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MODERN ALGORITHM AND SYSTEM FOR MONITORING AND CONTROL OF MILLING AND FLOTATION PROCESS

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Abstract: The main reason of milling and flotation process fluctuations is a mixing of ores in various proportions from various sections of a deposit. According to estimates, instability and non-optimized parameters of flotation take 3% to 6% of losses of valuable component. Without ore averaging systems, milling and flotation process are characterized by considerable fluctuations of all input, output and intermediate parameters. In these conditions, applying various mathematic models does not allow controlling the process by action on input parameters with further precise reaching required values of output parameters of the process.
Criteria of milling process control are formed to provide required productivity at keeping preset quality. Solution of a task of improving effectiveness of flotation process control requires application of multi-level schemes, providing for regulation of both physico-chemical and technological parameters of the process. Stabilizing and optimizing the main technological parameters allows increasing effectiveness of milling and flotation process. Copyright © 2008 IFAC

Keywords: algorithm, stabilizing, optimization, adaptation, X-ray analyzer.

1. INTRODUCTION

Development of modern automatic control systems and algorithm remains rather promising way of increasing effectiveness of flotation process. For elaboration of effective and well-balanced systems and algorithms of milling and flotation parameter control, we used the following principles:
- criteria of milling process control are formed to provide required productivity at keeping preset quality;
- algorithm of calculation of technological parameters must be based on information on grades (types) of ores and steady data on optimal parameters of concentration of distinct ores grades (types);
- algorithm of ore evaluation must use maximally mathematic model of concentration process;
- algorithm of evaluation of ore grade is to be stable

against one-time and systematic failures of analyzers of technological process conditions;
- algorithm for control of concentration process parameters, based on evaluation of ore grade, is to be consistent with other local control systems in operation.

2. THE SYSTEM OF OPERATIVE CONTROL OF MILLING PROCESS

Automatic control systems are to provide steady process of milling in the most efficient field of operational parameters. Generalized structural scheme of algorithms of milling process control is presented in Fig. 1.

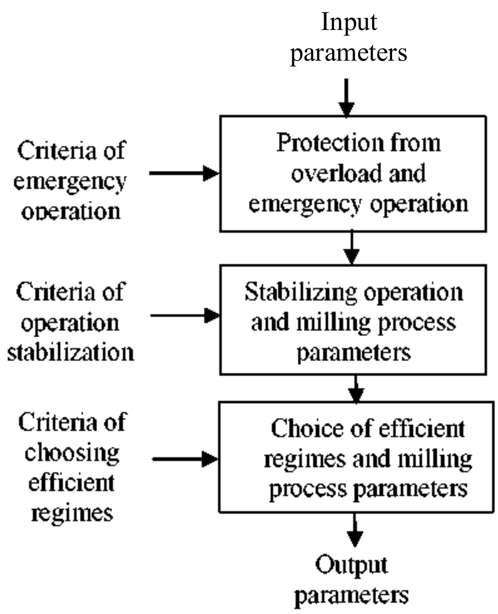

Fig. 1. Structural scheme of algorithms of milling process control

Criteria of emergency operation are taken as follows: mill overload; failure of water regime of mill, technical failure of mill, etc.
As criteria of operation stabilization, the most important (for realizing technological task) controlling effects are taken: deviations in pulp density and granulometric composition of solid particles (Ulitenko, *et al,* 2005). As criteria of effective operation, productivity (in ore or yield of finished class (grain size)) of power consumption has been chosen. Stabilization means here a keeping of milling parameters in framework of preset limits. As meeting preset limits for all key parameters of technological process is impossible, the parameters are to be ranked by priority, depending on their importance in milling process. We ranked the parameters as follows: 1. -Volumetric loading of mill; 2. - Yield of finished class; 3. - Density of hydrocyclone discharge; 4. -Pulp level in sump; 5. - Pressure at the hydrocyclone input.

Similarly, the controlling forces are ranked as follows: 1. Feed of water into mill; 2. Feed of ore into mill; 3. Feed of water into sump of hydrocyclone; 4. Regulation of rotation speed of hydrocyclone pump drive.
Criteria of milling process control are formed to provide required productivity at keeping preset quality, which, in turn, is defined in milling process as providing required granolometry (grain size) of products. In this case, as an auxiliary criteria, minimizing power consumption, minimizing consumption of milling bodies (and other, decreasing resources consumption in the production) can be taken.
As an example of creation of system, meeting the listed requirements, a system of milling process control, used at processing plant "Erdenet", (Mongolia), can be taken. Block scheme of the system of milling process control is presented at Fig. 2.

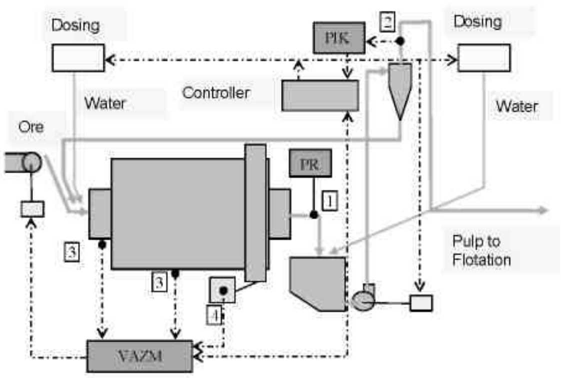

Fig. 2. Structural scheme of system of milling process control

Controlled input technological parameters are as follows: - supply of ore into mill; - supply of water into mill and hydrocyclone sump; - density of hydrocyclone discharge (measured by densitometer PR-1027M (1)); yield of finished class (measured by granulometer PIK-074 (2)); filling inner volume of mill (measured by analyzer VAZM-1 (3)); active capacity of mill (4); pulp level in sump and other auxiliary parameters, not presented in Fig. 2. Output parameters (set by operator or automatic control system) are controlling and regulating forces (effects): feed of ore into mill; - feed of water into mill; - feed of water into sump of hydrocyclone; - rotation speed of hydrocyclone pump drive. Processing of input parameters and forming output parameters is implemented at technological controller, which, by Ethernet interface, is linked with operator station and server for storing and imaging information.
The presented system allows to solve both local tasks of control and to provide effective operation of the whole complex of milling copper-molybdenum ore.

2. ALGORITHM OF OPERATIVE CONTROL OF FLOTATION PROCESS

The integrated system consists of 3 local stabilization and optimization control systems. Theoretically the algorithm of flotation process control should take into account both operative information on current standing of the technological process and on accumulated information on the main regularities of the process. An attempt to realize such complex approach resulted in elaboration of the proposed algorithm of flotation process control, based on monitoring of ore grade (Morozov, *et al.,* 2006). At Fig. 3, the proposed algorithm of flotation process control is presented.

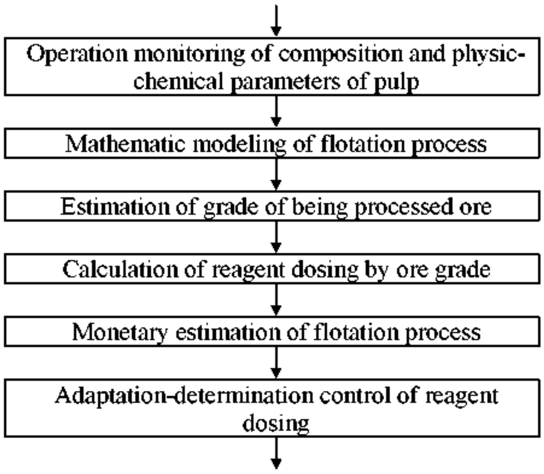

Fig. 3. Algorithm of flotation process control

3. THE SYSTEM OF OPERATIVE MONITORING OF FLOTATION PROCESS (KEYFLOT)

The main task of the system and algorithm of operative monitoring of flotation process KEYFLOT consists in providing balance account of quantities of the main components of natural resources in products of concentration process: ore, concentrates, tails, commercial products. Unlike standard methods of the calculation on contents of components in products of the process, the proposed system (Fig. 4) realizes a possibility of increasing preciseness of calculations at the expense of measuring and use of additional pulp characteristics: density and volumetric consumption rate. Calculation of balance parameters of flotation scheme (Fig. 4) is implemented in overdetermined system, allowing calculating a parameter by two and more ways. The algorithm of the KEYFLOT program estimates preciseness of sensors by comparison of balance parameters calculated by contents of valuable components, and parameters calculated with the use of figures of density and consumption rate of initial feed and concentration products. To increase preciseness of the balance calculations, correction of measurements obtained by the least-precise sensor is conducted.

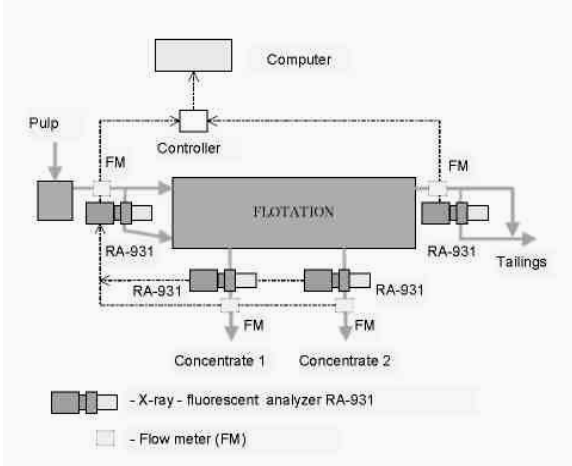

Fig. 4. The scheme of the control system with the use of sensors of composition, density and pulp consumption rate

Application of the KEYFLOT system allows calculating not only extraction figures in individual processes and in the cycle as a whole, but also actual yield of metals in any given time periods. This allows estimating effectiveness of production stage "milling-flotation" as a whole.

The system of automatic regulation of flotation process - RA-931 (JSC "Elscort", Russia) includes multi-channel X-ray-fluorescence analyzer, designated for control of element composition of pulp solid phase, and electrochemical analyzer of pulp liquid phase composition (Morozov, *et al,* 2004a). The XRF analyzer determines concentrations of elements from Al to U. The electrochemical sensor is separated from analyzed flow by a filtering membrane. Concentrations of hydrogen and sulfur ions are determined by potentiometric or voltammetric methods. A special system of pumping solutions through inner hollows of the sensor provides cleaning the electrodes, sensor calibration and regeneration of filtering membranes. General structure of the control system, based on the RA-931 analyzer, is presented in Fig. 5.

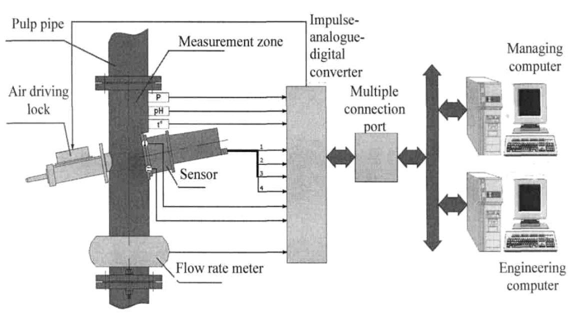

Fig. 5. A scheme of RA-931 automatic control system of composition of solid and liquid phase of concentration products

4. THE SYSTEM OF FLOTATION REGIME CONTROL BY GRADE OF ORE (POLYFLOT)

Operative evaluation of grade of the ore processed with the use of the system and algorithm POLYFLOT is based on application of physico-chemical model of the flotation process and is implemented with the use of vector method of calculation of shares of affiliation to several typical grades of ore. The typical ores are distinguished by technologists experimentally and are a field of searching optimum solution in our task.
The vector method consists in founding share of affiliation of vector of ore, coming in processing, to basic vectors, corresponding the typical grades of ore in multi-dimensional space of controlled technological parameters (Morozov, et al., 2004b). An essence of calculation of the shares of the ore belonging into pre-set type consists in the fact that the ore can be classified, in various proportions, into each of 4 known ore types.
To solve the task of determining ore grade with the use of the POLYFLOT algorithm, physical parameters of ore on conveyer before milling and concentration can be used (fig. 6), or a set of physical and physico-chemical parameters of pulp as well (fig. 4).

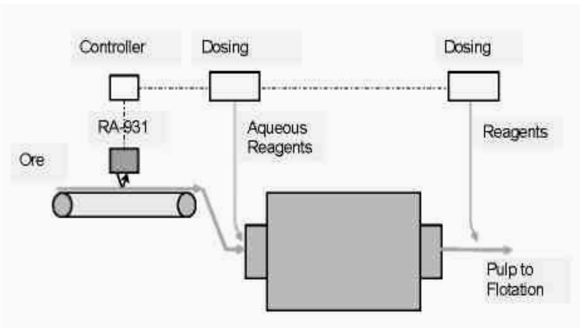

Fig.6. Scheme of the control system with the use of ore composition monitoring on the conveyer

At Fig. 7, time dependencies of processed ore composition at the first section of the "Erdenet" concentrator are given. The results are consistent with available data on composition and volumes of ores, processed for this period. Basing on results of analysis of ore grade – i.e. information of ore composition, we can calculate recommended dosing of reagents for flotation of arrived ore. In the simplest case, the recommended dosing can be determined as weight-average one (among each type of ore d1-d4):
lime dosing:

$$LD = d1LD1 + d2LD2 + d3LD3 + d4LD4, \quad (1)$$

collector dosing:

$$CD = d1CD1 + d2CD2 + d3CD3 + d4CD4, \quad (2)$$

foaming agent dosing:

$$FD = d1FD1 + d2FD2 + d3FD3 + d4FD4, \quad (3)$$

where LD1 is lime dosing for ore type 1, LD2 is lime dosing for ore type 2, LD3 is lime dosing for ore type 3, LD4 is lime dosing for ore type 4, and, respectively, CD1, CD2, CD3, CD4 are dosing of collector, and FD1, FD2, FD3, FD4 are dosing of foaming agent.

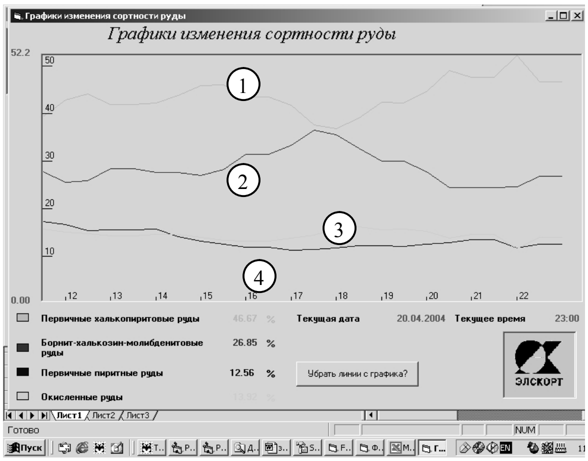

Fig. 7. Results of estimation of processed ore grade at "Erdenet" concentrator 1 - Primary chalcopyrite ores; 2 - bornite-chalcocite-molybdenite ores; 3 - primary pyrite ores; 4 - oxidized pyrite ores

In actual case, interaction between ore types, resulting in difference between calculated and actual optimum dosing of each reagent, should be taken into account (Morozov, *et al.*, 2004a).

5. THE SYSTEM OF FLOTATION CONTROL WITH THE USE OF ECONOMIC CRITERIA (ADDEFLOT)

The main task of the system and the algorithm ADDEFLOT is optimizing flotation process, using principle of minimizing valuable components losses and production costs (Avdokhin and Morozov, 2001). On the basis of system, composed of 3 analyzers of solid phase and flow rate meters (Fig. 3), the algorithms of flotation process control are realized.
The regulation is conducted at two levels. The lower level provides for keeping up, in liquid phase of pulp, optimal concentrations (pH, pS) or ratios of concentrations of ionic components. For calculation of required concentrations of reagents, special physico-chemical models are used, linking concentrations of the liquid phase components in optimum flotation conditions. At the upper level, adaptation of the model used (the driving function) is conducted. The adaptation essence consists in fitting such value of a parameter (pH, pS), at which maximal effectiveness of the process is achieved.
As the effectiveness criterion in the ADDEFLOT algorithm, presumptive economic criterion is used (Morozov *et al.*, 2004a):

$$Q_t = \varepsilon^*_{Me1} C_{Me1} \alpha_{Me1} + \varepsilon^*_{Me2} C_{Me2} \alpha_{Me2} + + \varepsilon_{Me3} C_{Me3} \alpha_{Me3} \quad (4)$$

where: E, E^*, C, a – recovery, losses, conditional price and contents of metals (the first metal (Me_1), the second metal (Me_2) and the third metal (Me_3), respectively, in the ore. The first and the second metals are valuable components, liable to extraction in the operation. The third metal is polluting component, decreasing cost of commodity product, or valuable component, which is irrevocably lost in the operation. Fig. 8 illustrates possibility and expedience of applying the proposed function. The plots demonstrate that at some set of conditions (floatability of minerals, content of the metals in ore, prices on the metals), an optimum value of pH exists, at which the best efficiency of the process is achieved (Morozov, *et al.,* 2004b).

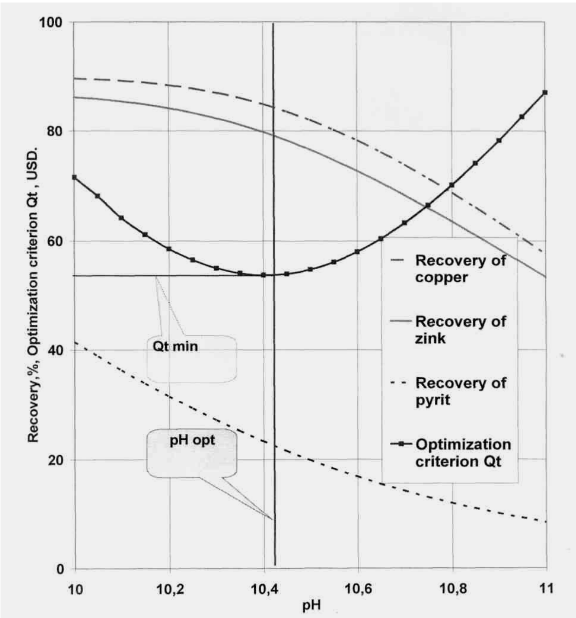

Fig. 8. Dependences of metals recovery and the optimization criterion of the regulated parameter of the flotation process

Keeping up optimal value of pulp pH provides achieving economically grounded level of extraction (recovery) and losses of valuable and polluting components and, finally, decreasing normalized metal losses (in money terms) in the concentration process.

6. CONCLUSIONS

Criteria of milling process control are elaborated to provide required productivity at keeping preset quality, which, in turn, is defined in milling process as providing required granolometry (grain size) of the products. The presented system allows to solve both local tasks of the control and to provide effective operation of the whole complex of milling copper-molybdenum ore.

Algorithm of flotation process control includes operation monitoring of composition and physico-chemical parameters of pulp, mathematic modeling of flotation, estimation of processed ore grade, calculation of reagent dosing by ore grade and adaptation-determination control of reagent dosing. Elaborated algorithms of monitoring and control of milling and flotation process have been tested at "Erdenet" processing plant (Mongolia). The tests showed reasonable reliability and effectiveness of the proposed algorithms.

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