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USING OF NEURAL CONTROL SYSTEMS IN CONCENTRATION PROCESS AUTOMATION

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Abstract. Ball drum mill are widely used on concentrating complexes of iron ore on mining and processing plant. Largely thanks to the beneficial properties of neural networks that are common to different types of nonlinear dynamic objects and solved the problem of identification, analysis, synthesis and hardware implementation of complex process control systems in non-stationary terms and with incomplete and fuzzy information. The implementation of the majority part of considered existing industrial automated control systems are based on proportional, integrating and differential regulators or their combinations (P, PI, PID controllers).However, systems with PID controllers can't always provide the necessary quality of controling, especially in terms of difficult technological processes with nonlinearity, nonstationarity, delay in time, random perturbations presence of fuzzy and incomplete information. For such technological processes can be attributed most part of mineral processing stages. Milling of iron ore is the preparatory process for the magnetic concentration of materials. The basic technological process of magnetic-concentration complexes is magnetic separation. For the main ways of preparing the ore on magnetic-concentration complexes can be attributed milling and classification of iron ore to controling particle size of ore, that incoming to the magnetic concentration. Considering the large number of components in the composition of the ore and it's variable characteristics, it is necessary to control of milling processes to achieve optimal size of milling ore and the optimum fractional composition of raw materials that incoming to the magnetic separation.

The purpose: Is to prove the possibility of using neurocybernetics approaches for controlling of technological process concentration technology in terms of mining and processing complexes.

Methods: identifying patterns of increasing efficiency of technological process controlling through synthesis and implementation of optimal controlling in the operation of control systems based on identification and forecasting condition of controlled processes with controlling of major disturbances.

Scientific novelty: introduction of optimal automatic control system of milling process is more efficient by production costs and economically expedient than using the traditional automated control systems based on regulators.

Practical relevance: the main potential of fuzzy logic is in implementing the functions of supervisory control. Using fuzzy logic makes possible to fully automate the technological process and review the formed rules and their interpretation for further analysis.

Results: review the researchers works allowed to organize and present the main technological units as a control objects. This made possible to define the direction of creating future neural control systems in concentration process automation.

Keywords. Drum mill, concentrating complexes, milling, control, optimization, fuzzy control system.

Introduction. Nowadays for domestic enterprises in mining and metallurgical industry increasing the competitiveness of production by reducing the cost of processing, energy optimization, stabilization or improving quality of product is sufficiently actual problem. It is well known that one of the most promising ways of solving this problem is complex automation of technological processes [1,2].

Ball drum mills are used for milling mineral products on mining and processing plant for mining and beneficiation plants, cement plants, thermal power plants.

The processes of materials milling are widely used in the chemical industry. The rates of development of the chemical and other related industries are need to improving the designs of equipment for milling, increasing its reliability and efficiency. In addition, the acute problem of reducing the cost of processing, improving it's quality and increase profitability. This problem can be solved by the widespread introduction of new technology and more efficient using of existing equipment.

The necessary intensification of the milling process can be achieved only through a deep knowledge of operating principle and construction of appropriate equipment and features of its operation. [3]

Currently, control system with the parameters adaptation or static optimization are used for automated control of crushing and milling processes with insufficient control quality in terms of ore quality variations and dynamic variable modes of equipment [4].

The fundamental works of M. Jalal, S. Quinn, K. Wong and McGreevey, R. Izerman are the theoretical and methodological base in the areas dedicated to processes controlling of materials resources concentration.

The problem of concentrating complexes automation were considered in research of G.A. Khak, B.D. Kosharskyi, A.N. Maryuta, V.V. Stalskyi, A.E. Kozin, V.Z. Tropa, Jh. Forrester, V.S. Morkun, E.V. Kochura, A.I. Kupin and many others.

Despite the history of research in the field of automatic control systems, these issues are relevant and important to modern production.

The main restrictions for the applying classical existing control systems on iron ore complexes are:

- the absence or not enough accuracy of the equipment;
- complications of works conditions of concentrating equipment due to the depletion of the mineral resource base and work with different sorts of iron ores;
- the necessity of multiparameter optimization and research for equipment pre-setting;
- significant influence, but rather a mutual influence, of technological processes and lines;
- permanent "drift" zone of optimal operations due to the instability of the input ore stream and equipment aging.

However, the development of artificial intelligence systems - artificial neural networks - allow to assume that such control systems can be designed and used effectively if they based on artificial neural networks because neural networks focused on processing large volumes of information, including slightly structured and capable to learning and adaptation [5].

Analysis of solutions in the field of methods and regulation systems allow to make the conclusion that modern automatic control theory provides opportunities to develop new automatic control systems that are used insufficiently at present. Development and using of these systems provide a significant increase of the product quality milling. The analysis of the patent review are shown in table 1.

Research in this area are empirical, due to this fact it’s impossible to get some theoretical patterns of forming mill signal and develop the method and principles of construction the reliable milling ore systems in ball mills. Therefore, the theme of article is actual.

Materials and methods. According to the technological scheme [6, 7] first stage of magnetic concentration includes mill, classifier and magnetic separator (figure 1).

Input system information are: mill productivity, output ore particle size in mill input, ore types. Regulated values are: solid content in the mill output and classifier sink density. Adjustment is made by changing the flow of water to classifier mill or sink by changing the ratio of "ore-water" or "solid, liquid” (S: L) in the respective units.

Technological complex of milling is important part of concentration process with expensive investment cost and high exploitative costs. Efficiency and profitability of all process are depend from efficiency of ore milling.

Milling is one of the most difficult processes in terms of regulation. It is highly nonlinear. There are a lot of adjustment parameters and they are strongly related to each other. Milling circuit is sensitive to many obstacles and compensation of their influence requires strong regulation. Ordinary regulation circuits can work well in some cases, but they don't consider mode violations and can ruin the entire process.

Therefore, regulation of milling process requires not only continuous adjustment, but logic control, which, if it’s necessary, can change adjustment strategy.

The automation system of the first stage of concentration with ore milling process optimization ball mills based on neural control systems is a subsystem of the automated control of concentration.

Technological scheme of magnetite quartzite concentration is shown in figure 2.

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Table 1. The results of patent review

Invention object	Invention features	Copyright number or patent certificate	Source of information
The method of milling regulation	Control of the combined setting ofoil pressure and consumption power drive	1066649, B02C 25/00	G.E. № 2, 1984
	Control with parameters combinations	1039560, B02C 25/00	G.E. № 33 1983
	Control with the combined adjustment of balls and ore loading	492303, B02C 25/00	G.E. № 43, 1975
		478606, B02C 25/00	G.E. № 48, 1975
Regulation of milling degree	Control by particle size milling	1253246, B02C 25/00	«Abroad inventions», 1968
		1507466, B02C 25/00	
		1607437, B02C 25/00	
		503593, B02C 25/00	G.E. № 7, 1976
	Control by degree of milling and Péclet number	1000105, B02C 25/00	G.E. № 8, 1983
	Control by the output frequency of non	1065020, B02C 25/00	G.E. № 1, 1984
Invention object	Invention features	Copyright number or patent certificate	Source of information
	milling pieces		
	Control by the output frequency deviation of non milling pieces	1066647, B02C 25/00	G.E. № 2, 1984
	Control by the content of minerals in the ore	919741, B02C 25/00	G.E. № 14, 1982
	Control by the viscosity and moisture sludge	1033197, B02C 25/00	G.E. № 29, 1983
Regulation for the noise level	Allotment of acoustic spectrum signal of noise level	358687, B02C 25/00	G.E. № 34, 1972
		1607560, B02C 25/00	«Abroad inventions», 1970
		3690570, B02C 25/00	«Abroad inventions», 1972
	Control with parameters combinations	961776, B02C 25/00	G.E. № 36, 1982
Regulation for the circulating load	Control by the ore weight	3779469, B02C 25/00	«Abroad inventions», 1973
	Control by the degree of download	481315, B02C 25/00	G.E. № 31, 1975
	Control by the ore, water and pulp costs	388790, B02C 25/00	G.E. № 29, 1973
	Control for the ore costs with correction for the circulating load	503592, B02C 25/00	G.E. № 7, 1976
	Control for the amperage consumed by the engine	1285278, B02C 25/00	«Abroad inventions», 1968
	Control for the level and density of the circulating load	3417927, B02C 25/00	
	Control for the instantaneous value of the circulating load	902831, B02C 25/00	G.E. № 5, 1982

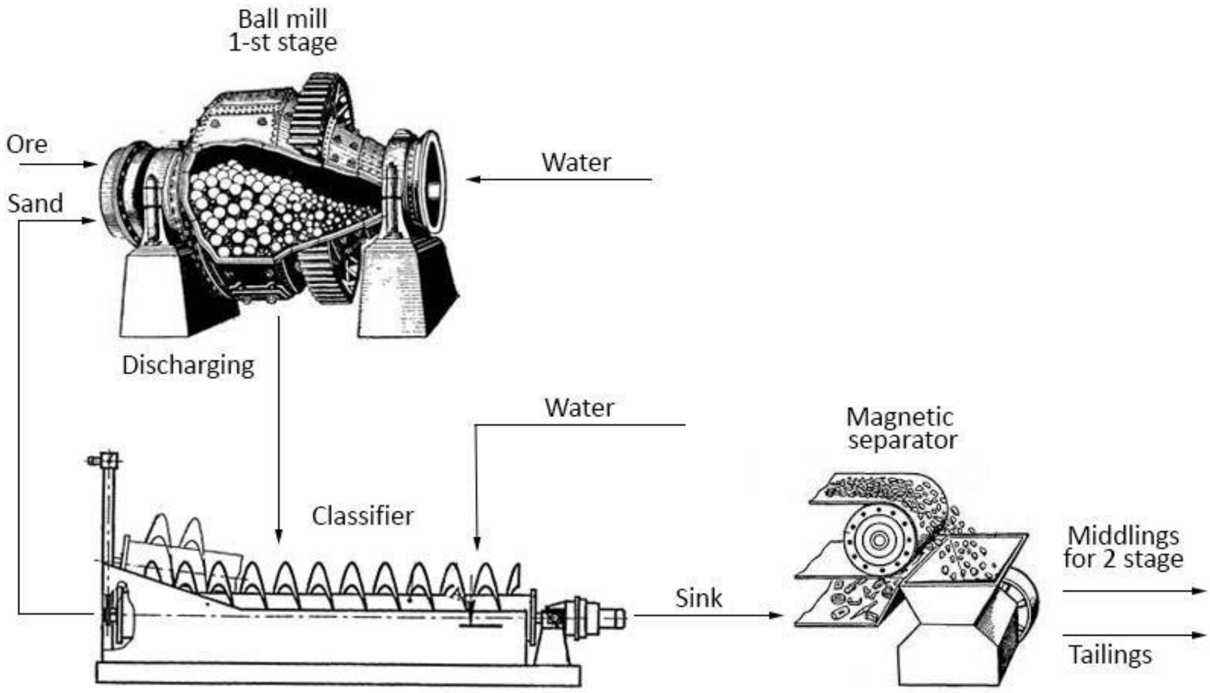

Figure 1. Technological scheme of first stage of magnetic concentration

ACSTP designed to perform complex information, control and support functions that provide the following:

- technological process optimization for providing the processing of required number of ore with minimal costs;
- receiving the set quality concentrate with minimal deviations from the planned values;
- condition monitoring of primary and secondary technological equipment
- operational condition monitoring of sections and prevent accidents;
- collecting and providing information about current process parameters in a convenient form for the operator;
- control of technical personnel actions;
- preparing protocols and reports about the section work;
-automatic diagnostics of equipment, which is part of the control system.

The purpose of the system creation is the replacement of morally and physically obsolete existing process control system. ACSTP must provide:

- reduce specific energy consumption of by increasing the number of processed ore, which will be achieved by improving mills specific productivity;
- reduce fluctuations of iron content in concentrate by improving control system of technological process of stabilizing the main technical parameters;
- increasing iron content in the concentrate by improving the efficiency of milling and concentration through automatic maintenance of optimum modes of mills, separators and deslimer;
- reducing losses of magnetic iron in tails by decreasing the input size of the first stage of wet magnetic separation (WMS) and mode optimization of separation and desliming;
- reserves for the further expansion of control system and the modernization of production, and transfer of the developed control principles, on the other sections of the factory;
- increasing technological discipline of operational staff by logging operator actions;
- simplify the concentration control process by providing specialists with operational information and technological tools of control and analysis;
- increase mechanisms reliability and survivability, reduce labor costs for exploitation due to operative diagnosis of equipment and prevention of emergency situations;

- improving the working conditions of operating staff by centralizing control, providing a complete, accurate, and timely information that is convenient considered, about the state of the object, and by signaling of pre emergency situations.

Theoretical research, computer simulation and industrial test [8-11] have shown potential possibilities of intellectual approaches to identify, control and optimize concentration processes. In particular, this applies to modern trends of artificial intelligence: neural control, fuzzy logic, classification control and evolutionary optimization.

Analysis of existing systems of automation concentration process shows the preferential using 1-2 channel adjustments system of first milling stage parameters is not always enables to stable support required values of section outputs, and therefore it's necessary to improve this approaches. It is necessary to made more research multichannel and multi related intelligent structures designed to identify and control in terms of technological concentrating process for the purpose, coordination and increased number of regulation channel that will make output figures more stable for the first stage of crushing [12-14].

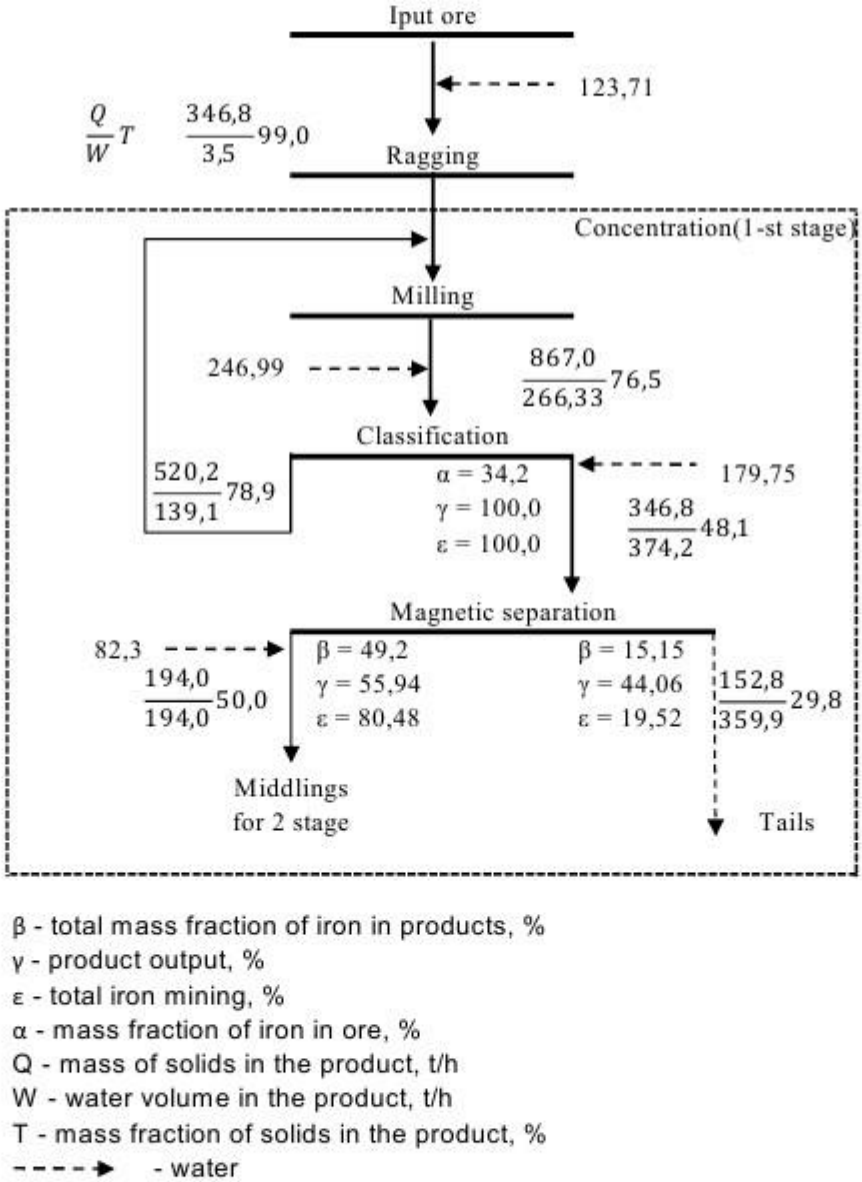

Figure 2. Technological scheme of first stage of magnetite quartzite concentration

Low accuracy, complexity, absence of possibilities or high cost of controlling some important concentrating parameters in real time mode are not always allow to determine correctly the necessary operational parameters and controls settings. It will cause the unacceptable deviations and inconsistencies during the process, and therefore requires the development of forecasting and ranging systems that can perform methods settings of intelligence identification of concentration processes.

Mineral release during milling process depends on the ratio of "liquid - hard" in the mill. This ratio is not constant, it depends on the ore properties. Due to the complexity, density and heterogeneity of its structure, and also other factors, automatic measurement of parameters , that characterizing their physical and mechanical properties, is difficult or impossible. But it's possible to accounting ore loading from mining sites to the hopper of concentrations complex. Therefore, while accounting traffic delays and mixing it may receive indirect data averaged physical and mechanical properties of the ore that fed on milling.

As a result, it is possible to create automation systems of first stage of concentration and optimization of milling control process.

To studying, in the work, as a research subject, was chosen industrial product milling process in the ball mill with the parameter value "ore-water" depending on the composition of boot raw.

From a technological point of view, the first stage is crucial for the quality of the original product. Therefore, the main object of automation at the concentration complex has a number of mechanisms that are part of the first stage of milling - mill, feeders, that serves ore in mill pipeline, which supplies water, spiral classifier, which serves as a feedback (technological) to the return of large inclusions in the mill, layers feeder .

Separately consider the technological complex elements and milling complex as a whole as control object

The mill is designed to reduce the size of ore coming.

The input control actions, in general, considered to be:

- ore amount, which fed to the mill, Q_{ore};
- water amount, which fed to the mill, $Q_{m.w}$;
- frequency of drum mills rotation, n, rot/min;
- bullet load q_b.

Block diagram of the mill as a controlled object is shown in figure 3.

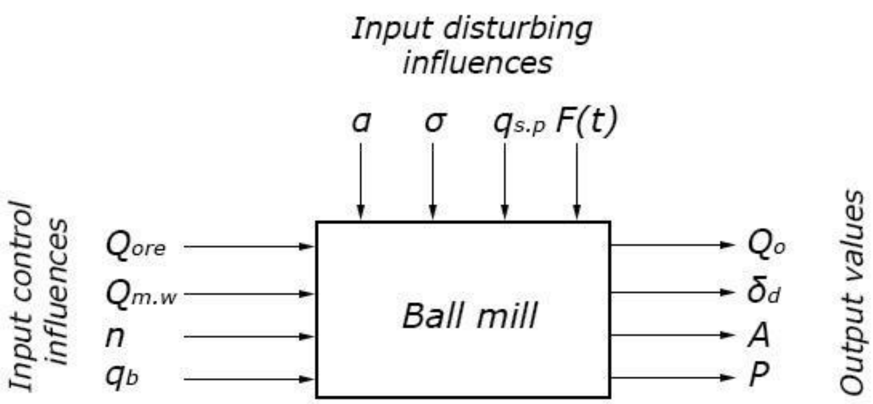

Figure 3. Block diagram of the mill as a controlled object

Input disturbing influences include:

- content of control size class in the original ore α,%;

- deviation in physical and mechanical properties of the input ore for the milling, σ;

- sands number $q_{s.p}$ (if the mill is working in closed loop with a classifier).

The obstacles include: wear of milling environment, wear of mill lining, equipment obsolescence in general - F (t).

Input values, which characterizing mill work are:

- volumetric pulp rate on the sink, Q_o, m^3/h;

- density of mills sink δ_d, kg/l;

- acoustic signal which issued from A working mill (usually in frequency Hz or amplitude in dB);

- power consumption by mill drive motor, P, kW.

The frequency of the drum mills rotation usually don't change during the process. It is determined while debugging technological complex at an optimum level for controlling the ore type and not change subsequently.

Usually as a main control channels are considering the follow:

- ore amount to the mill - sink density of the mill;

- ore amount to the mill - acoustic signal that issued by the mill;

- ore amount to the mill - amount of finished class in the mill sink.

Water is supplied to the mill, depending on how much ore goes into it. Water consumption - the so-called driven parameter, leading - consumption of ore to the mill.

Spiral classifier (figure 4) is designed to separate the milling product by class size. Mills sink (usually the first stage of milling) enters to the trough classifier. Classifier is supplied also a water (point of water is defined in practice and is closer to the classifier sink limit).

Input control influences of classifier include:

- classifier water consumption $Q_{cl.w}$;

- frequency rotation of classifier spiral n, r/m.

Input disturbing influences include:

- volumetric pulp consumption which supplying to classifier Q_p, m^3/h;

- physical and mechanical properties of the solid in the pulp (grains particle size, particles shape, hardness, etc.) σ;

- composition of finished class size in classifier input, $\alpha_{cl.f}$, %.

Obstacles include: overgrowing the bottom of the classifier, spirals wear and other - F(t).

Output values, characterizing classifier spiral works include:

- sink density and pulp sands of the classifier δ_o, $\delta_{s.p}$, kg/l;

- volumetric sink consumption Q_o, m^3/h;

- pulp sands number $Q_{s.p}$, t/h;

- composition of finished class in sink α_o and in sands pulp $\alpha_{s.p}$.

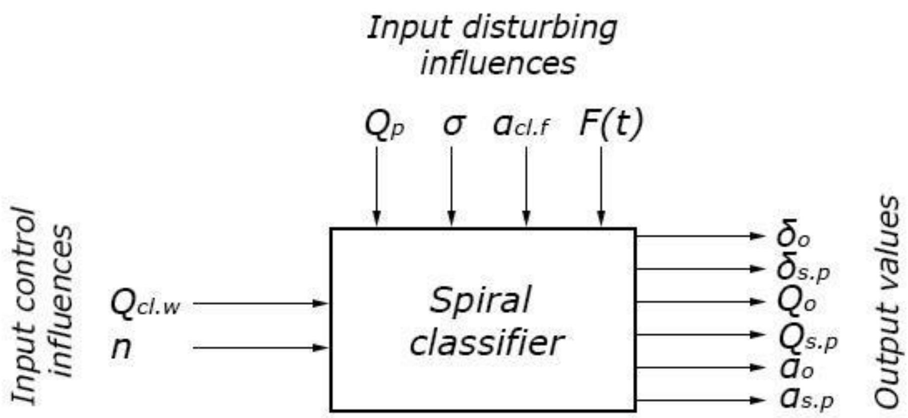

Figure 4. Block diagram of the spiral classifier as a controlled object

Due to the fact that the frequency rotation of spiral classifier usually does not change during the process, it remains one operating influence - water consumption in classifier.

In this regard, the main control channel in a spiral classifier is - water consumption in classifier - density (grain size) of classifier sink.

As an input can be used both of density or particle size of classifier sink, depending on what is more convenient to measure in real factory conditions.

During the process of separation it can be selected values that represent practical interest: raw consumption in the input of concentrate and tails, density of pulp, concentrate and tailings, iron content in input and output (in concentrate and tails) and others.

However, all these components depend on three major variables through which they can be expressed: the number of magnetic iron, rock and water per time unit, or consumption of the concerned product.

In this case, in order to simplify assume that the incoming pulp flow composed of magnetic iron, rocks and water in the first approximation can be ignore the magnetite and rocks fusion.

The separator is considered like ideal mixing apparatus, so the iron content in the concentrate and tails is proportional to its concentration in the separator bath.

The main channels are:

- magnetite consumption in the pulp (input) - the volume of magnetite in the bath of separator (output);

- rock consumption (input) – the volume of the rock in the bath of magnetic separator (output);

- water consumption in the pulp (input) - the volume of water in the bath of magnetic separator (output);

Input control influences of magnetic separator (figure 5) include:

- sands pulp density before the magnetic separation, $\delta_{p.sep}$, kg/l;

- water consumption to the separator $Q_{sep,w}$;

- intensity of magnetic field, H_{sep};

- the rotational speed of the separator drum, V_{sep};

- the content of useful component in the initial charge, γ_{sep}.

Input disturbing influences include:

- volumetric pulp consumption which supplying to separator $Q_{p.sep}$, m^3/h;

- physical and mechanical properties of the solid in the pulp (grains particle size , particles shape, hardness, etc.) σ;

- composition of finished class size in separator, $\alpha_{sep.f}$, %.

Obstacles include: wearing of mechanical separator parts, equipment obsolescence in general, infraction of material temperature control and other - F(t).

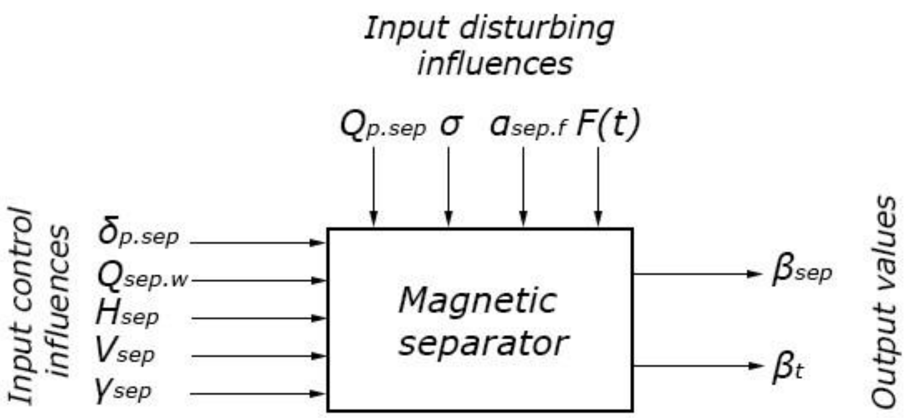

Figure 5. Block diagram of the magnetic separator as a controlled object

Output values, characterizing separators works include:

- losses of mineral products in tails, βt;

quality of industrial product on separator output, β_{sep}.

Let consider a concentration technological complex in general as a control object (figure 6).

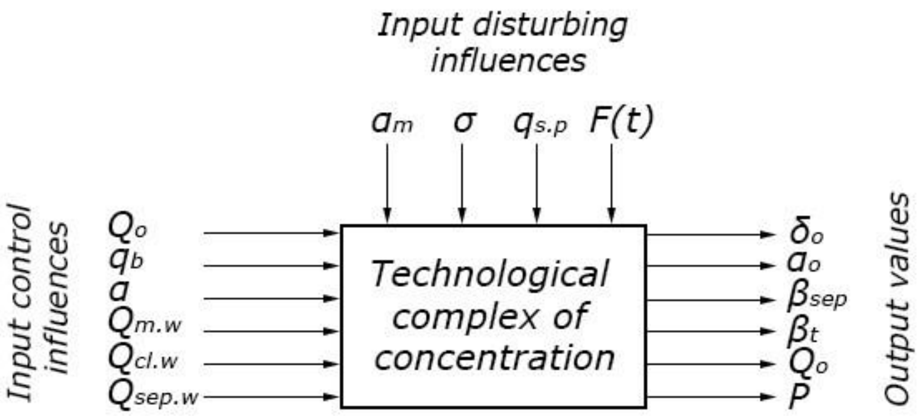

Figure 6. Block diagram of the concentration technological complex as a control object

This technological complex consist of: ball mill, spiral classifier and a magnetic separator.

The concentration technological complex as a control object is characterizing by the follow input parameters:

- ore consumption to complex Q_o, t/h;
- bail charge q_b;
- particle size composition α;
- consumption of water supplied to the mill, $Q_{m.w}$, m^3/h;
- water consumption to classifier $Q_{cl.w}$, m^3/h;
- water consumption to separator $Q_{sep.w}$, m^3/h.

Main disturbing influence:

- composition of finished class size in input ore α_m, %;
- the physical properties of ore (grains particle size , particles shape, hardness, etc) σ, %;
- $q_{s.p}$ – the pulp sand amount that are returned to the mill for re-milling.

Obstacles include: any obstacle in the work of separator, mill or classifier - F(t).

As input values of complex mostly used the following parameters:

- density δ_o and composition of finished class size in classifier sink α_o;
- power consumed by the mill electric drive P, kW;
- volume consumption of classifier sink Q_o, m^3/h;
- losses of mineral products in tails, βt;
- quality of industrial product on separator output, β_{sep}.

As the control channels can be accepted:

- ore consumption to complex - a solid content in classifier bath;
- water consumption to the mill - water consumption in classifier bath;
- water consumption to the mill – content of the finished class size in classifier bath ;
- water consumption in classifier – content of the finished class size in classifier sink ;
- magnetite consumption in the pulp (input) - the magnetite volume in the magnetic separator bath (output);
- rock consumption (input) – the rock volume in the magnetic separator bath (output);
- water consumption in pulp (input) – the water volume in the magnetic separator bath (output).

Results. Analysis of typical circuit block diagram of section units of iron ore magnetic concentration and review the researchers works allowed to organize and present the main technological units as a control objects.

This made possible to define the direction of creating future system in general and local subsystems (processes) and also a variety of control actions, operational parameters, input and output disturbances signals.

The block diagram of the concentration technological complex as a control object enables to create a neural control system for the first stage of concentration. The key to the successful implementation of fuzzy logic in industrial automation - in skillful combination of traditional means.

Fuzzy logic doesn't replace the automated control system but supplements it with highly efficiency methodology of multiply control strategies realization.

Therefore, the main potential of fuzzy logic is in implementing the functions of supervisory control. Using fuzzy logic makes possible to fully automate the technological process and review the formed rules and their interpretation for further analysis.

Conclusions. Introduction of optimal automatic control system of milling process is more efficient by production costs and economically expedient than using the traditional automated control systems based on regulators.

Further improvement of the regulation system is based on the expansion of the so-called object multi connection. The realization of this technique is possible on the basis of using mathematical modeling and computer which opens new perspectives in the development of automation.

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