating D_i includes the formation of an initial database for assessing the machine quality. These include the following: performance accuracy factors, dynamic characteristics, thermal deformations, reliability rating estimates. The database (DB) of the initial state of the machine forms the basis of the temporal machine DI built on the principles of the e-Mind Machine (e-MM) [10, 11].

If we are talking about the machine in use, its state is considered under processing typical test parts or on test modes subject to the technical requirements and a test program. The structure of the machine DI in the operation processes (D_s), considering the e-MM, is shown in Fig. 2.

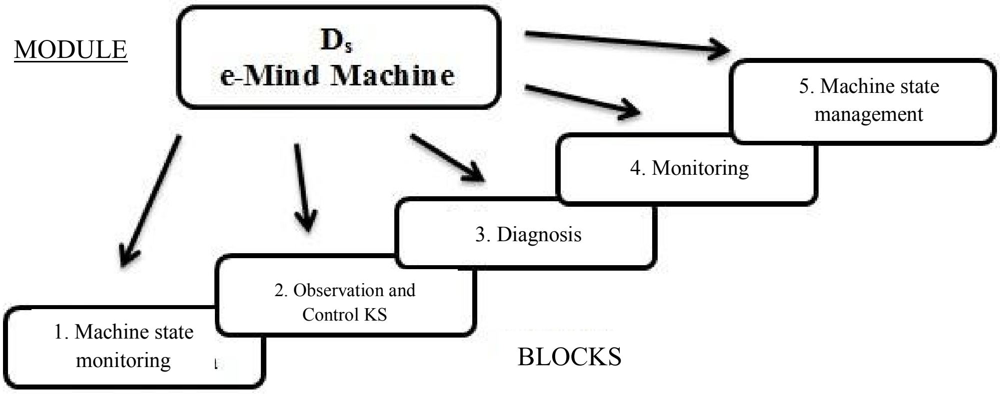

Fig. 2. Structure of machine dynamic DI at service stage (D_s)

The DI state specificity is determined by the alternation of the operation, maintenance and repair processes. The DI intelligence depends on the knowledge system (KS) located in the blocks of the machine temporal DI.

Solutions based on the embedded expert systems (ES) and information obtained from the diagnostic and monitoring units are synthesized in the modules for controlling the machine technical state. They identify the measured parameters of the machine, the process and its result, which enables to diagnose and evaluate the state of processes and devices. In this case, a situational assessment of the system state, which is necessary for the management, adequate to the current situation, is performed, and the results are predicted. Based on the decisions made, control actions are generated corresponding to the block assignments. Considering the huge amounts of stored data, optimizing analysis techniques can be used under the system operation — for example, online diagnostics with the aid of Mel-frequency cepstral coefficients [12].

At this, it is important to apply not quantitative, but qualitative assessments and concepts based on fuzzy procedures of processing, accumulating and applying knowledge and meta-knowledge. It is advisable to use temporal ES. First, they work in real time. Secondly, training and adaptation algorithms are built into such ES, and they are able to improve the performance of the machine subsystems.

Under the intelligent control with the KS units during the machine operation period, complete information on the DI state can be represented as an ordered set (vector) of possible states of the machine system and control:

$$S = \left(S_w, S_i, S_v, S_z, S_u\right).$$

Here, S_w, S_i, S_v, S_z, S_u are, respectively, sets of states of the machining process, the tool, the technical state of the machine components, the state of the product (workpiece - part) and control. The set of admissible vectors (S) is called the admissible set of DI states, and we denote it as $\tilde{S}$. KS synthesizes sets of time-ordered regulated actions: $U_p \in \tilde{U}$. They provide transformation of the vector of the DI initial condition $S^* \in \tilde{S}$ from a hypothetically identified admissible set of states ($\tilde{S}$) to the specified goal state $S_g \in \tilde{S}$. This search is based on the analysis of knowledge about the functionality of a specific machine tool system. Actually, KS should realize λ_S indication:

$$\lambda_S : \tilde{S} \times \tilde{S} \to \tilde{U} \mid U_p = \lambda_S\left(S^*, S_g\right),$$

which, out of the set of admissible controls ($\tilde{U}$), finds such control ($U_p \in \tilde{U}$) that corresponds to the of the initial state vector ($S^* \in \tilde{S}$) and to the specified goal state ($S_g \in \tilde{S}$). In this case, $U_p \in \tilde{U}$ control enables the transition of the machine from $S^* \in \tilde{S}$ state to $S_g \in \tilde{S}$ state. The management apparatus ($U_p \in \tilde{U}$) is based on the formalisms of fuzzy algebra and fuzzy sets. This approach allows for the formulation of a plausible hypothesis about the organization of the appropriate behavior of the machine tool system. In this case, a coherent transition from one state to another is observed, and at each transition, information about changes in the machine DI is generated [15]:

$$S_{j-1} \xrightarrow{U_P} \left(S_j, I_j\right).$$

Here, S_{j-1} is DI state at the beginning of *j*-th transition; S_j is DI state obtained as a result of *j*-th transition; I_j are changes to be made in the descriptions of DI state obtained as a result of *j*-th transition; U_p is control ensuring the transition from S_{j-1} state to S_j state.

The current state (S_j) obtained as a result of the *j*-th transition is determined by the state of:

- product (workpiece - part) (S_{zj}),
- tool subsystems (S_{ij}),
- object (S_{vj}).

That is

$$S_{zj} = \left(S_{zj}, S_{ij}, S_{vj}\right).$$

Models of technical condition management, built on this KS base, are the framework for building a digital system for autonomous control of machine tools.

Developers and researchers pay serious attention to the automated maintenance of machine operability, especially, under the conditions of computerization of production and improvement of information support [1].

The digitalization systems developed for the technological machines maintenance require the application of integrated and/or remote software and hardware support components. These systems are created to fulfill the following tasks:

- to obtain information on the equipment state in real time,
- to forecast the development of the state of various devices/units (D/U),
- to give the personnel warning of emergency and other dangerous equipment conditions,
- to carry out self-maintenance and troubleshooting,
- to conduct maintenance or updating of the control programs in the process of equipment operation.

Within the framework of the e-MM concept, an automated autonomous control of the technical state of machine tools (AUTS) was created [16]. AUTS means independent automated control. Special tools and informational links allow it to assess the state and role of the machine. Based on these estimates, the AUTS provides certain signals or acts on a specific machine device to maintain or restore its operability.

The AUTS features are listed below.

First, the system should be equipped with a sufficient number of sensors that transmit reliable information on the status of units and devices.

Secondly, when recognizing the obtained data, it is necessary to exclude noise and determine the parameters informatively describing the state of the equipment.

Thirdly, the forecasting systems should flexibly adjust the indicators in real time, focusing on the information obtained from the diagnostic unit.

Fourthly, the decision should include the possibility of reducing the risk from the machinery breakdown or wear reduction of the equipment components, and it should comply with the selected treatment program with minimal departure from the optimal process.

In view of the above, the structure of the system and the autonomous control of the machines technical state is developed [15]. The algorithm of the state monitoring system is presented in Fig. 3.

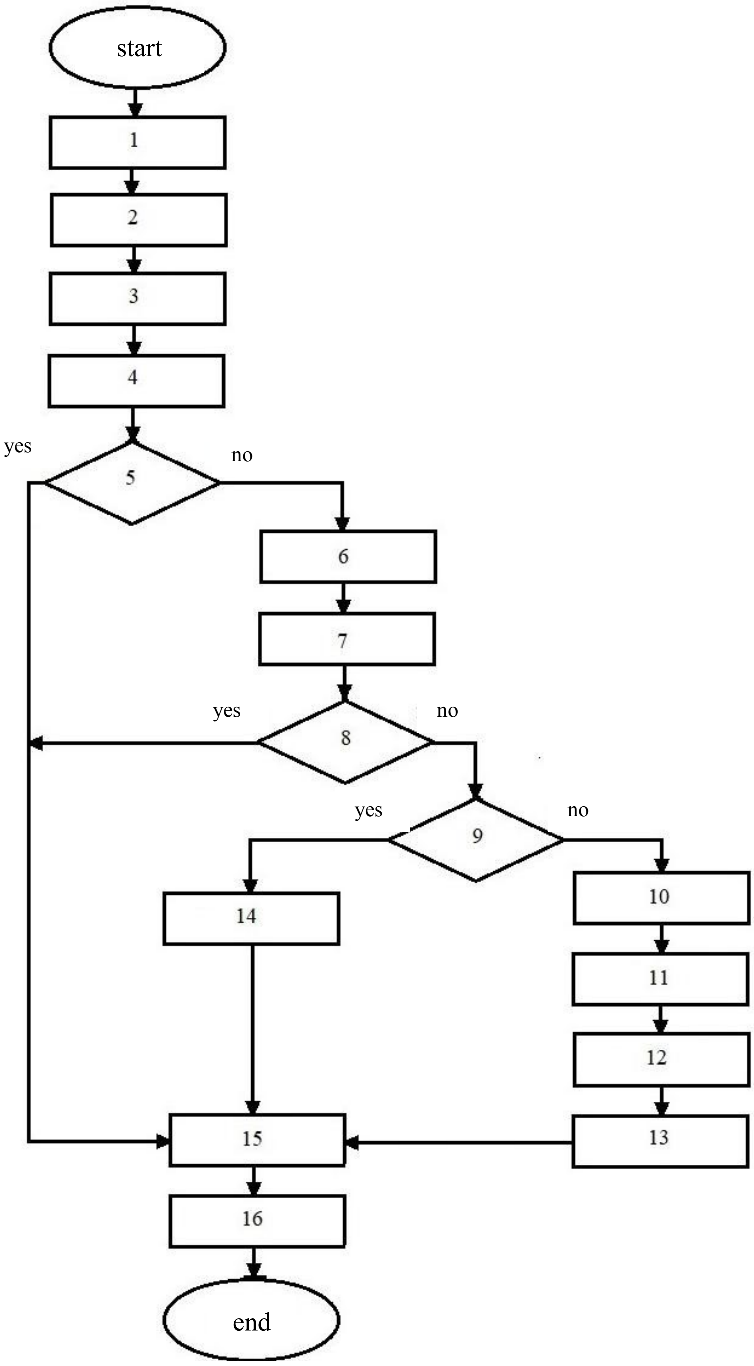

Fig. 3. Flowchart of state monitoring system (AUTS)

The algorithm provides the following actions.

1. 1. Search for information on the D/U inheriting states (i.e., at the preceding stage – n - 1) in the knowledge system, and basing the *n* stage states into the monitoring unit DB.

2. Obtaining current operational data of diagnostics of the D/U state at *n* stage.

3. Creation (change) of the current image of the D/U state in the working memory of the knowledge system of n – KS_n stage of the machine condition monitoring unit.

4. Determination of the ES belonging to the KS of the monitoring unit, and tendencies of changes in the D/U state.

5. Comparison of the obtained state estimates with the parameters of the fuzzy boundaries of the D/U operability state extracted from the database.

6. Predictable assessment of the preservation of permissible state parameters within the limits of the D/I operability under the condition of work on the input control program of the CNC device.

7. Estimation of the accessibility of fail-safety under the condition of correction of the processing program components.

8. Decision-making on the accessibility of fail-safety.
9. Decision-making on technical condition management.
10. Correction of the D/I state without processing interrupt.
11. Part process shutdown for the correction (restoration) of the state.
12. Selection of the offline means to prevent (eliminate) malfunction of the D/U or external services.
13. Conducting off-line servicing.
14. Support call to the external services for troubleshooting of the technical condition.
15. Diagnosis and assessment of the D/I status after maintenance.
16. Logging and input of the list of the operations performed and the resulting assessments of the D/I state to the KS. Accumulation of experience in assessing the technical condition and autonomous state control in the KS.

In this case, the decision-making and autonomous control of actions to maintain working capacity is made on the basis of the presented approach to the digitalization of machine tools, and this is the key feature of the unit for monitoring the object state and of the algorithm for monitoring the AUTS state.

Conclusion. The construction of machine digital images in accordance with the main stages of its life cycle is proposed. The automated maintenance of machine tools based on digitalization through the creation of autonomous technical condition control systems is considered. These systems transmit information on the equipment state in real time, signalize purposefully about the equipment state, and maintain (restore) its performance.

References

1. Schwab, K. Chetvertaya promyshlennaya revolyutsiya. [The fourth industrial revolution.] Moscow: “Eksmo”, 2016, 138 p. (Top Business Awards) (in Russian).

2. Tugengold, A.K., Lysenko, A.F., Statovoy, D.A. Sistema znaniy v vide intellektual'noy elektronnoy tekhnicheskoy dokumentatsii dlya mnogooperatsionnykh stankov. [Knowledge-based system by way of intelligent electronic technical documentation for multi-operation machines.] Vestnik Mashinostroeniya, 2015, no. 11, pp. 14–17 (in Russian).

3. Kemerait, R.C. New cepstral approach for prognostic maintenance of cycle machinery. Proceedings of the IEEE Southeast Conference in Tampa, 1987, pp. 256–262.

4. Fisher, C., Baines, N.C. Multi-sensor condition monitoring systems for gas turbines. Journal of Condition Monitoring, 1988, no. 1, pp. 57–68.

5. Tugengold, A.K., Voloshin, R.N., Yushchenko, S.V. Monitoring sostoyaniya mnogooperatsionnykh stankov na baze kontseptsii e-MindMachine. [Monitoring of multioperational machines based on the concept of e-MIND MACHINE.] Vestnik of DSTU, 2016, vol. 16, no. 1 (84), pp. 77–86 (in Russian).

6. Tugengold, A.K., Voloshin, R.N. Gibkiy monitoring mekhatronnykh tekhnologicheskikh mashin. [Flexible monitoring of mechatronic technological machines**.**] Vestnik of DSTU, 2016, no. 4, pp. 51–58 (in Russian).

7. Byington, C.S., et al. Shaft coupling model-based prognostics enhanced by vibration diagnostics. Insight, 2009, vol. 51, pp. 420–425 (Non-Destructive Testing and Condition Monitoring).

8. Tan, C. K., Irving, P., Mba, D. A comparative experimental study on the diagnostic and prognostic capabilities of acoustics emission, vibration and spectrometric oil analysis for spur gears. Mechanical Systems and Signal Processing, 2007, no. 21, pp. 208–233.

9. Tugengold, A.K., et al. Monitoring sostoyaniya stankov i stanochnykh sistem. [Monitoring the state of machines and machine tools.] STIN, 2017, no. 3, pp. 11–17 (in Russian).

10. Tugengold, A.K., et al. Monitoring and Control of Tools in Multifunctional Machine Tools. Russian Engineering Research, 2017, vol. 37, no. 5, pp. 440–446.

11. Tugengold, A.K., et al. Monitoring of Machine Tools. Russian Engineering Research, 2017, vol. 37, no.8, pp. 440–446.

12. Tugengold, A.K., Izyumov, A.I. Printsipy kontseptual'nogo podkhoda k sozdaniyu podsistemy «INSTRUMENT» v smart-pasporte mnogooperatsionnogo stanka. [Principles of conceptual approach to creating TOOL subsystem for multioperation machine smart-passport.] Vestnik of DSTU, 2014, vol. 14, no. 2, pp. 74–83 (in Russian).

13. Tugengold, A.K. Smart-Passport otkrytoy mekhatronnoy tekhnologicheskoy sistemy. Kontent. [Smart-Passport of open mechatronic technology system. Content.] Saarbrucken: Lambert Academic Publishing, 2013, 83 p. (in Russian).

14. Tsifrovoy dvoynik (Digital Twin) [Digital Twin.] CADFEM CIS. Available at: https://www.cadfem-

cis.ru/products/ansys/systems/digital-twin/ (accessed: 01.02.18.) (in Russian).

15. Tugengold, A.K., et al. Upravlenie tekhnicheskim sostoyaniem stankov. [Machine Condition Management.] STIN, 2018, no. 7, pp. 8–15 (in Russian).

16. Tugengold, A.K. Smart-pasport mekhatronnogo tekhnologicheskogo ob"ekta. Kontsept. [Smart-Passport of mechatronic production facility. Concept.] Vestnik of DSTU, 2012, no. 7, pp. 33–41 (in Russian).

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