водности и решение полученной краевой задачи.

Методика. Применение известных интегральных преобразований Лапласа, Фурье, а также разработанного нового интегрального преобразования для кусочно-однородного пространства.

Результаты. Найдено нестационарное температурное поле сплошного кругового цилиндра внешнего радиуса R в полярной системе координат, кусочно-однородного в направлении полярного радиуса *r*, который вращается с постоянной угловой скоростью вокруг оси *OZ*, с учетом конечной скорости распространения тепла. Теплофизические свойства в каждом слое не зависят от температуры при идеальном тепловом контакте между слоями, а внутренние источники тепла отсутствуют. В начальный момент времени температура цилиндра постоянная, а на внешней поверхности цилиндра известный тепловой поток.

Научная новизна. Впервые разработана математическая модель распределения температурного поля в кусочно-однородной цилиндре в виде краевой задачи Неймана для гиперболического уравнения теплопроводности. Впервые разработано новое интегральное преобразование для кусочно-однородного пространства, с помощью которого найдено температурное поле сплошного кусочно-однородного кругового цилиндра в виде сходящихся ортогональных рядов по функциям Бесселя и Фурье.

Практическая значимость. Найденное аналитическое решение обобщенной краевой задачи теплообмена цилиндра, что вращается, с учетом конечности величины скорости распространения тепла, может найти применение при моделировании температурных полей, которые возникают во многих технических системах (в спутниках, прокатных валках, турбинах и т. д.).

Ключевые слова: *краевая задача Неймана, интегральное преобразование, время релаксации*

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CONTROL REGULARITIES OF THE USEFUL MINERAL EXTRACTION FROM ORE FEED STREAM WITH BALL GRINDING. CORRELATION ANALYSIS

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ЗАКОНОМІРНОСТІ КЕРУВАННЯ ВИЛУЧЕННЯМ КОРИСНОГО МІНЕРАЛУ З РУДОПОТОКІВ ІЗ КУЛЬОВИМ ПОДРІБНЕННЯМ. КОРЕЛЯЦІЙНИЙ АНАЛІЗ

Purpose. To define the indicative events characterizing a process state on "useful mineral content in ore –useful mineral content in a concentrate" control channel at an ore concentrating plant with ball grinding using correlation analysis method with the purpose of an operator exclusion out of a control circuit.

Methodology. Correlation analysis of the control object parameters.

Findings. According to the mutually correlation function a range of indicative events is determined which characterize a process state on "useful mineral content in ore –useful mineral content in a concentrate" control channel.

Originality. Comparison of numerical values of recession time and the equivalent delay of autocorrelation and correlation functions of the general iron content and a time constant of a dressing process line obtained in the normal operation of ore concentrating factory with ball grinding has been made out for the first time.

Practical value. The indicative events obtained by the type and parameters of the correlation functions between the content of a useful mineral in the feedstock and concentrate can be used for automatic system creation for situation-dependent process control of ferrous and non-ferrous ore dressing as both at separate ball grinding sections, and at separate plants which include these sections.

Keywords: *automation, indicative events, system of situation-dependent control, correlation analysis, iron ore dressing, ore concentrating factory with ball grinding*

Introduction. Difficulty of controlling concentrating processes consists in their random and unsteady character. The concentrating technology devices are objects with variable parameters and, moreover, with random parameters. At Ukrainian plants an operator determines the choice of vector components of the controlling influences, their values and the issuing moment on "useful mineral content in ore –useful mineral content in a concentrate" control channel for all dressing sections. For his exclusion from a control circuit it is necessary to understand response of a control object to the change of controlling influence values.

Analysis of the recent researches and publications. The greatest interest in the concentrating process automation was in the early seventies of last century when there was a problem of the automated process control system creation. Theses for a Doctor's degree were written on the subject of concentrating factory technology control by Arshinsky V. M. (Irkutsk), Kozin V. Z. (Yekaterinburg), Maryuta A. N. (Dnipro), Horolsky V. P. (Kryvyi Rih). In Kozin's work the method was taken only from statistical dynamic view and correlation analysis, therefore, it hardly featured any sufficient generalizing force. Arshinsky V. M. and Horolsky V. P. approached the control object description from classical view of the automatic control theory – transfer functions. Maryuta A. N. relied on the determined description of technological devices.

The practical value of these works consists in application of regulation and control for local systems of the key technological parameters at ore concentrating plants (OCP): automated mode with processing tasks in technological operations in the enrichment section and the collection of information in a database for its display at the level of concentrating factory dispatcher [1], the gradual build-up of integration and interaction between various control subsystems [2], controlling each step of the ore grinding process to the finished concentrate dewatering [3]. In the last decade this fact and development of computer techniques allowed bringing up a question of on-line information use by the operator for task output to operators of local system regulation and control: the first stage of ore concentration [4], feeding ore in ball mill of first stage load concentration [5], the process of loading ore and balls, depending on the ore properties [6], technological complexes "ball mill – classifier" [7]. Some researchers have evenly brought up a question of excluding a person from a control circuit of separate ore dressing technological units: closed-cycle of wet grinding ball [8], the processes of crushing and grinding of ore [9], nonlinear dynamic objects [10].

Unsolved aspects of the problem. To make it possible for the OCP automatic management system to "understand" the control object response on the value change of the controlling influences it is necessary to define the indicative events characterizing a process state on "useful mineral content in ore – useful mineral content in a concentrate" control channel.

Presentation of the main research and explanation of scientific results. For extraction of the useful mineral from ore feed stream with ball grinding, technological di-agrams with the following features are used at Ukrainian mining and processing plans (MPP) (Fig. 1):

- at least ten similar sections work in parallel within one ore concentrating plant;
- each section consists of three ore dressing stages;
- a finite number of operations is carried out in each dressing stage: disclosure (Fig. 1, unit 1), division (Fig. 1, unit 2), extraction (Fig. 1, unit 3) of the useful mineral (division according to the useful mineral content) and filtering saleable concentrate (Fig. 1, unit 4);
- all back couplings on the material flows do not cross boundaries of separate dressing stages.

The initial ore arrives from the bunker, saleable concentrate is transported to a ware-house, and rejects are transferred to the rejecting storage.

The basis of this research is data obtained by results of normal technological approbations of all sections of ore concentrating plant No. 1 (OCP-1) with ball grinding of Inhulets Mining and Processing Plant (InMPP) for stationary season (summer). The observation duration is five days, resolution is one hour. In total more than 1200 values for each of the following technological parameters were obtained: ore processing (t), production (t/hour), concentrate output (%), moisture in a concentrate (%), the general iron content in ore (%), the magnetic iron content in ore (%), the general iron content in a concentrate (%), the general iron losses in rejects (%), magnetic iron losses in rejects (%), magnetic iron extraction in rejects (%), general iron extraction in concentrate (%).

The obtained basic data have the following features:

- the initial ore with the identical content of the useful mineral feeds all OCP-1 section input;
- general and magnetic iron content in rejects is determined as the same one for all sections: in their final agitation place;
- general iron content in a concentrate is determined for each section;
- during data accessing OCP-1 did not operate within five hours; therefore, each observation series consists of two observation series: 64 and 43, respectively;
- in addition to the general hours of OCP-1 downtime, Section 6 stood idle within seven hours that divided the first observation series into two ones, and the second observation series had identical duration with the appropriate observation series at the rest of sections.

Based on these data there were designed autocorrelation functions of the general iron content in the initial ore (α) (Fig. 2), in concentrate (β) (Fig. 3) at each section output, in rejects (ν) (Fig. 2) and correlation functions of the general iron content in a concentrate from its content in the initial ore for each section (Fig. 4). It allowed estimating key parameters and distribution laws of recession time and the equivalent delay of autocorre-

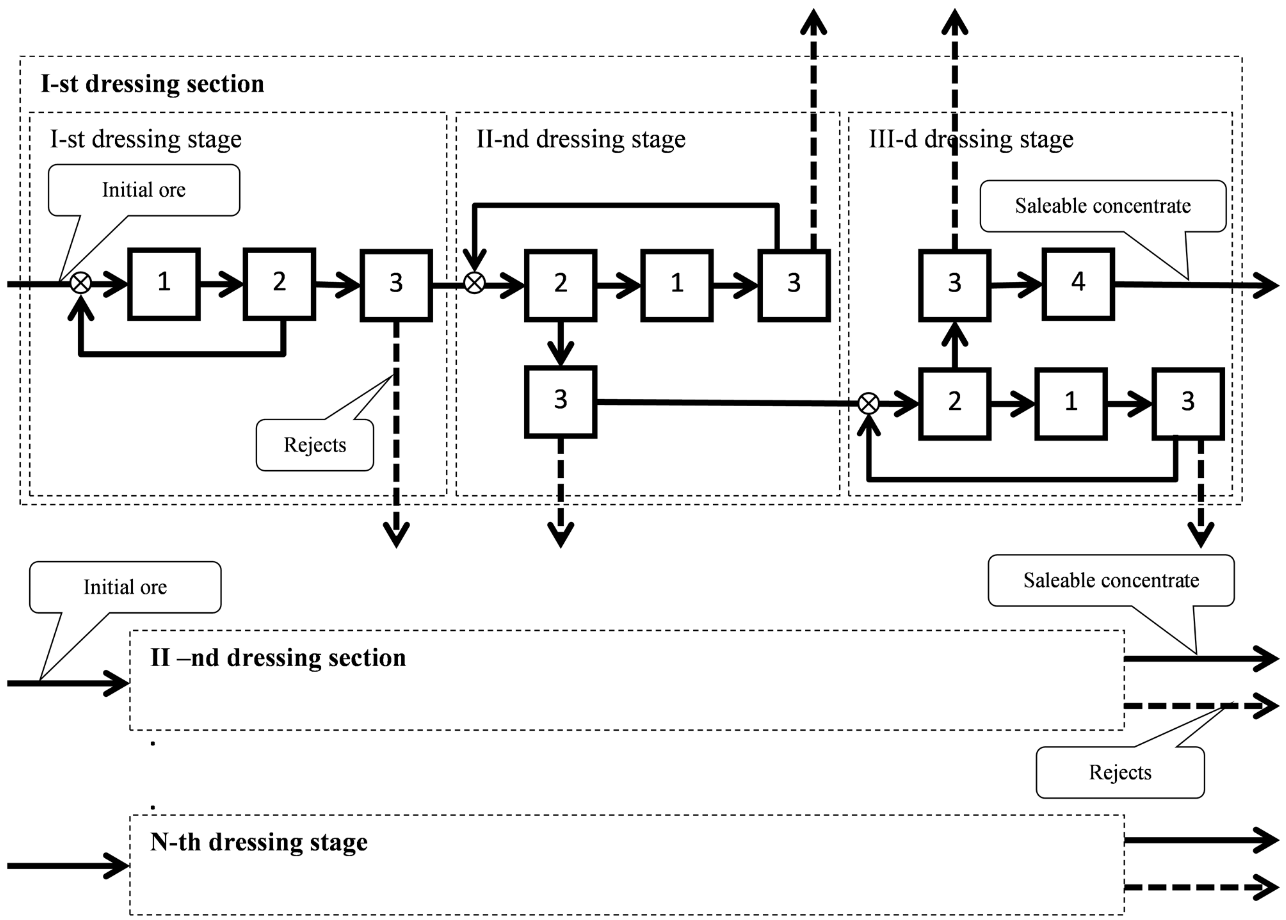


Fig. 1. The diagram of OCP ore feed stream with ball grinding

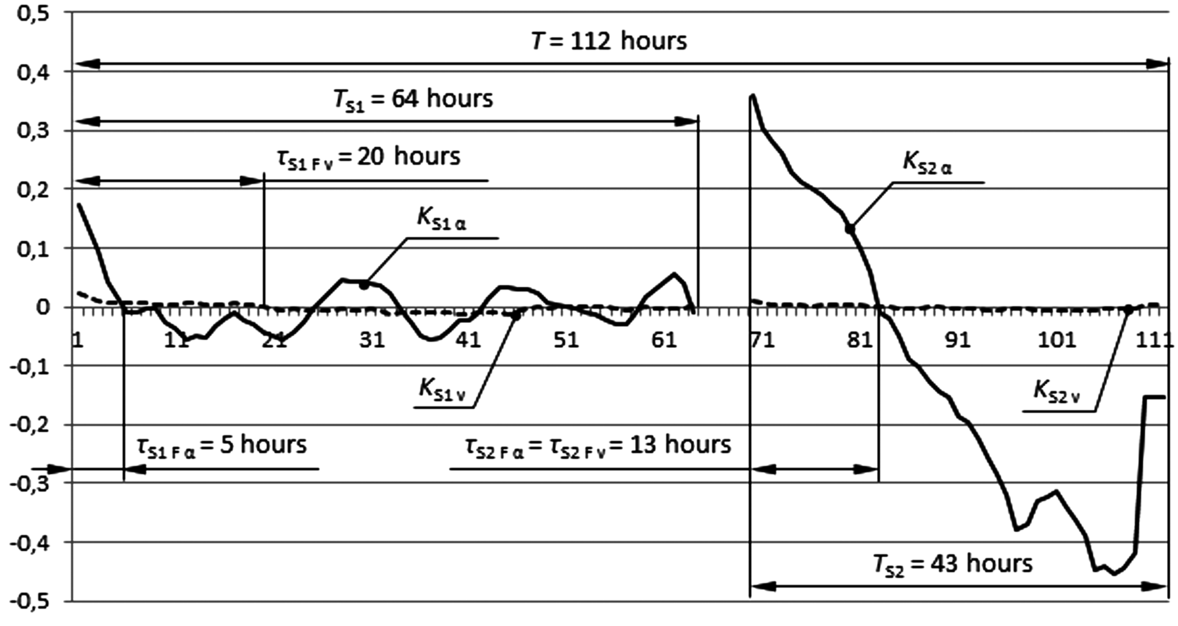


Fig. 2. The autocorrelation functions of useful mineral content in ore feed stream and in rejections

lation and correlation functions of useful mineral content in OCP-1 ore feed stream (Fig. 5).

The dip time of an autocorrelation function of general iron content in the initial ore is 5 hours for the first series ($K_{S1\,\alpha}$) and 13 hours for the second series of observations ($K_{S2\,\alpha}$). For rejects this value is 20 for the first ($K_{S1\,\mathrm{v}}$) and 13 hours for the second series of observations ($K_{S2\,\mathrm{v}}$), respectively.

For the first and second observation series the dip time minimum of autocorrelation function of general

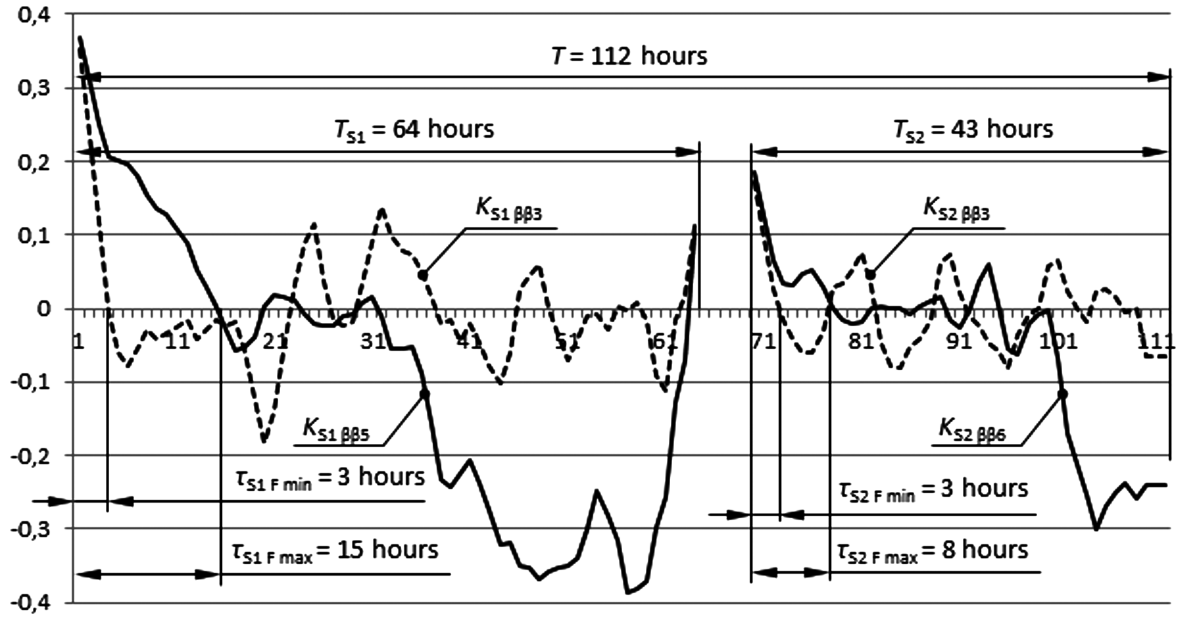


Fig. 3. The autocorrelation functions of general iron content in concentrate

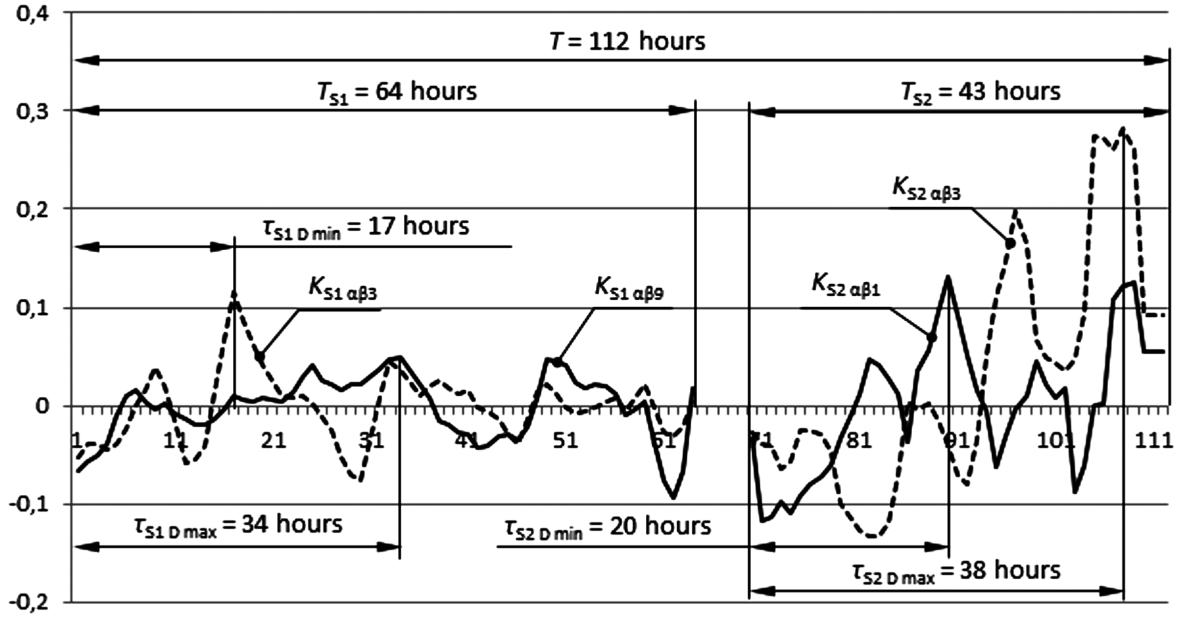
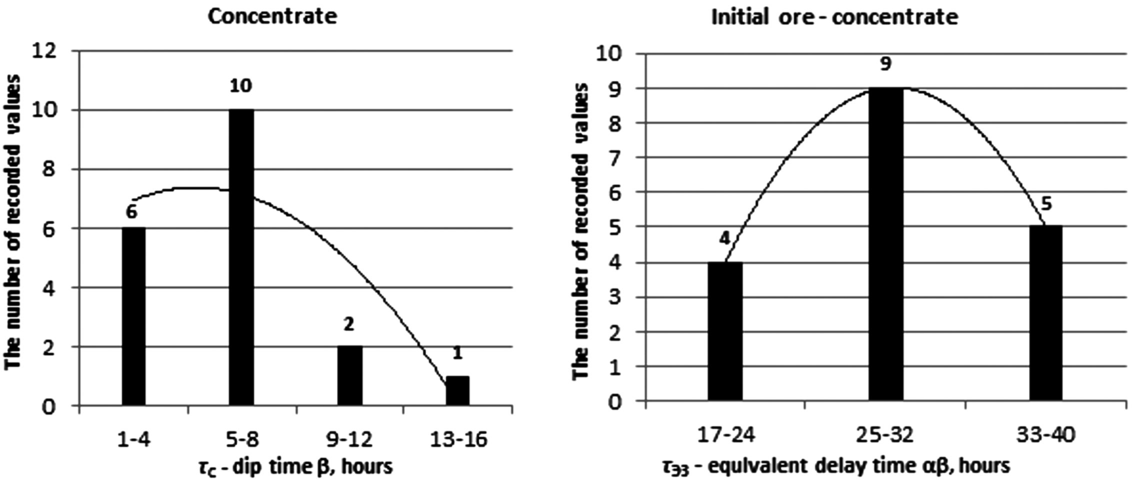


Fig. 4. Correlation functions of the general iron content in a concentrate from its content in the initial ore

iron content in a concentrate was fixed at the third section ($K_{S1\ \beta\beta3}$, $K_{S2\ \beta\beta3}$) and was equal to 3 hours. The dip time minimum for the first observation series was fixed at the fifth section ($K_{S1\ \beta\beta5}$) and was equal 15 hours, for the second one – at the sixth section ($K_{S2\ \beta\beta6}$) – 8 hours.

The autocorrelation function type allowed making the conclusion that all processes in the considered technology are stationary and ergodic: both for the first observation series and for the second one. All of them are comparable with each other. However, the first series characteristics completely differed from those of the second series. For example, autocorrelation functions dip time of the first series has a rather stable value (with some acceptable dispersion). The dip time of the same function for the second observation series also has a steady value, but it is much less than for the first series. This fact shows that dressing process is influenced by absolutely different parameters, conditions and actions. As a result, it is possible to draw such conclusions in first approximation. In the first series the perturbations were shown slowly, and the frequency of their appearance was rather small. In the second series perturbations appeared much more often, and their influence was more essential.

Minimum equivalent delay time of the correlation function of general iron content in a concentrate from its contents in the initial ore was 17 hours for the first observation series at the third section ($K_{S1\ \alpha\beta3}$), and for the second series it was recorded 20 hours ($K_{S2\ \alpha\beta1}$) at the first section. The maximum equivalent delay time for



a *b*

Fig. 5. Distribution of dip and the equivalent delay time of autocorrelation and correlation functions of general iron content:

a – concentrate; b – initial ore - concentrate

the first observation series was registered at the ninth section ($K_{S2\ \alpha\beta9}$), and for the second series – at the third section (*K*S2 αβ4), it was 34 and 48 hours, respectively.

The research of correlation functions of the general iron content in a concentrate from its content in the initial ore for the first observation series has found out that there is a close positive correlation between valuable mineral contents in the initial raw materials and a concentrate that is quite naturally. For the second series a steady negative correlation between these parameters is observed. This phenomenon shows that the factors which are not connected with raw materials properties, affected technological index formation. These could be subjective actions of a technological staff for giving the desirable direction to process.

An observation duration value order for both series is identical. It gave the possibility to use all observation series duration of 43 and 64 hours for creation of dip and the equivalent delay time distribution function of autocorrelation and correlation functions of the general iron content in a concentrate. Proceeding from extreme values in their distribution (3 and 13 hours) for creation of a dip time distribution function the interval is accepted to a half of a shift duration (Fig. 5, *a*), and for function creation of the equivalent delay time distribution an interval length is equal to one shift duration (Fig. 5, *b*).

It is known that the laboratory test analysis selected from the appropriate material streams is applied for efficiency determination for separate sections and concentrating plant in general. Even in case of manual selection, delivery to laboratory and chemical ore feed stream test analysis the results are received in 2–3 hours. It is less than the minimum dip time value of an autocorrelation function of general iron content in a concentrate (Fig. 3, *a*). Results of such approbations usually come at the end of shift, i. e. in 6–7 hours after its beginning. As we see, concentrating process goes quite steadily, and information-processing time is much less than equivalent delay and dip time of correlation functions. Thus, the operator has an opportunity to obtain information which does not become outdated by the submission time of the controlling influence according to target control function on the "useful mineral content in ore – useful mineral content in a concentrate" channel, both for a separate section, and for the plant in general. Automatic control is rather effective in such conditions as time for the analysis is reduced practically to 0.

Let us estimate a possibility of wet ball grinding section control on the "useful mineral content in ore – useful mineral content in a concentrate" channel by comparing the dip time τ_C of the appropriate correlation functions and equivalent delay time τed of correlation function of general iron content in a concentrate on its content in the initial ore (Fig. 5) with the transient process time *T*.

Each device has the system characteristic according to which an input flow quality index conversion is carried out. For grinding it is the grinding characteristic of A, and for separating devices there are separation characteristics of *P*i. According to laws of device connection we obtain the connection characteristic (Fig. 6)

$$P_c = \frac{A \cdot P_1 \cdot P_2 \cdot P_3}{\left(1 - A \cdot \left(1 - P_1\right)\right) \cdot \left(1 - P_2 \cdot \left(1 - P_3\right)\right)}. \qquad (1)$$

The device transfer functions have the form: $W_A = \frac{1}{T_i\,p+1}$; $W_1 = \frac{\gamma_1}{T_1 p+1}$; $W_2 = \frac{\gamma_2}{T_2 p+1}$; $W_3 = \frac{\gamma_3}{T_3 p+1}$; $T_i = \frac{V_i}{Q_i}$; $T_1 = \frac{V_1}{Q_1}$; $T_2 = \frac{V_2}{Q_2}$; $T_3 = \frac{V_3}{Q_3}$.

We add transfer functions instead of P_i in (1)

$$W_1(p) = (W_A \cdot W_1 \cdot W_2 \cdot W_3) \Big/ \Big[1 - W_2\left(1 - W_3\right) - W_A\left(1 - W_1\right) + W_A W_2\left(1 - W_3\right)\left(1 - W_1\right)\Big]. \qquad (2)$$

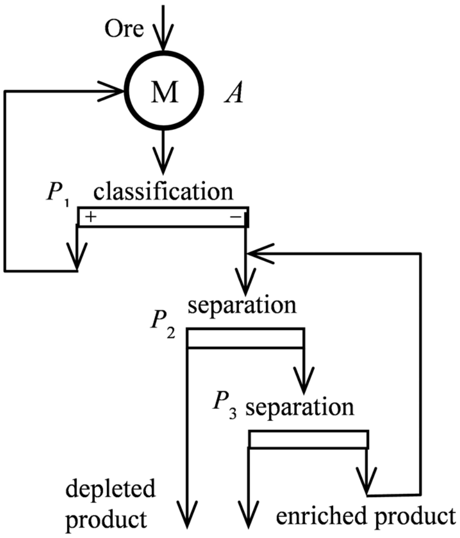


Fig. 6. The diagram of the concentrating technological unit

After substitution in (2) expressions for transfer functions, some identical conversions, removing the brackets in a denominator and bringing similar members, we receive, where

$$a_0 = \gamma_1\gamma_2\gamma_3; \quad a_0 = T_1^2 T_3 T_M;$$

$$a_2 = T_1T_3T_M + T_1^2T_M + T_1^2T_M\gamma_3 + \\ +T_1T_2T_i - T_1T_3T_i + 2\cdot T_1^2T_M;$$

$$a_3 = 2T_1T_3 + T_1T_i\left(1+\gamma_1+\gamma_1\gamma_3\right) + T_1^2T_i\left(1+\gamma_3\right) + \\ +T_3T_i + T_1T_i - 2T_3T_i\gamma_1 + T_1^2 + \\ +2T_1T_3 - T_1T_3\left(\gamma_2-\gamma_1\right);$$

$$a_4 = T_1\left(4+2\gamma_3+\gamma_1\gamma_3+\gamma_2-\gamma_2\gamma_3\right) + \\ +T_i\left(1+2\gamma_1+\gamma_3\right) + T_3\left(1+\gamma_1\right);$$

$$a_5 = 2 + \gamma_3 + \gamma_1 + \gamma_1\gamma_3 + 2\gamma_2 + \gamma_1\gamma_2\gamma_3 - \gamma_1\gamma_2.$$

Based on this expression the form and the period of transient operation in a technological process are estimated. According to the technological diagram of OCP-1 device connection that is given in the third part of "The reference book on ore dressing" by Bogdanov O. S. edition, transfer function of all dressing process (DP) has the following form

$$W(p) = W(p)_{FB1}W(p)_1W(p)_2W(p)_3W(p)_{FB2}\times \\ \times W(p)_4W(p)_5W(p)_8W(p)_9W(p)_{10}W(p)_{11}\times \\ \times\left(W(p)_{FB3}+W(p)_{FB4}\right)W(p)_{13}W(p)_{14}\times \\ \times W(p)_{FB5}W(p)_{15}W(p)_{16}, \tag{4}$$

where $W(p)_{FB1} = \dfrac{1}{1-W(p)_1W(p)_{2\_1}}$ is back connection at the first grinding stage; $W(p)_{FB2}$ = $= \dfrac{1}{1-W(p)_4W(p)_{5\_1}W(p)_7W(p)_6}$ is back connection at the second grinding stage; $W(p)_{FB3}$ = $= \dfrac{1}{1-W(p)_{10}W(p)_{11\_1}W(p)_{12}}$ is back connection at the third grinding stage; $W(p)_{FB4} = 1\big/\left[1-W(p)_{OC3}\times \\ \times W(p)_{10}W(p)_{11}W(p)_{13}W(p)_{14}W(p)_{OC5}W(p)_{16\_2}\right]$ is back connection for filter overflow; $W(p)_{OC5}$ = $= \dfrac{1}{1-W(p)_{15}W(p)_{16\_1}}$ is back connection for filtrate.

The complicate function terms (4), which are transfer function of separate technological devises, have the form

$$W(p)_1 = W(p)_6 = W(p)_{12} = \frac{1}{0{,}1\partial+1};$$

$$W(p)_2 = W(p)_{2\_1} = \frac{0{,}5}{0{,}4\partial+1}; \quad W(p)_3 = \frac{0{,}6}{0{,}01\partial+1};$$

$$W(p)_{3\_1} = \frac{0{,}4}{0{,}01\partial+1}; \quad W(p)_4 = \frac{1}{0{,}2\partial+1};$$

$$W(p)_5 = \frac{0{,}7}{0{,}01\partial+1}; \quad W(p)_{5\_1} = \frac{0{,}3}{0{,}01\partial+1};$$

$$W(p)_7 = \frac{0{,}7}{0{,}01\partial+1}; \quad W(p)_{5\_1} = \frac{0{,}3}{0{,}01\partial+1};$$

$$W(p)_7 = \frac{0{,}9}{2{,}5\partial+1}; \quad W(p)_{8\_1} = W(p)_{13\_1} = \frac{0{,}1}{2{,}5\partial+1};$$

$$W(p)_9 = \frac{0{,}85}{0{,}01\partial+1}; \quad W(p)_{9\_1} = \frac{0{,}15}{0{,}01\partial+1};$$

$$W(p)_{10} = \frac{1}{0{,}4\partial+1}; \quad W(p)_{11} = W(p)_{14} = \frac{0{,}9}{0{,}01\partial+1};$$

$$W(p)_{11\_1} = W(p)_{14\_1} = \frac{0{,}1}{0{,}01\partial+1}; \quad W(p)_{15} = \frac{0{,}95}{\partial+1};$$

$$W(p)_{15\_1} = \frac{0{,}05}{\partial+1}; \quad W(p)_{16} = \frac{0{,}9}{0{,}05\partial+1};$$

$$W(p)_{16\_1} = W(p)_{16\_2} = \frac{0{,}05}{0{,}05\partial+1}.$$

Coefficients in above-stated function denominators are received as the ratio of technological device volumes to their volume productivity. The device volumes of the OCP-1 iron ore dressing process are known and their numbers correspond to numbers of transfer functions in expression (4): 1 is the first grinding stage mill (V_1 = = 45 m^3); 2 is double-helix qualifier (V_2 = 33 m^3); 3 and 7 stand for separator CBW-90 × 250 ($V_3 = V_7$ = 0.4 m^3) (CBW – Constant magnetic Ball Wet); 4 is a middling sump (V_4 = 19 m^3); 5 and 11 stand for hydro cyclone GH-710 ($V_5 = V_{11}$ = 0.4 m^3); 6 and 12 stand for the second and third grinding stage mills ($V_6 = V_{12}$ = 60 m^3); 8 is MD-9 (Magnetic Deslimer) deslimer (V_8 = 138 m^3); 9 and 14 stand for separator CBW-100 × 300 ($V_9 = V_{14}$ = = 0.5 m^3); 10 is technological sump (V_{10} = 37.2 m^3); 13

and 15 stand for MD-9 deslimer ($V_{13} = V_{15} = 40$ m^3); 16 is vacuum filter ($V_{16} = 2$ m^3).

Adding to expression (4) the equations of transfer device functions, and executing identical conversions for getting the proper algebraic fraction (Mathcad program) from this expression, we obtain in a denominator a polynomial representing a characteristic equation of a differential equation of transient process in TDL (Technological Dressing Line). The conversion result turns out in the form of the proper algebraic fraction of rather high order (the denominator turned out more than the 20th order concerning p argument). As a result, the transient process time T for OCP-1 was defined and was equal to 16 hours.

Calculation of transient process time by means of transfer functions assumes that influence happened owing to volume productivity change in case of concentrating devices regime parameter change. When change occurs owing to a deviation of concentrating characteristic indices then in a dressing process there are static changes which change correlation connections and therefore can be found by means of mutual correlation functions.

So $\tau_C < T$ (Fig. 5, *a*); therefore, by the time of transient process end the initial information hopelessly becomes outdated and, consequently, control according to comparing these parameters becomes impossible. On the other hand, the input influence – change concentrating characteristics – did not prove itself on concentrate quality since $\tau_{ed} > T$ (Fig. 5, *b*) though technological process continues to fulfill static connection of valuable mineral content in the concentrate from its content in the initial ore. And the concentrate quality change continues the trend according to initial ore quality which entered the TDL time T back. Therefore, time for determination of control application need is more than enough.

Observing the concentrate quality change according to operation technological approbations (the approbation period Δt), we see tendency of this index change. And if during $2 \cdot \Delta t$ time the quality increments has the same sign, then it is possible to make the decision on control expediency, but it is required to define what quality of the initial ore was at the time of $T + 2 \cdot \Delta t$ back. According to series of observations, we determine the concentrating characteristic value of the initial raw materials, then model technological conversions and the control need problem is solved. Thus, control is carried out on a deviation.

Conclusions and recommendations for further research.

1. Comparing the dip time and the equivalent delay of autocorrelation and correlation functions of the general iron content and a constant time of dressing process showed that on the "useful mineral content in ore – useful mineral content in a concentrate" channel control is possible on a rejection of the useful mineral contents in a concentrate from the set value.

2. By form of the mutual correlation functions between the useful mineral content in the initial raw materials and in a concentrate it is possible to select the next indicative events characterizing a process state on the "useful mineral content in ore – useful mineral content in a concentrate" control channel:

- weak correlation or its absence means that the useful mineral extraction process from the initial raw materials proceeds in the steady mode;
- the positive correlation indicates the natural concentrate quality dependence on ore quality;
- the negative correlation signals about transient process connected with subjective technological staff's actions for giving to process of the desirable direction or about change of ore grindability;
- the type of function which does not correspond to classical expectations of it shows that the effect of concentrating process control was not neutralized, and concentrating process proceeds in transient regime.

3. Spectrum analysis and determination of OCP-1 amplitude-frequency characteristic should be the following step in determination of indicative events, characterizing a process state on "useful mineral content in ore – useful mineral content in a concentrate" control channel.

References.

1. *Decisions for a mining and processing complex according to the Saturn company of a data international.* [online] Available at: http://www.saturn-data.com/img/forall/file/Mining_rus_mod.pdf [Accessed 11 February 2017].

2. Automated process control systems of concentrating factories: according to the PROM-TECH company. [online] Available at: http://www.promtex.ru/custom-pages.html?layout=edit&id=185/ [Accessed 11 February 2017].

3. IRON ORE BENEFICIATION SOLUTIONS: according to the Outotec company. [online] Available at: http://www.outotec.com/en/Products-services/Ferrous-metals-and-ferroalloys-processing/Iron/Iron-ore-beneficiation/ [Accessed 5 February 2017].

4. Porkuyan, O. V., Davidenko, A. M. and Katz, M. D., 2010. Identification and suboptimization of technological process of iron ore dressing as object of automatic control. *Visnik of East-Ukrainian University by Volodymyr Dahl*, 6(148), Part 2, pp. 71–75.

5. Khotskina, V. B., 2013. Process control automation of iron ore dressing technology complex with Petry net model use. *Visnik of Krivorizky National University*, 34, pp. 15–18.

6. Khorolsky, V. P., Khotskina, V. B. and Khorolska, T. V., 2013. Intellectual control system of iron ore dressing technology complex. *Mining electromechanic and automatic equipment*, 91, pp. 47–53.

7. Konokh, I. S. and Nayda, V. V., 2014. The analysis of relevance of development of information technologies for optimization of operation of the first stage of concentrating factory of Ferrexpo Poltava Mining. *Visnik of Kremenchutsky National University named after Mikhail Ostrogradskyi*, 5(88), pp. 68–76.

8. Kuvaiev, Ya. H., 2006. Automatic expert energy saving management system closed loop of wet spherical grinding. *Science and innovations*, 3, pp. 48–53.

9. Ivanov, A. B., Kuvaiev, V. N. and Kuvaiev, Ya. H., 2010. Perspective directions of process automation of ore crushing and grinding. *Mining Magazine*, 11, pp. 74–77.
10. Kupin, A. I., 2008. Statistic parameter estimation of artificial neurostructures for control of nonlinear dynamic objects. *Naukovy Visnik Chernivetsky University*, 423, pp. 77–82.

Мета. Для виключення оператора з контуру керування методом кореляційного аналізу визначити індикативні події, що характеризують стан процесу по каналу управління „вміст корисного мінералу в руді – вміст корисного мінералу в концентраті“ рудо-збагачувальною фабрикою з кульовим подрібненням.

Методика. Кореляційний аналіз параметрів об’єкта керування.

Результати. За видом та параметрами взаємокореляційних функцій виділено ряд індикативних подій, що характеризують стан процесу по каналу управління „вміст корисного мінералу в руді – вміст корисного мінералу в концентраті“.

Наукова новизна. Уперше проведено порівняння чисельних значень часу спаду та еквівалентного запізнювання автокореляційних і кореляційних функцій вмісту загального заліза й постійної часу технологічної лінії збагачення, отриманих у процесі нормальної промислової експлуатації рудозбагачувальної фабрики з кульовим подрібненням.

Практична значимість. Індикативні події, що одержані за виглядом та за параметрами взаємокореляційних функцій між вмістом корисного мінералу у вихідній сировині та концентраті, можуть бути використані для побудови автоматичної системи ситуаційного управління процесом збагачення руд чорних і кольорових металів як на окремих секціях з кульовим подрібненням, так і на фабриках, до складу яких ці секції входять.

Ключові слова: *автоматизація, індикативні події, система ситуаційного управління, кореляційний аналіз, збагачення залізної руди, рудозбагачувальна фабрика з кульовим подрібненням*

Цель. Для исключения оператора из контура управления методом корреляционного анализа определить индикативные события, характеризующие состояние процесса по каналу управления „содержание полезного минерала в руде – содержание полезного минерала в концентрате” рудообогатительной фабрикой с шаровым измельчением.

Методика. Корреляционный анализ параметров объекта управления.

Результаты. По виду и параметрам взаимокорреляционных функций выделен ряд индикативных событий, характеризующих состояние процесса по каналу управления „содержание полезного минерала в руде – содержание полезного минерала в концентрате“.

Научная новизна. Впервые проведены сравнения численных значений времени спада и эквивалентного запаздывания автокорреляционных и корреляционных функций содержания общего железа и постоянной времени технологической линии обогащения, полученных в процессе нормальной промышленной эксплуатации рудообогатительной фабрики с шаровым измельчением.

Практическая значимость. Индикативные события, полученные по виду и параметрам взаимокорреляционных функций между содержанием полезного минерала в исходном сырье и концентрате, могут быть использованы для построения автоматической системы ситуационного управления процессом обогащения руд чёрных и цветных металлов как на отдельных секциях с шаровым измельчением, так и на фабриках, в состав которых эти секции входят.

Ключевые слова: *автоматизация, индикативные события, система ситуационного управления, корреляционный анализ, обогащение железной руды, рудообогатительная фабрика с шаровым измельчением*

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