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AUTOMATION AND CONTROL EQUIPMENT DEVELOPED BY RIVS FOR MINERAL PROCESSING INDUSTRY

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RIVS Science and Production Association sees its mission in planning and turnkey construction of mineral processing plants, and the design of automation equipment and systems is the priority area of activity.

This paper reviews the prime operating results of the company in the specified area. In the highlight is improvement of manufactured facilities belonging mainly in low-level automation, and design of new automation equipment and control systems.

The authors exemplify implementation of the develop automation equipment and systems and various process machines.

The emphasis is made on sampling and analytical control of process flows. The structure of the automated analytical pulp control system, including operational and inventory sampling, as well as X-ray fluorescent analysis and methodical–mathematical, metrological and program support is described.

The discussion involves the concept and algorithm of automatic control of flotation, accounting for grades of ore under treatment.

The authors point at the promising application of basic provisions of the statistic control theory based on Shewhart cards in mineral dressing process control.

Capabilities of automated analytical control of recycled water being one of the most important factors that influence flotation efficiency are discussed.

Finally, the authors draw a conclusion on continuing development of low-level and local automation equipment, considering the concept of unified control over mineral dressing process proposed by RIVS Science and Production Association.

Key words: *ore processing, automation and control equipment, automated sampling and control systems, control algorithms and programs.*

You can only manage what you can measure.
Walter Shewhart

RIVS Science and Production Association sees its mission in design and turnkey construction of mineral processing plants, development and introduction of new beneficiation technologies as well as in manufacture and delivery of processing and automation equipment. RIVS lively expands the related areas of activity, including development of advanced automated control systems.

The epigraph clearly defines significance of low-level automation equipment and local automated control systems (ACS) that make incontestable background for creation of effective systems for automated process control (APCS), automated production control (APRCS) and automated enterprise management (AEM). These automation levels conform to SCADA, MES and ERP systems in the international standards. It is obvious that for higher efficiency, these systems should use unified hardware and software (HS) and represent an integrated computer-aided control system (ICCS).

This article considers RIVS approach to designing and improvement of primary tools and systems for automation of production processes in mineral beneficiation.

It is more than twenty years ago that RIVS Science and Production Association has become a machine-building company in the area of mineral dressing [1]. Flotation machines designed by the company required inherent automation and ACS to elevate to desired level of production data, which naturally initiated development of low-level automation tools and systems.

Among the top-ranked implementations partly discussed in [2], it is worth mentioning the following projects.

RIVS has developed an automated system for pulp level and air flow stabilization (ASPL-AFS) that have successfully been applied to control operation of pneumatic mechanical flotation machines. The signature of ASPL-AFS as against the systems of the other known manufacturers is measurement of pulp level by pulp level piezometer sensors.

From the experience, advantages of pulp level piezometer sensors, aside from reliable and low cost operation, include the option of measuring density of the medium the sensors are in. The medium density measurability allows higher accuracy control and adjustability of pulp level, and furnishes with additional information used for flotation machine operation control.

Improvement of ASPL-AFS follows the way of application of advanced element base and optimization of control algorithms enabling efficient performance of flotation machines, in particular, under conditions of sizeable fluctuation of quantitative characteristics of flotation feed.

Another area of activities of the Company in the field of automation is batching of flotation agents. The reagent dosing systems RDS-RIF enable:

- setting reagent intake manually, on operator's panel, or on command from the upper level control, at each dosing point;
- accounting of reagent concentration per each dosing point;
- diagnostics of faults of feeders;

• accounting of bank of reagents in holding tanks and forecasting of residue stock of reagents at the end of a shift.

Various modifications of dosing systems meant for high accuracy feed in the range from a few milliliters to tens liters per minute at a dosing point in pulsed and continuous modes have been designed and manufactured.

Aimed to expand the range of the process equipment, RIVS developed ore pretreatment automation equipment. For instance, the developed Hydrocyclone Automated Control Systems HCACS equal in functional capabilities the best foreign analogues.

Current HCACS accomplish:

• control of pulp level in sump by adjustment of rotation velocity of pulp pump drives;

• control of pulp pressure in hydrocyclone feed supply by adjustment of quantity of working vessels;

• pulp density control by adjustment of water feed in sump of pulp pumps in accord with the readings of densometer at hydrocyclone drain;

• automated actuation and shutdown of pulp pumps with washout of pumping line at startup and on drainage of pulp residue under shutdown.

Actualization of the listed functions involves the appropriate control technique. It is intended to improve the system by including the data on grain-size composition of hydrocyclone drain. To this effect, it is planned to use automated pulp granulometer PGM-RIF designed by RIVS and currently subjected to trial operation.

The granulometer uses the pulp preparation method that allows concurrent control of solid particles by size grades. Measurement cycle takes 15–20 min.

In connection with manufacture of vibrating screens for processing plants, RIVS has designed a screen product size sensor — screen product granulometer SCP-RIF. This inexpensive device scanning ore flow surface by a laser level gage detects offsetting of product size from reference dimension and furnishes operator with flow characteristics of screen separation products.

It is difficult to overestimate the role and importance of sampling and analytical control in mineral dressing. RIVS company carries out research&development aimed at designing an exclusive automated analytical control system (AACS) for pulp. By now the automated pulp sampling system (APSS) —one of the most important component elements of AACS — has been developed, trialed and certified. In this case, pulp sampling means a series of operations on sampling and preparation of representative samples for estimating one or a few characteristics of material constitution of products under control.

The structure of APSS includes the following master components, including their modifications:

1. Air-driven cross-flow pulp sampler (ACPS-RIF) for inventory and operational sampling;
2. Air-driven pressure sampler (APS-RIF) for operational sampling;
3. Vacuum accumulating sampler (VAS-RIF) for operational sampling;
4. Sample accumulation and pneumo transmission station (APTS-RIF)
5. Sample intake and deaeration station (IDS-RIF);
6. Air-driven sampling reducer (ADR-RIF);
7. Vacuum sample filtration unit (VFU-RIF);
8. Sampling and sample delivery control cabinet (DCC);
9. Sample reducing control cabinet (RCC);
10. Sample circulation control cabinet (CCC);
11. Sample filtration control cabinet (FCC);
12. Central control station (CCS);
13. Automation-equipped working place (AWP) that is the APSS Operator's AWP hardware-and-software package.

Practical implication at a processing plant, for instance, in operational or inventory sampling, air transport or hand haulage of accumulated samples to a test lab, dictates configuration of hardware/software tools of APSS. For example, Carmen Copper Corporation (Philippine), Ararat gold extraction plant (Armenia) and Zangezur copper–molybdenum plant (Armenia) only wanted to purchase automated sampling sets composed of sampler, sample accumulation and air delivery station and sampling–air delivery control cabinet, while processing plant of Gaisky Mining-and-Processing Integrated Works (UMMC, Russia) and Nikolaevskaya PP of Kazakhmys Corporation (Kazakhstan) needed full-contained sampling line, up to automated making and accumulation of dewatered check and inventory samples. Thus, APSS can be divided into following enlarged packages:

• automated sampling package (ASP-RIF) composed of a sampler, sample accumulation and air delivery station and a local sampling and delivery control cabinet;

• automated sample preparation package (ASPP-RIF) composed of a sample intake and deaeration station, sample reducer, filtration unit and the appropriate control cabinets;

• automated circulating-type sample feed package (ACSFP-RIF), i.e. feeding of pulp samples to analysis, composed of a circulating pump, flow cell of pulp analyzer and a control cabinet.

The list of equipment included in APSS shows that one and the same line of the automated sampling is capable of integrated handling of operational problems and inventory tasks. The control cabinets can be fitted with pneumatic control components and programmable logic controllers of any type and manufacture, on a basis of wish and capacity of a customer.

Another important constituent of AACS in dressing is analytical unit (AU) based on X-ray fluorescent (XF) wave- or energy dispersion spectrometers or analyzers. The up-to-day AU or XF packages include methodical-mathematical, metrological and software support to actualize automated or fully automatic operation. As a rule, the listed types of support are a part of various top-level hardware/software packages of AACS, for instance, AWP for an adjuster, analyst and an operator, or various purpose servers. Some conceptual developments of RIVS in the field of design of the in-house AACS and AU are presented in [3, 4].

It is worthy of emphasizing that without representative sampling, it is impossible to obtain reliable survey data required both for process flow adjustment and control in mineral beneficiation. In this connection, RIVS studies and improves sampling equipment as well as methodical-mathematical, metrological and software support of XF packages and AACS as a whole on a dedicated test-and-display stand.

A comparatively new area of activity is automation of attrition scrubbing systems progressively included in flotation. Automation equipment for attrition scrubbing systems involves a controller, volume flowmeters and densometers mounted on feed stock pipes, power sensors at electric stir-

ring devices, adjustable reagent feeders, ion composition sensors for pulp at machine outlet, automatic ball batcher and a noise sensor to control ball loading trajectory. The automation equipment enables optimized conditions for mechanical activation of mineral surface during flotation.

At the same time, the current resources allow RIVS the transition from local automation of individual processing units and stages to integrated production management. Indeed, a final objective of a process stage can only and exclusively be attained with consistent performance of all process stages and operations within a process flow, under single measure of efficiency. The efficient management is only possible with available data on qualitative–quantitative characteristics of product meant for flotation. To this effect, RIVS has designed an automated device for pulp flow control and distribution. The device contains a multi-channel controller, pulp divider with a preset number of branches, sensors for content of useful components and physico-mechanical properties of process material. Each branch of the controller is fitted with a flow meter and pulp flow adjustment actuator. This allows, firstly, controlled distribution of initial feed between the concurrent process lines and, secondly, implementation of pattern recognition technique that sorts ore minerals based on a set of characteristics of content of useful components, mineral composition and physico-mechanical properties of ore minerals. These data can be used for timely selection of the most suitable processing method to immaculately attain the preset measures of efficiency. This paper authors have developed an approach to on-line handling of that problem. The desired outcome of the approach introduction is the enhancement of flotation efficiency due to:

- timely adjustment of processing modes for various grade ore;
- higher operational efficiency of the process flow control by continuous monitoring of the process parameters with regard to the production procedures;
- reduced human factor;
- improved performance of insufficiently experienced personnel.

The developed approach assumes implementation of the following algorithm:

1) Conditional classification of ore based on the analysis of its material constitution;

2) Division of the flow chart into control loops for calculating balance of metals per loop based on the developed procedure;

3) Recording of local efficiency measure in each control loop for the flotation process stage and for the specified ore grade and generation of the appropriate archives;

4) When generation of data archives is accomplished, the grade of process ore is defined and attainment of the preset efficiency at the flotation process stage is stated, in case the effect is beneficial, the settings of the local control systems remain unchanged, if the result is negative, performance of each local control loop is evaluated; as soon as the inefficient loops are detected, the related data are compared with the archived data on the analogous ore grades, and new settings are generated for the control loops on this basis.

Aiming to follow time “drift” of the information, the archived data accumulated within a preset period are updated by means of replacement of the primary measurement data by the latest measurements taken at the moment of attainment of the preset efficiency.

An important and topical, from the viewpoint of the present paper authors, area of integrated automation of mineral processing industry is a wide application of principles of the static control theory based on Shewhart charts [5]. This area of activity is encouraged by the standardization of statistical process control based on Shewhart charts in Russia (State Standard R 50779.42-99) and by the universality of these control methods enabling detection of deviation of the control process off the statistical controllability (standard) and determination (at a certain probability) of causes of the deviation, at least, at a level of expert judgment.

The analysis of the issues concerned with optimization of flotation should involve the influence exerted on flotation efficiency by such significant factors as, for instance, recirculated water quality. At the present time, this factor is important both technologically and ecologically. Express estimation of low concentrations of various elements and compounds in recirculated water is a difficult but feasible problem. In this context, it is worthy of referring to positive experience gained in design and use of AACS-inbuilt AU including X-ray fluorescent and voltammetric analyzer (Spectroscan-U and AZhE-11M, respectively) [6]. The latter work discussed methodology of construction of distributed AACS for continuous automated sampling, delivery of samples and pre-analysis treatment, express measurement of low (under 10 mg/l) concentration of many electrochemically active cations and anions using the voltammetric method and higher (over 5–10 mg/l) concentrations of any elements between 12Mg - 92U by the X-ray fluorescent method. The analytical block of distributed AACS is placed directly at a control point. Design and introduction of the automated ecology monitoring system (AEMS) for a natural water body and the automated industrial effluent control based on the flow analyzer AZhE-11M and the hardware/software tools produced by GE company (USA) are described in the work [7]. The authors [6, 7] used the automatic multi-element analyzer AZhE-11M that is virtually an electrochemical or voltammetric spectrometer with a continuously refreshable electrode in the form of a mercury micro-drop. This conditions high sensitivity of the analyzer, but its use is constrained due to mercury. In connection with this, AACS and/or AEMS based on automated AU using X-ray fluorescent crystal-diffraction spectrometer Spectroscan MAKS G and mercury-free voltammetric analyzer AKV-07MK with a solid rotating Au-electrode seems promising [8]. It is found that such integrated AU exhibits sufficient competitive ability as against the classical atomic absorption with plasma atomization. The application of the two methods and plants is conditioned by the following basic factors:

- coverage of the entire range of concentrations and higher reliability of the results with the of arrangement of cross metrological control;
- backup of the equipment and procedures, which ensures efficient and continuous analytical control of process flows.

It is worthy of saying that most of the designed and described systems, plants and methods have obtained or are obtaining patent protection.

In conclusion, back on the epigraph, the authors would like to emphasize the role and weight of the low-level and local automation systems in mineral dressing processes, as well as their development and integration in the unified control system.

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X-RAY FLUORESCENT UNIT FOR THE EXPRESS ANALYSIS OF PULP SLURRY

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The paper describes the development of automatic X-ray fluorescent unit (XFU) intended for the express analysis of pulp slurries, as well as its software, methodical–mathematical and metrological support. It is emphasized that this XFU modification is difficult to implement but is best suitable for mineral processing plants, first of all, for operational control of flotation processes.

In accordance with the concept of an automated analytical control accepted by RIVS, the designed automated analytical control system (AACS) is composed of XFU joined with an automated pulp sampling system (APSS) The authors review in brief the functions of the full-scale AACS and its constituents — XFU and APSS.

The emphasis is made on the problems and features of XFU with the particular attention given to its analytical and instrumentation characteristics. The designed unit is compared with the best Russian and foreign analogues.

The results of the analysis of powder and pulp samples of ore and ore dressing products are presented. It is shown that prime calibration of XFU is possible using model pulps — boric acid-based pellets.

Finally, the authors conclude that the designed XFU meets the demands imposed on the express analytical control of ore and ore dressing precuts, and is usable as a prototype for various modifications.

Key words: *X-ray fluorescent energy-dispersive spectrometer, silicon drift detector, analytical unit, program support, analytical parameters, instrumentation accuracy, methodical–mathematical support, element analysis, pulp slurry products.*

Automated analytical control systems (AACS) have found wide application in mineral mining and processing. Commercial-scale integrated AACS at processing plants are composed of two basic subsystems: an automated pulp sampling system (APSS) including various sampling facilities and an analytical unit (AU) based on X-ray analyzers of powder and slurry samples of ore and ore treatment products.