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Article

On the functional structure of the ergatic system of precedent management of a complex production facility

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Abstract. The problem of the formation of the functional structure of the ergatic control system of a complex (poorly formalized) production facility (technological unit, human-technical complex, production) is considered, the solution of which is based on the use of a precedent approach to the development and implementation of control decisions (actions). The formulation of the synthesis problem for the procedure for constructing control solutions in an ergatic system is presented. The description of the classical CBR-cycle of making precedent decisions is given and its modification is developed, taking into account the peculiarities of the process of managing a complex object. The main subsystems and enlarged functional blocks of the control system are determined. An example of the application of the functional structure of the precedent management system as applied to the production process of steelmaking in an oxygen converter is presented.

Keywords: ergatic control system, production facility, precedent approach, CBR-decision-making cycle, functional structure, proximity metrics, optimal choice of precedents

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О функциональной структуре эргатической системы прецедентного управления сложным производственным объектом

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Аннотация. Рассматривается задача формирования функциональной структуры системы эргатического управления сложным (слабо формализуемым) производственным объектом (технологическим агрегатом, человеко-техническим комплексом, производством), решение которой базируется на применении прецедентного подхода к выработке и реализации управляющих решений (воздействий). Представлена постановка задачи синтеза процедуры построения управляющих решений в эргатической системе. Дано описание классического CBR-цикла принятия прецедентных решений и разработана его модификация, учитывающая особенности процесса управления сложным объектом. Определены основные подсистемы и укрупненные функциональные блоки управляющей системы. Представлен пример применения функциональной структуры системы прецедентного управления применительно к производственному процессу выплавки стали в кислородном конвертере.

Ключевые слова: система эргатического управления, производственный объект, прецедентный подход, CBR-цикл принятия решений, функциональная структура, метрики близости, оптимальный выбор прецедентов.

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Introduction

The problem of automated control of poorly formalized production facilities (PFPF), which include many technological units and human-technical complexes of different industries, today cannot be recognized as effectively solved on the basis of the traditional (model) approach. This is due to the following factors: a wide variety of states of objects; intensity, complexity, multi-connectivity, and nonstationarity of production processes; incompleteness and errors of control of numerous parameters; multi-mode operation and variability of the characteristics of machines and units during operation; multivariance of products; the presence of a person in the control system. The named factors, as well as the insufficient efficiency of modern automated management of many PFPFs, induce to look for other approaches to making management decisions [1–4]. In particular, to develop the theory of decision-making and the theory of control of objects belonging to the class of PFPF, in the direction of creating automated (ergatic) control systems capable of accumulating and using field data on the practical experience of developing and implementing control decisions. In this paper, we consider the problem of constructing the functional structure of the ergatic control system of the PFPF, based on the method of precedents (precedent control systems, PCS). The latter allows you to move from a model approach to making control decisions to go to a full-scale model [5] and full-scale approaches, which are limited to the use of models of the control object “in small”, verbal models, or, in some situations, do without models.

1. CBR-cycle of decision-making as the basis for constructing ergatic control of PFPF

The method of decision-making based on precedents is widely known and is clearly represented by the so-called CBR-cycle, [6–8]. The classic version of CBR (Case-based reasoning) — the cycle includes 4 main stages of forming a solution for a new problem (new situation):

- retrieving from the knowledge base of one or more solutions – precedents of similar tasks (situations);
- reuse of the best solution-precedent;
- correction (adaptation, revise) of the selected precedent, taking into account the peculiarities of the new task (situation);
- retention of a new use case in the precedent library.

Concretization and modification of the classical CBR-cycle in relation to decision-making in the ergatic control system of PFPF consists in taking into account its features associated with the presence of a decision-maker (DM), with a variety of situations in the system (external influences, states of control objects, output actions, control impacts, control objectives, constraints), with the implementation of the decisions made and the results obtained, with the correction (retrospective optimization) of the implemented, but insufficiently effective control actions, with the actualization of the precedent database. The result of such concretization, in the form of a modified cycle for the development and implementation of control decisions, is shown in Fig. 1.

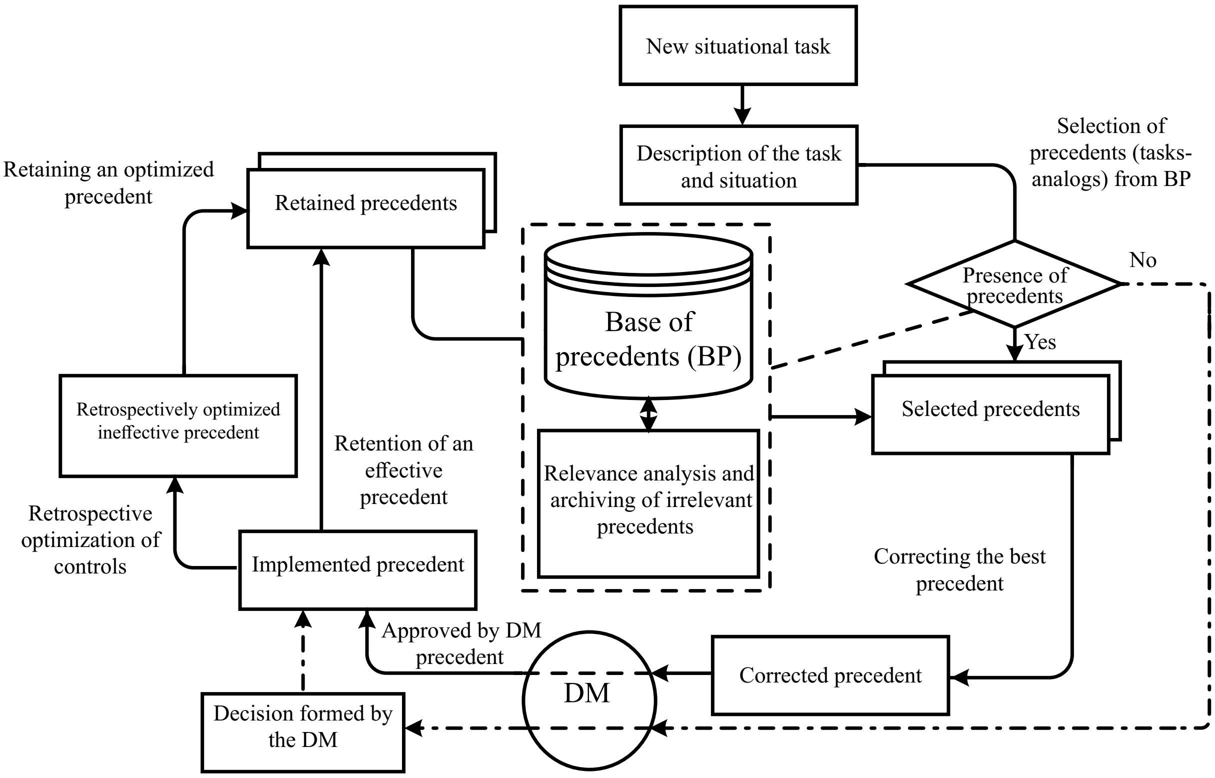

Fig. 1. Modified cycle for the development and implementation of management decisions in the management system of PFPF

2. The proposed functional structure of the precedent management system

The functional structure of the PCS is determined by the procedure for the formation and implementation of management decisions. Such a step-by-step procedure for management decisions in the form of a program of work for PFPF in the coming period includes the following actions.

1. Determination of data related to the conditions of the task of forming a program of work for a production facility in the coming period $[t, t+T]$.
2. Search in the base of precedents for such programs of the object's work, which according to the initial conditions and the results obtained are as close as possible to the conditions and required results of the task of the forthcoming period. The metrics recommended in [9] can be used as optimality criteria, supplementing them with restrictions on the admissible values of the parameters of the result obtained.
3. Correction of the control solution of the optimal precedent, taking into account significant differences in the initial conditions of the new and precedent problem of forming a work program. In this case, the model of the control object “in small” is used, as presented in the work of the authors [10]. The decision-maker (for example, operator-technologist, foreman, deputy head of the shop) participates in the correction procedure.
4. The implementation of the resulting control solution is carried out by a special subsystem after the approval of its decision-maker. Replenishment and updating of the base of precedents include the following operations:
   - reading of data corresponding to the implemented program of operation of the production facility;
   - retrospective optimization of the actually implemented work program, if it has drawbacks (unforeseen downtime, errors of personnel, or automation equipment, decrease in the values of performance indicators), using simple rules for recalculating in increments;
   - saving the actual (if there are no comments to it) optimized precedent;
   - removal from the base of precedents of those instances that become obsolete over time (due to significant changes in the characteristics of PCS, updating the assortment of products, and for other reasons).

The general diagram of the precedent management system of the PFPF, corresponding to the above actions, is shown in Fig. 2. The latter contains the following conventions:

- ⍖ denotes measurement information sensors;
- ⍏ denotes executive devices;
- U^d, Y^d, W^d_H, W^d_K are vectors of actual (with subscript d) control actions (decisions), output actions, uncontrolled (subscript H) and controlled (subscript K) external influences of the control object;
- U^H, S^H, W^H_K are vectors of full-scale (index H) signals of measuring information about control actions, about the state of the object, about controlled external influences, about the output actions of the control object;
- $\{PR^H\}$ is a subset of natural (subscript H) retrieved precedents;
- PR^* is the optimal case solution.

The structure of the PCS includes four automated subsystems: monitoring, implementation of the current decision, selection of precedents, formation and updating of the base of precedents. Monitoring is focused on the formation and storage of primary data on the functioning of the object, which are necessary to create an information model for each precedent. It pays special attention to the functions of monitoring and managing the reliability of data, including through automatic calibration of sensors with the notification of specialists in the operation of control equipment.

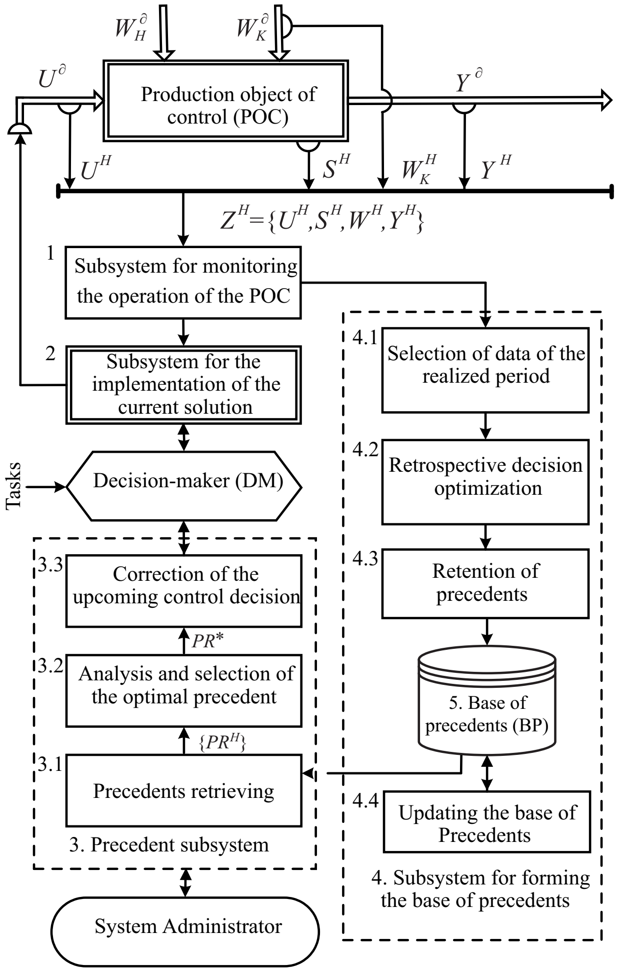

Fig. 2. Enlarged functional structure of the system for forming control decisions based on precedents

The implementation of the current decision (in the form of a previously adopted management program for the current period of the work of the PFPF) is carried out with the direct participation of the decision-maker and automatic control facilities. The selection of precedents is carried out during the current period of work of the PFPF, the duration of which is determined by the technological or calendar cycle of the object's work. The formation of the base of precedents is carried out at the end of each cycle of the object's operation and involves not only storing data on high-quality precedents but also preliminary (before saving) optimization of satisfactory precedents using the so-called recalculating (corrective) mathematical [11], as well as ontological [12] models. Updating the base of precedents is necessary in cases where the base fills up quickly and some of its precedents become obsolete, that is, it becomes very rarely in demand in new conditions. This part complicates and lengthens the procedure for finding optimal use cases and should be moved from the workspace of the use case base to the archive part.

3. An example of concretization of one of the subsystems of the functional structure of the PCS

The general functional structure presented in Fig. 2 is further partially concretized in relation to the production organizational system — the steelmaking shop, for which the problem of the automated construction of the steel melting program is solved by each shift brigade. Concretization refers to the subsystem for forming the base of precedents. The problem of choosing the optimal precedent is formulated as follows [13]. Given:

1. The information model of the j-th smelt is a precedent, the structure of which is enlarged in Fig. 3 and includes information: about the output effects Y_j of the

control object (the steel-making complex), control U_j and controlled external W_j^K effects on the object, the parameters S_j of the state of the main technological unit.

2. Formed at the current time base of precedents, including data $Z_j\{Y, U, W, S\}_J$ on the set $J = \{j\}$ of past melts of steel for a period of time T (month, quarter, year).
3. Many known measures (metrics, criteria) $M = \{m_1, \ldots, m_K\}$ of the proximity of situations for past and forthcoming steel melting.
4. Limitations that should be taken into account when selecting the best case heats:
   - the precedent should include the steel grade specified for the upcoming melting;
   - the actual precedents should include only those steel melts that were smelted further than a day (week, decade, month) before the upcoming melting;
   - an acceptable precedent (for rarely smelted steel grades) can be melting performed on another similar unit of the workshop.

It is required to choose on a set M the best metric of the proximity of the past and present melts of steel and to develop an algorithm for selecting a given number of optimal melts according to the criterion of the proximity of situations — precedents that satisfy the constraints.

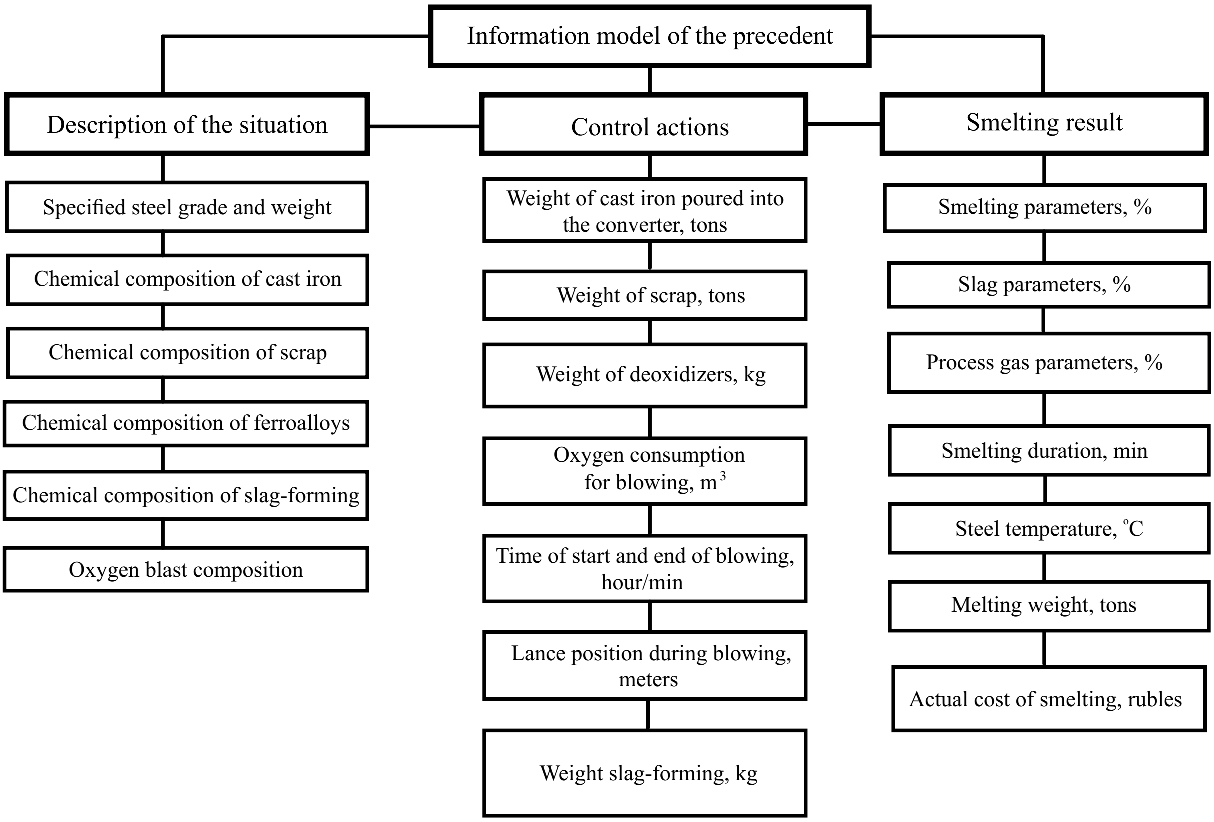

Fig. 3. Structure of the information model of the smelting-precedent

The following metrics were chosen as the initial set of proximity measures.

1. Euclidean measure $d_K(Z_j, Z^*)$, which is represented by the following expression:

$$d_E(Z_j, Z^*) = \sqrt{\sum_{i=1}^{n} (z_{ji} - z_i^*)^2}, \qquad (1)$$

where Z_j is the vector of parameters of the j-th precedent, Z^* is the vector of parameters of the upcoming melting; z_{ji} is the normalized value of the i-th parameter of the j-th precedent; z_i^* is the normalized value of the i-th parameter of the upcoming melting.

2. Hamming measure, represented by the expression:

$$d_H(Z_j, Z^*) = \sum_{i=1}^{n} |z_{ji} - z_i^*|. \tag{2}$$

3. The Manhattan measure is an extended case of the Hamming or Euclidean measure, with the only difference that it uses the parameter importance coefficient, for example:

$$d_{ME}(Z_j, Z^*) = \sqrt{\sum_{i=1}^{n} a_i (z_{ji} - z_i^*)^2}, \tag{3}$$

$$d_{MH}(Z_j, Z^*) = \sum_{i=1}^{n} a_i |z_{ji} - z_i^*|, \tag{4}$$

where a_i is the coefficient of the importance of the i-th melting parameter (as a rule, $a_i \in [0, 1]$).

4. Generalized counting distance:

$$d_0(Z_j, Z^*) = \sum_{i=1}^{n} \begin{cases} 1, & if\ z_{ji} \in (z_i^* \pm \delta Z_i) \\ 0, & if\ z_{ji} \notin (z_i^* \pm \delta Z_i) \end{cases}, \tag{5}$$

where $d_0(Z_j, Z^*)$ is the number of vector coordinates Z_j, Z^* by which these vectors differ from each other by an amount less than the neighborhood $\pm \delta Z_i$ of the vector Z^* coordinates $\{z_i^*\}$.

The proposed human-machine procedure for selecting the optimal precedents includes the following actions, which must be performed 10–20 minutes before the end of the current steel melting.

1. The workstation of the decision-maker (foreman and operator of the distributor) receives a task for the upcoming smelting (new situational task), containing the parameters of the situation for a new smelting, including: a given smelt mass and steel grade (chemical composition, temperature), the chemical composition of liquid iron, scrap, ferroalloys, and slag-forming.
2. The decision-maker launches the process of forming the 2 closest, to the current moment in time, samples from the base of precedents and an algorithm for selecting several optimal precedents, while:
   (a) out of 2 samples, subsets of precedents are selected that satisfy the restrictions on the grade and temperature of steel, the weight of the melt, the presence of bulk materials;
   (b) on the basis of a given measure of proximity, a limited group of optimal (that is, the ones closest to the up-coming melting in terms of the values of situational parameters) precedents is formed;
   (c) representatives of the group of optimal precedents are consistently displayed by decision-makers in a concise form, who, at their discretion, choose a use case

for implementation. If the decision-maker does not find a suitable precedent, then they can change the measure of proximity or constraint and again refer to step 2.2 to form a new group of optimal precedents.

3. The decision-makers accept the selected precedent for implementation "as is" or make adjustments to it.

Conclusion

The CBR-cycle of decision-making is considered the basis for constructing a procedure for human-machine control of a poorly formalized production object. The general functional structure of the precedent control system has been developed. The concretization of individual modules of the functional control scheme associated with the selection of optimal precedents for the production organizational system — steel-making workshop is presented. Criteria and limitations are presented, as well as a procedure for choosing optimal precedents from a regularly updated database of past steel melts.

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