Principles of intellectual control and classification optimization in conditions of technological processes of beneficiation complexes

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Abstract. These theses contains realization of a typical technological beneficiation complex for automation of control processes (in the context of beneficiation of iron ore - magnetite quartzites). The hierarchy scheme of intelligence control system for such complex combining principles of neurocontrol, classification and optimal control has been shown. Results of computer modeling of classification optimization process in the context of actual indicators of magnetite quartzites concentration have been shown.

Keywords. Intellectual control, classification optimization, beneficiation technology, iron ore, magnetite quartzites

Key Terms. Intelligence, Control System, Model, Classification

1 Introduction

Nowadays the problem of intellectual control of technological processes is considered rather actual. Thus necessity of constant improvement of manufacture, increase of competitiveness, minimization of technological environmental impact demands application of complex automation systems is based on modern information technologies (IT) and intelligent control systems (ICS) [1].

Let's consider the complex of technological processes of iron ore beneficiation (magnetite quartzites). As the object of control such complex is characterized by sufficient complexity (multichanneling, nonlinearity, non-stationary, illegibility and incompleteness of information along with great value of transport delay of output parameters, presence of noise and disturbance, presence of recycles on the majority of stages, etc.) [2]. Taking into account these properties, statement of a problem and potential approaches to their decision such complex can be considered as typical [3-4].

Works of [2-10] are of great importance for the development of intellectual control theory of beneficiation technology objects. At the same time, despite of considerable quantity of research and development, existing systems of automation do not always meet modern requirements and do not provide the effective decision of difficult tasks in actual conditions in beneficiation process line.

2 Review of existing decisions and task setting

Taking into account multidimensionality, illegibility and incompleteness of technological information on all levels of control it is necessary to use ICS to support operators' (controllers, technologists and other) decision making and increase their quality [1]. The further task setting of intellectual control of a process line (a section) can be also conditionally represented by means of classical cybernetics chart "black box" (Fig. 1). Accordingly, for controlling the beneficiation process set of vectors *X, U, Y, V* on the basis of can be formed as follows.

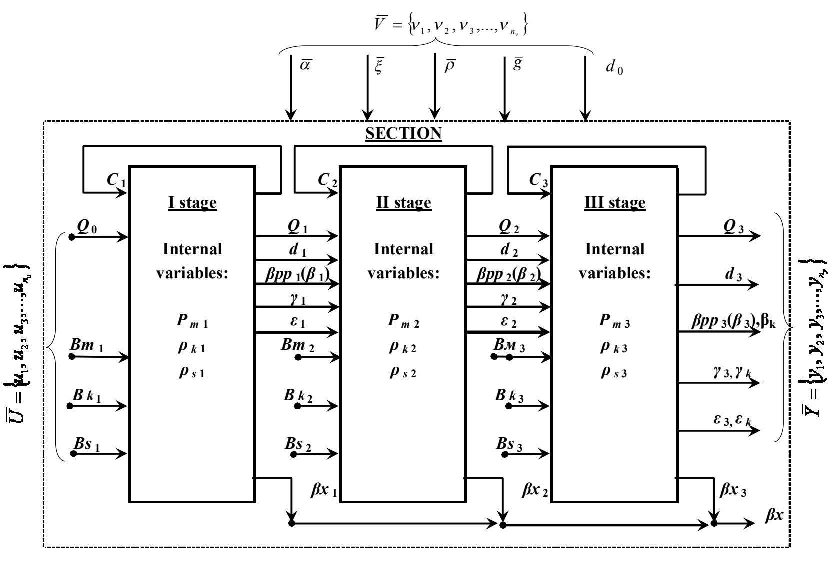

Fig. 1. Process line (section) of concentrating as the object of intelligence control

In Fig. 1 such notations are taken: $i = 1 \ldots N_r$ is a number of industrial variety of ore; N_r is quantity of industrial varieties; $\overline{\alpha} = \{\alpha_i\}$ is estimated raw ore grade; $\overline{\xi} = \{\xi_i\}$ is specific gravity of every variety of ore; $\overline{\rho} = \{\rho_i\}$ is an index or a group of indices that characterize physical and chemical properties of ore (for example, density of corresponding varieties of ore, strength, grindability, etc.); $\overline{g} = \{g_i\}$ is index that characterizes mineralogical and/or morphological properties of ore (for example, averaged size of magnetite dissemination in ore after varieties); d_0 is averaged ore coarseness before beneficiation; Q_0 is an ore consumption on the first stage of beneficiation; $j = 1...N_s$ is number of beneficiation stage; N_s – is quantity of stage; $\overline{Q} = \{Q_j\}$, is processing output of each stage; $\overline{C} = \{C_j\}$ is circulation load; $\overline{d} = \{d_j\}$ is averaged product coarseness; $\overline{P}_m = \{P_{m\,j}\}$ is a solid content in pulp; $\overline{B}_m = \{B_{m\,j}\}$, $\overline{B}_k = \{B_{k\,j}\}$, $\overline{B}_s = \{B_{s\,j}\}$ are consumption of water to the mill, classifier and magnetic separation respectively; $\overline{\rho}_k = \{\rho_{k\,j}\}$ is a pulp density in the process of classification; $\overline{\rho}_s = \{\rho_{p\,j}\}$ is a pulp density before magnetic separation; $\overline{\beta}_{pp} = \{\beta_{pp\,j}\} = \{\beta_j\}$ is an estimated grade in the industrial product; $\overline{\beta}_x = \{\beta_{x\,j}\}$ is loss of a commercial component in tails; β_k is a quality of concentrate; $\overline{\gamma} = \{\gamma_j\}$ is an output of useful component in an industrial product; γ_k is an output of useful component in concentrate; $\overline{\varepsilon} = \{\varepsilon_j\}$ is an extraction of useful component in an industrial product; ε_k is an extraction of useful component in a concentrate.

Thus distribution of state vector on input and output indexes is conditional enough because most parameters on output, for example, of the first stage will be input for the second, etc.

For further application of multidimensional model such as Fig. 1 (for example, for decision of identification tasks or synthesis of automated control systems of beneficiation TP) with using artificial intelligence technology a number of typical neural network structures that will be offer by the author here.

3 The hierarchy scheme of intelligence control system for such complex combining principles of neurocontrol, classification and optimal control

The results of tests of such intelligent systems have proved the possibility of their application in the beneficiation TP. At the same time, to ensure their operation it is necessary to determine the values of settings and / or trends in their paths. Further studies have shown that the determination of the required setting values it is necessary to carry out by combination of the following [7]:

1. Classification control, that is founded on the basis of permanent accumulation of technological parameters history database (DB), their grouping on certain signs (clustering) and determination of value of setting for the measure of similarity to the current values of vectors: input, output and internal parameters[8, 9].

2. Optimal control, which requires the design of general purpose functionality for the system and the application of global optimization methods [4, 10].

Main advantages of the classification approach are their potentially high fast-acting due to the use of well-known methods of clustering and patterns recognition (for example, neural networks classification). The disadvantage is low accuracy (the chosen decision is not necessarily optimal, and even quasioptimal). Also, application of the approach does not always guarantee the result. In particular, this may be due to such cases:

- at the beginning of the system operation, when the database of technological situations parameters is quite small;
- in the case when necessary (similar) combination of parameters (cluster) has not been met yet in the process of exploitation of ICS;
- in changing of flowsheet, regime map, presence of considerable disturbance of properties of primary raw material (ore, its amount and correlation of mineral varieties, etc.).

On the one side, optimization approaches in the case of multidimensional goal function are also characterized by disadvantages that are caused by:

- the difficulty of obtaining a sufficiently adequate mathematical model of TP [4], which is typical for most inertial processes (in particular, the beneficiation);
- the bad conditionality of optimization task (presence of great amount of local extremums) that appears in the case of application of well-known identification methods of the multidimensional systems (regressive models, Wiener–Hopf equation, synergetic and self-organizations, artificial neural networks and others in particular) and greatly limits the application of well-known methods of multidimensional optimization;
- slow convergence rate of computing process during optimization in large number of cases.

On the other hand, in the case of the possibility of designing the mathematical model and a good choice of hill climbing algorithm (method) it is possible to solve control task, which allows to define a really optimal (or quasioptimal) settings, with certain limitations. Taking into account well-known advantages and disadvantages of the above-mentioned approaches for the implementation of multichannel ICS of TP of iron-ore beneficiation the approach based on combination of classification and optimization algorithms has been offered. Structure of multichannel hierarchical ICS of TP of beneficiation complex based on the system of coupling of neurocontrol, classification and optimization methods is shown in Fig. 2.

In Fig. 2 such notations are taken: OC_{ij} is a control object (channel), j its number (j=1,…,k_i; k_i is an amount of control channels), i is a number of the stage for local TP (for example, fragmentation, classification, magnetic separation, etc., i=1,…,N_s; N_s is amount of the stages of beneficiation TP); NC_{ij} – intelligence neurocontroller of OC_{ij}; V_{ij} is a vector of disturbing influences for OC_{ij}; Y_{ij} – a vector of output characteristics of OC_{ij}; U_{ij} is a vector of control influences (actions) of OC_{ij}; X_{ij} is a vector of informative parameters about the state of OC_{ij}; Y^s_{ij} is a vector of settings of output characteristics of OC_{ij}; TP^*_i is the complex of all local TP of the certain stage; V^*_i is a vector of main influences of disturbing of TP^*_i; Y^*_i is a vector of output characteristics of TP^*_i; X^*_i is a vector of information parameters about current stat of TP^* complex $_i$; Y^{*s}_i is a vector of tasks (settings) for output characteristics of TP^*_i; NE^*_i – neuroemulator (predictive mathematical model or predictor) for TP of the corresponding stage.

Three main control levels 1) of local regime parameters (ore and/or water consumption, pulp density, etc.); 2) quality indices (content of useful component, output, exception, etc.); 3) complex of TP (fragmentation, classification, magnetic separation) are divided in the structure.

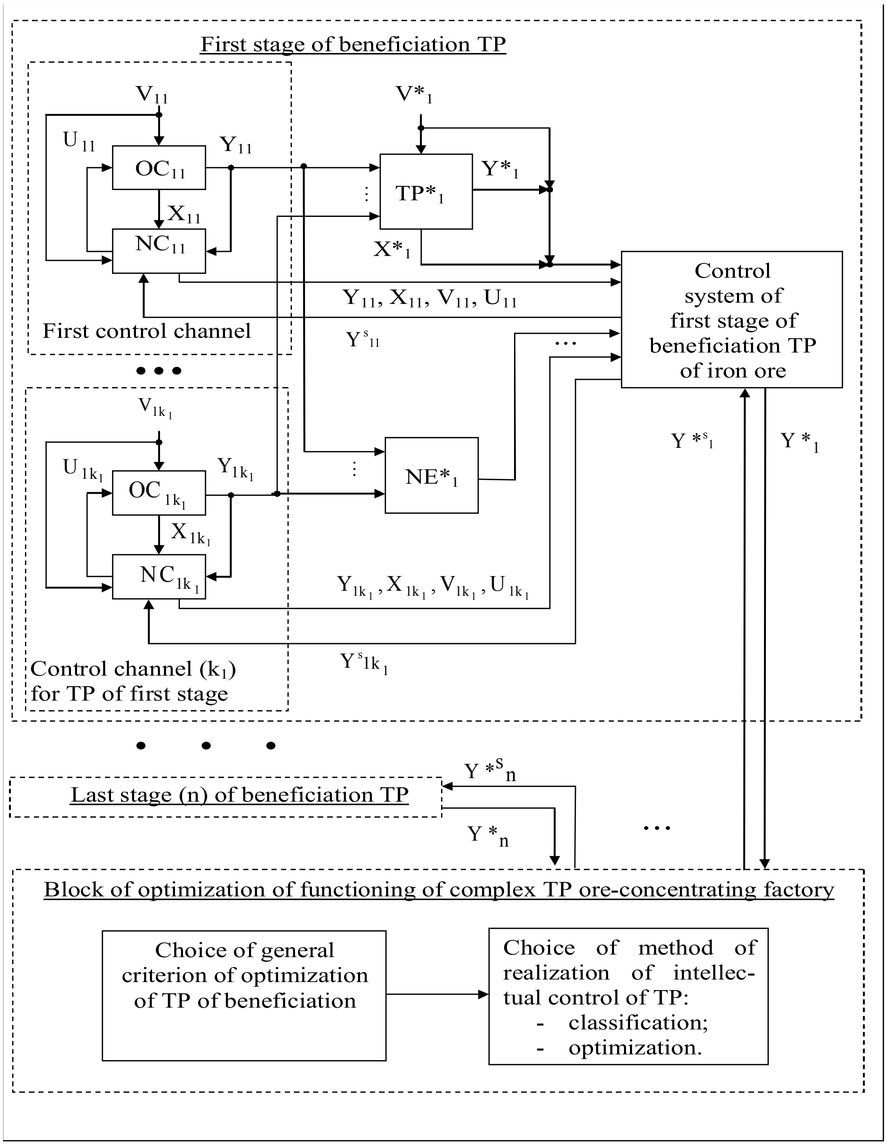

Fig. 2. The structure of combined multichannel ICS of TP of magnetite quartzites beneficiation (classification-optimal control)

So, for example, for a complex of TP of the first stage (supposing that for TP of fragmentation i=1, k_1=2): the first channel (OC_{11}) is the correlation of "ore-water"; the second channel (OC_{12}) is the mill productivity output (at unloading); V_{11}={coarseness of grading (averaged coarseness) of input product}; V_{12}={physical and chemical and mechanical properties of ore}; Y_{11}, Y_{12}={ coarseness of grading (averaged coarseness) of industrial product, productivity after the industrial product, output of the prepared class}; U_{11}={mill water consumption }; U_{12}={ ore input productivity}; X_{11}={content of solid in the middle of the mill}; X_{12}={all regime indices of mill work}. Similarly the formalization for other TP of the first stage (classification, magnetic separation) is carried out. Then the resulting characteristics for a complex of TP (all stages) as a whole are formed as follows: $V^*_1=V_{11}\cup V_{12}$ ($\cup$ is the operation of logical combination of vectors); Y^*_1={quality of industrial product by quality of useful component, productivity on the output stage}; $X^*_1=X_{11}\cup X_{12}$.

The idea of the approach is in application of combined algorithm with combination of classification and optimal control approaches in order to ensure the acceleration decision-making process in multichannel ICS of TP of magnetite quartzites beneficiation. The main features of the implementation of such a system are as follows [1, 7].

The intellectual analysis of current state of control object is carried out constantly at the end of the next step of discrete time by the top level of the system on every stage of beneficiation in the block of optimization of beneficiation complex operation. The determining of settings (tasks) for the control systems of the corresponding stages (middle level) is carried out on the basis of a coherent analysis of indexes of all beneficiation stages. At the same time, in contrast to existing approaches, decision-making process (definition of the necessary settings) in the system (Fig. 2) can be occurred through intelligent classification (classification control) or global optimization (optimal control). Algorithms for the implementation of corresponding computational procedures will be given in the future.

On the middle level control of TP complex for separate stages is carried out. For this purpose the level is given the value of optimal settings from a top level and it determines a task (proves these settings) for the regulators of all local TP and their corresponding channels of control of every beneficiation stage. From the other side middle level systems collect primary information about the state of every channel (control actions, outputs, disturbing) from the subsystems of the bottom level, carry out its primary processing, prediction of values of input and output indexes of the stage using of neuroemulator (NE*i). Certain data are also passed on the top level for decision making and determination of optimal settings for the purpose of the coordinated control of all stages and complex of beneficiation TP as a whole.

The bottom level of the system controls separate local TP of each stage. For this purpose the level contains the number of control channels. Each channel has its own inverse neuroregulator that recreates the inverse dynamics of the process. The task of work of such regulator is maintenance of necessary value of settings, that is determined at the top level of the system and given from the corresponding control subsystem of the certain stage (id est. middle level). In turn, the bottom level subsystem passes information about the state of each channel (indexes of control influences, value of output and information signals, disturbance) to the middle level system at first and then to the top level.

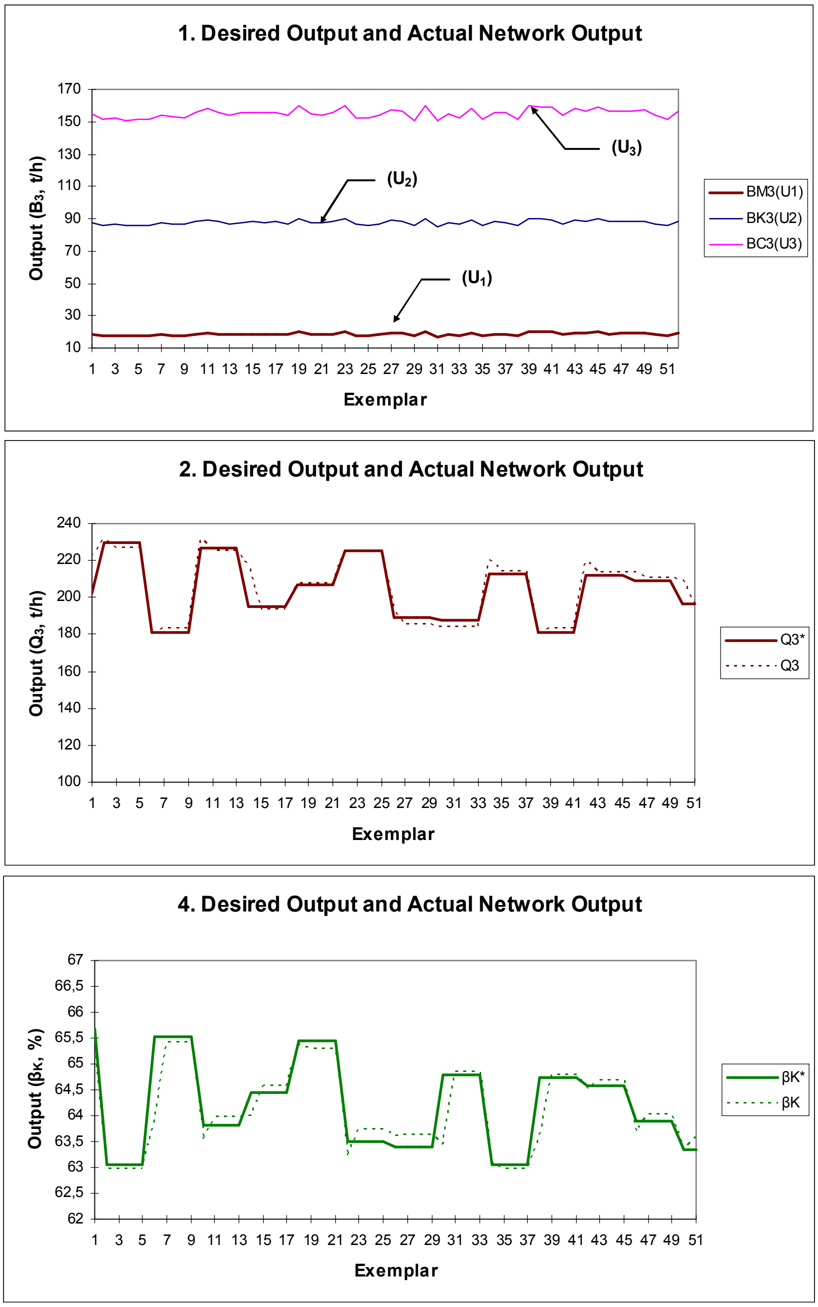

Fig. 3. Results of computer modeling of classification optimization process in the context of actual indicators of magnetite quartzites concentration

4 Conclusions

For the hierarchy scheme of ICS of beneficiation technological complex on the basis of combination of principles of neurocontrol, intelligence classification and global optimization contingency approach at forming limit cluster of certain "special technological situations", that allows to control TP automatically in real-time mode, determine and propose corresponding control influences has been offered.

The conducted researches, results of computer modeling (Fig. 3) and industrial tests [1, 5-7] proved that application of neural networks schemes on the basis of inverse models and neuroemulators as regulators of separate channels of beneficiation TP has a sufficient dynamics (reasonable time of settings exercise on condition of its presence), the possibility of the proper disturbance rejection at 10% level and operation on the conditions of nonlinear limitations (changes of controller parameters) on the basis of satiation principle. Thus, the task of this work is the verification of possibilities of classification strategy for reliable determination of optimal values of current parameters of TP (in the form of the relevant tasks or setting for controllers), that will provide stable work of local regulators in the above-mentioned terms.

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