Research and neutralizing of spiral deterioration impact to the accuracy of measuring of the volume of sand classifier

Vasilii A. Kondratets[a], Anatolii N. Matsui*[a], Wojciech Surtel[b], Yedilkhan Amirgaliyev[c], Vladimir Kovalenko[d], Aigul Iskakova[e]

[a]Kirovohrad National Technical University, Prospect Universytetskyi 8, Kropyvnytskyi, 25030 Ukraina; [b]Lublin University of Technology, Nadbystrzycka 38A, 20-618 Lublin, Poland; [c]Institute of Information and Computational Technologies, Almaty, Kazakhstan; [d]Kotel'nikov Institute of Radio-engineering and Electronics (IRE) of Russian Academy of Sciences; [e]Kazakh National Research Technical University after K. I. Satpaev, Almaty, Kazakhstan

ABSTRACT

The findings have been expounded of the theoretical research aimed at the disclosure of the precise impact of the wear of the mechanical classifier spiral's working parts on the measurement accuracy of the amount of sand in the inter-turn space based on the sand body height. It has been demonstrated that the wear of the spiral's working parts affects both the amount of sand at a certain value of the height of its body and the measurement accuracy of the height itself, with the measurement conducted by the locating method. At a certain constant height of the sand body, less sand is accommodated in the spiral inter-turn space when the operational wear of the working parts is observed, and that "less" can amount to up to 30%. As a result of the working parts' allowable operational wear, the sand body height measurement vertical line coordinates change leading to a relative systemic error, which can reach 20%. That does not make it possible to directly measure the amount of sand in the inter-turn space based on the height of the sand body. The approaches developed make it possible to neutralize the relative sand body height measurement error and to ensure the determination of the amount of sand based on the height of its body with an error not exceeding the process requirements for that parameter's monitoring accuracy.

Keywords: classifier, wear of the spiral, neutralization of the impact, amount, sand body height, measurement errors

1. INTRODUCTION

In most countries of the world, reserves of high-grade iron ore are already depleted at present, and a steady transition is being made to mining deposits of low-grade ore containing iron at a level of 20...35% with the aim of bringing that content to 65% through the beneficiation process. In China, for instance, the objective has been set to obtain marketable iron concentrate with an iron content of 60.79% from the ore containing only 18.64% of iron compounds[1]. Such a tendency is corroborated, for example, by the data stated in paper[2]. Before beneficiation, low-grade iron ores are crushed and then classified. At the first stage of crushing/classification, big overruns in electric power, balls, lining material and mechanical classifier spiral's working parts are made, which results in an increase in the iron concentrate's production cost constituting a problem to the mining industry.

Actuality of the paper. This problem is tackled by various means, in particular, by optimizing crushing and classification process charts[3], by improving the process equipment and especially the difficult-to-control spiral classifier viz. through increasing the height of its overflow edge by 250 mm [4], through advancing the height of its boards (beginning at 2/3 of its length) by 250…300 mm and that of the overflow edge by 150…200 mm [5], through increasing the height of the overflow edge in areas of added slurry speed [6], and through enhancing the spiral classifier working parts' wear resistance [7]. Along with that, the crushing/classification industrial process models are being improved [8] as well as those of ball mill crushing [9]. Taking into account the fact that crushing and magnetic separation processes' automation is a powerful means of increasing production efficiency, enhancing concentrate quality and reducing metal losses into the beneficiation tailings, it is right that way that the problem should be mainly tackled [10], the obstacle here, however, lies in the lack of the necessary information facilities. That is especially relevant with regard to the spiral classifier. That is why paper [11] emphasizes the need to develop the appropriate information facilities, to enhance their reliability and accuracy, as well as to lower their cost. The spiral classifier sand consumption acts here as the main process parameter, since the

Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments 2017, edited by Ryszard S. Romaniuk, Maciej Linczuk, Proc. of SPIE Vol. 10445, 1044565
 · doi: 10.1117/12.2280955

classification efficiency is closely related to the circulating load [12]. That is why the circulating load determination has been paid much attention to in the recent years. Thus, paper [13] suggests an iteration calculation chart to account for the circulation sand, that chart based on the probabilistic model of crushing material in ball mills operating in the spiral classifier closed-loop process. Paper [14] also suggests circulating load iteration calculation for closed-loop crushing. Paper [15] suggests yet another approach to calculating that process parameter. It is necessary to note that the above approaches of circulating load calculation use the iteration method related to step-by-step selection of solutions, which leads to delayed action. On top of that, such circulating load identification is characteristic of a stable operating mode, which is virtually non-existent in real crushing/classification processes. That is why the classifier operation efficiency evaluation by circulating load, determined according to an indirect method, is inappropriate due to the timing non-concurrence for the process parameter value determination and for the material as-per-size separation in the process unit. Taking account of that fact, the task of improving control of the sand leaving the classification process is relevant, and requires further research.

Aim of the research. It is more efficient to evaluate the material separation process in the classifier by the sand's yield, after finishing the process operation, taking direct measurements of the sand body, since a relationship has already been obtained between the solids' amount in the inter-turn space and their level along the vertical line running through the point of contact of the bed and the spiral's rear turn at the bottommost position [16]. Based on the analysis of the relationship obtained, a conclusion has been made on the possibility of a direct measurement of the mechanical spiral classifier sand productivity. This approach for determining the amount of sand in the classifier spiral inter-turn space on the basis of the height of the sand body is devoid of the delay quality, and ensures sufficiently high accuracy. However, the impact of the spiral wear and the possibility of the latter's neutralization during such measurements have not been considered.

The aim of research is to determine the impact of the spiral wear of a serial classifier on the sand amount measurement accuracy in the spiral inter-turn space by means of registering the material's body height and to neutralize that impact.

2. METHOD

At the first stage of crushing the incoming ore, the material crushed in the ball mill is sent to the mechanical single-spiral classifier, where it is separated into the finished product and sand. High-capacity beneficiation plants use as a matter of fact mechanical single-spiral classifiers that are set at an angle of α=18°30' to the horizon. The classifier spiral has a radius of R_C=1.5 m, and is made double-start with a pitch of B=1.8 m. It usually rotates at 3 rev/min (0.05 rev/s), and is equipped with working parts 0.33 m high. The amount of sand in the spiral inter-turn space perfectly describes the progress of separation of the crushed material into the finished and coarse products, but the operational wear of the spiral from R_C1.5 m to the allowable end value of the radius simultaneously affects both the amount of material at the same height and the accuracy of measurement of the height itself.

Determining the amount of sand by the height of its body is conducted under fairly complicated process conditions, where spiral replacement working parts wear out, and the spiral's diameter becomes smaller.

The height of the sand body is appropriate to be measured by a locating device along the vertical line passing through the point of contact of the bed and the spiral's rear turn at the bottommost position. This raises a number of peculiarities. Firstly, the spiral operation results in its wear and the ensuing reduction of its diameter while its pitch remains unchanged. Secondly, the reduction of the spiral's diameter is accompanied by the respective decrease in the cylindrical bed diameter. Thirdly, raising the cylindrical bed according to the spiral wear degree changes the installed base of the locating device measuring the distance to the sand body. Fourthly, raising the cylindrical bed parallel to the spiral axis offsets the position of the sand body height measurement vertical. Those peculiarities can substantially influence the measurement results for the amount of sand in the mechanical single-spiral classifier.

When using this approach, the amount of sand in the single-spiral classifier should be determined by the height of the sand body along the vertical line as shown in Fig. 1, a. It is impossible to measure the sand body height immediately under the process conditions. That is why it is determined by the distance from the locating device to the horizontal surface of the material as shown in Fig. 1, b.

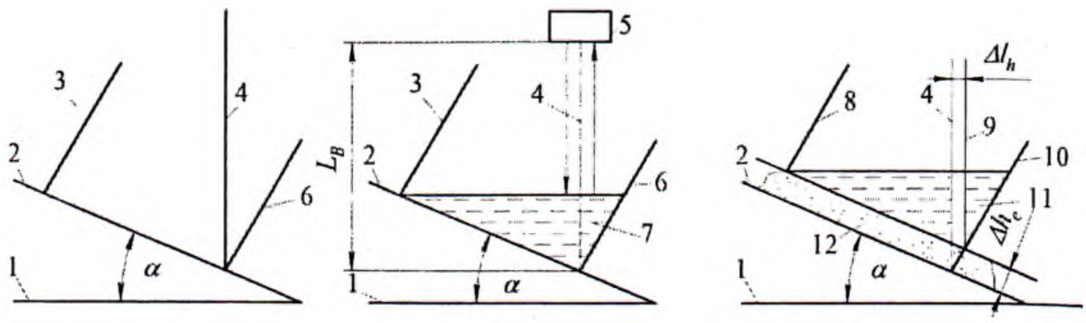

Figure 1. The features of the sand body height measurements in a mechanical single-spiral classifier: a – height measurement vertical; b – distance locating meter positioning; c – sand body height measurement vertical shift triggering mechanism; 1 – horizontal surface; 2 – cylindrical bed base when the spiral's working parts are unworn; 3 – unworn spiral's front turn working part; 4 – sand body height measurement vertical; 5 – distance locating meter; 6 – unworn spiral's rear turn working part; 7 – sand's position when the spiral is unworn; 8 – worn spiral's front turn working part; 9 – sand body height measurement vertical offset; 10 – worn spiral's rear turn working part; 11 – sand's position when the spiral is worn; 12 – additional cylindrical bed formed when the spiral's working parts become worn

During the spiral's operation, it wears out and its diameter becomes smaller. Since the cylindrical bed also changes its position, the sand body height measurement vertical becomes offset as shown in Figure 1, c. As shown in Figure 1, c, when the spiral's working parts are worn by a value of Δh_e, the sand body height measurement vertical offset stands at Δl_h. That makes the results of determining the single-spiral classifier sand body height uncertain.

Any measurements are characterized by errors that are divided into systematic and random ones, as well as blunders. Blunders practically do not occur if automatic measurements are organized properly. Random errors in this case will be specific to measuring the distance from the ultrasonic level meter to the horizontal surface of the sand. However, the distance measurement error range for a particular level meter is known, for example, it is ± 3 mm, and will not change under the undisturbed conditions of its operation. Let us, therefore, consider the impact of systematic errors on the sand body height measurement results.

Systematic errors may remain unchanged or change as per a certain pattern. Most often, we have to deal with instrumental systematic errors or with those that arise as a result of external factors. Instrumental systematic errors can occur because of improper process arrangement or information facility manufacturing flaws. Particular examples are inaccurate instrument scales, wear and aging of the device. Systematic errors can also be caused by the incorrect installation of the device, the effects of the ambient temperature, the atmospheric pressure, the air humidity, as well as external magnetic and electric fields. Systematic errors can be of theoretical nature, a result of incorrect assumptions or simplifications in the very method of measurement [17]. As analysis shows, all the systematic errors cited can be eliminated from the measurement procedure of process parameters. Let us assume that those errors are non-existent, and consequently do not affect the measurement results. However, even in this case, a systematic error of different nature still occurs due to the spiral wear.

The mechanism of that systematic error occurrence is revealed in Fig. 2. Given the unworn spiral, the sand body height measurement is conducted along vertical line 4 from point A of a contact between base bed 2 and the edge of working part 6 to device 3 measuring the distance on the base area L_B. In the event that the spiral becomes worn by a value of Δh_e, working part 6 becomes shorter by a segment of AB. In this area, built-up bed 8 from the sand product is made, as well as base 7 of the shifted bed. That being the case, base 7 of the shifted bed is in contact with the edge of worn working part 6 at point B, point B being offset relative to point A. Offset vertical line 5 of the sand body height measurement runs through point B. As shown in Figure 2, the sand body height measurement must be conducted along new vertical line 5, but it is actually done relative to vertical line 4, and that brings about a systematic error.

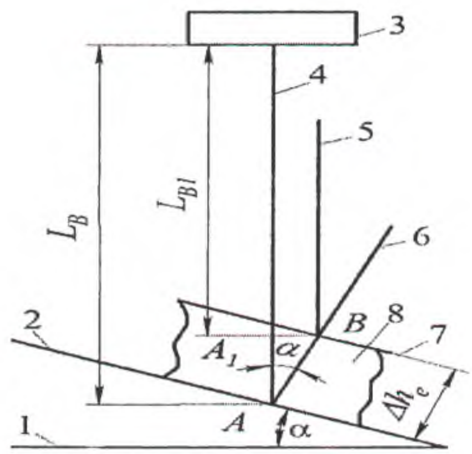

Figure 2. The mechanism of systematic error occurrence: 1 – horizontal surface; 2 – bed base; 3 – distance meter; 4 – sand body height measurement vertical; 5 – sand body height measurement vertical offset; 6 – spiral's working part; 7 – base of the shifted bed; 8 – built-up bed

The procedure for the sand body height measurement in the mechanical single-spiral classifier is demonstrated in Fig. 3, which shows that, if the spiral's working parts are unworn, the reference for the sand body height is point A, based on cylindrical bed 2. That being the case, sand body height AD equals:

$$AD = h_{PT} = L_B - DF = L_B - l_P \tag{1}$$

where L_B – base distance from the measurement point to the locating device; l_P – measured distance from the locating device to the horizontal surface of the sand.

If the spiral's working parts are worn, for instance by a value of $AB=\Delta h_e$, the measurement conditions will still not change. Given the fact that the locating device remains at vertical line 7 (Fig. 3), the measured value of the sand body height will be overestimated because the operation should have been done along vertical line 8. Analysis shows that, when the spiral's working parts become worn, the measurement vertical line realignment may not be done and the locating device may be left at the initial position that corresponds to an initial spiral size of R_C = 1,5 m.

Let us assume that the value of working parts wear degree is known, and equals $AC=\Delta h_e$. It is necessary to determine sand body height BE that is equal to segment CD along vertical 7 (Fig. 3), which corresponds to unworn working parts of the spiral. Distance DF along vertical line 7, measured by the locating device, equals EG, measured along offset vertical line 8. Hence, an equation can be set down:

$$L_B = DF + CD + AC \tag{2}$$

where: $DF=l_P$; $CD=h_{PTZ}$ – sand body height with the spiral's working parts worn; $AC=\Delta h_e \cdot cos\alpha$.

Then:

$$L_B = l_P + h_{PTZ} + \Delta h_e \cdot \cos\alpha \tag{3}$$

hence the sand body height with the spiral's working parts worn equals:

$$h_{PTZ} = L_B - l_P - \Delta h_e \cdot \cos\alpha \tag{4}$$

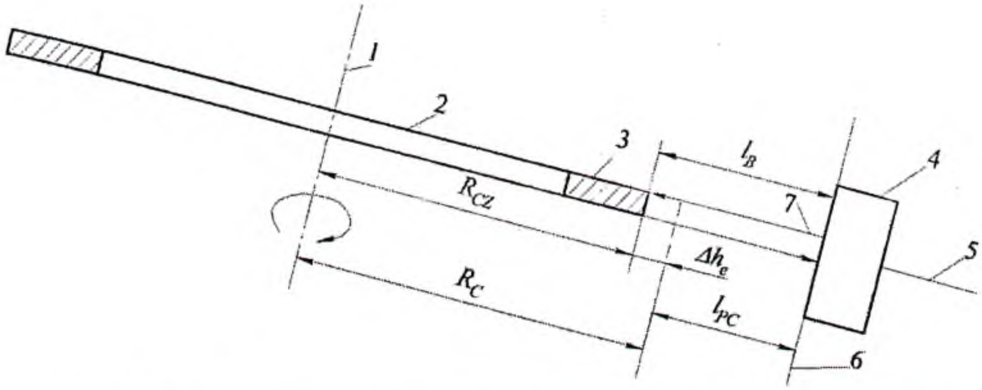

Figure 4. The wear degree measurement diagram for the classifier spiral's working parts: 1 – spiral's axis of rotation; 2 – spiral's turn; 3 – spiral's working part; 4 – distance locating meter; 5, 6 – horizontal settings of the distance meter; 7 – vertical setting line of the distance meter

The specific process conditions make it possible to adopt the values of the constants in function (6), i.e., $L_B = 3200$ mm, $l_{PC} = 500$ mm, $\alpha = 18°30'$. Then function (6) may be represented as:

$$h_{PTZ} = 3200 - l_P - (l_B - 500)\cos 18°30'$$

or:

$$h_{PTZ} = 3200 - l_P - 0{,}9483(l_B - 500) \tag{7}$$

where l_P and l_B are expressed in mm.

The second component of the sand amount measurement error is the material's volume change due to the wear of the spiral's working parts while the sand body height remains the same. It was established that, given the operational wear of the spiral's working parts, the amount of sand between the turns becomes lower at a certain height of the sand body compared to the situation where the working parts are unworn. The research was conducted by the graphic-analytical simulation according to the technique developed by the authors. Within the circulating loads' range considered, the relative deviation of the sand amount totaled 30.63...9.95%, showing a pattern of decrease while the sand body height was increasing, with the absolute deviation of amount tending to increase.

During the process of simulation, sand amount vs. sand body height relationships were obtained both for unworn working parts of the spiral and for those worn to a boundary value of 0.04 m, which can, accordingly, be approximated by mathematical formulas:

$$V_{PT} = 2063{,}1h_{PT}^2 - 331{,}7h_{PT} + 32{,}714;\ \mathrm{dm}^3 \tag{8}$$

and:

$$V_{PTZ} = 2220{,}8h_{PTZ}^2 - 423{,}32h_{PTZ} + 33{,}825;\ \mathrm{dm}^3 \tag{9}$$

where h_{PT} is expressed in m.

Analysis showed that graphs built as per functions (8) and (9) run almost parallel to each other. Given the fact that the sand body configuration, defined by the profile and the position of the spiral turns, does not change as a result of the working parts' wear it is possible to assume that the amount of the material decreases in a uniform way during the process. Under those conditions, when determining the sand body amount at any stage of the spiral's working parts wear and at that of a random process situation, the function:

$$V_{PTZa} = V_{PTa} - \frac{(V_{PTa} - V_{PTda})}{\Delta h_{ed}} \cdot \Delta h_{ea} \tag{10}$$

must be applied, where symbol "$_a$" denotes a specific process situation, which is unambiguously defined by measurable parameters l_B and l_P; V_{PTZa} – amount of sand identified in the inter-turn space; V_{PTa} – amount of sand with the spiral's working parts unworn and the actual sand body height; V_{PTda} – amount of sand with the spiral's working parts worn to the boundary value; Δh_{ed} – wear boundary value for the spiral's working parts that equals 0.04 m; Δh_{ea} – actual wear degree of the spiral's working parts.

Having measured distances l_B and l_P by the locating devices and having involved (5) and (7), we can find Δh_e and h_{PTZ}, and, using formulas (8) and (9), after determining $h_{PTa} = h_{PTZa} + \Delta h_{ea}$ cosα, we can calculate sand amount values V_{PTa} and V_{PTZ}. Formula (10) makes it possible to determine the actual amount of sand in the classifier spiral's inter-turn space.

3. RESULTS AND DISCUSSION

If the sand body height (4), with the spiral's working parts worn, is determined without component $\Delta h_e \cos\alpha$ taken into consideration, its values will be overestimated. Component $\Delta h_e \cos\alpha$ is an absolute error of the sand body height measurement. As can be seen, its value is determined by constant angle α of the classifier spiral axis tilt to the horizon and the variable wear of the working parts. The relative measurement error can be determined by means of the formula:

$$\delta = 100\Delta h_e \cos\alpha / h_{PT}\ ,\% \tag{11}$$

It also depends on the size of the circulating load, i.e. on the sand body height that can vary, being process-conditioned, quite widely. Let us determine the relative sand body height measurement error under the conditions of the spiral wearing from R_C=1.5 m to R_C=1.4 m and the sand body height changing from a minimum value of 0.15 m to a possible one of 0.25 m. The data is summarized in Table 1. The Table 1 data shows that the wear of the spiral's working parts leads to significant sand body height measurement errors. They are especially high for small values of the sand body height (for small values of the circulating load). However, the errors are also significant for possible biggest values of the sand body height. Even at the biggest value of the sand body height and the spiral wear of only 5 mm the systematic error is 1.9%. If the degree of wear stands at 0.04 m under the same conditions, the relative error equals 15.17%.

To measure the sand body height, a locating device should be chosen. An ultrasonic level meter of the 8175 type suites the conditions in question fairly well[18,19]. It has the following specification: measured distance – up to10 m; error range – ± 3mm; dead zone – 0.3 m; operating temperature – -40...+ 80 °C. A device of the 8175 type suites all requirements. Its accuracy, however, needs to be reviewed.

Table 2 presents the error range of the inter-turn space sand body height measurements for a mechanical single-spiral classifier, with varying values of the sand body height, with the working parts being unworn and with an absolute measurement error of ± 3 mm.

Table 1. The relative systematic error of mechanical single-spiral classifier sand body height measurements depending on the wear degree of the spiral's working parts, %

Sand body height, m	*The degree of wear of the spiral's working parts, m*										
	0,005	0,01	0,02	0,03	0,04	0,05	0,06	0,07	0,08	0,09	0,10
0,15	3,16	6,32	12,64	18,97	25,29	31,61	37,93	44,25	50,58	56,90	63,22
0,20	2,37	4,74	9,48	14,22	18,97	23,71	28,45	33,19	37,93	42,67	47,42
0,25	1,90	3,79	7,59	11,38	15,17	18,97	22,76	26,55	30,35	34,14	37,93

Table 2. The error range of the inter-turn space sand body height measurements for a mechanical single-spiral classifier, with varying values of the sand body height and with the working parts being unworn

Basic values of the sand body height h_{PT}, mm	*Measured distance from the locating device to the horizontal surface of the sand l_P, mm*	*Measured values of the sand body height h_{PT}, mm*	*Absolute error of the sand body height measurement, mm*	*Relative error of sand body height measurement, %*
150	3050±3	150±3	±3,0	±2,0
200	3000±3	200±3	±3,0	±1,5
250	2950±3	250±3	±3,0	±1,2
300	2900±3	300±3	±3,0	±1,0

The Table 2 data shows that, regardless of the sand body height, the absolute error of its measurement by an ultrasonic level meter of the 8175 type stays the same and amounts to ± 3 mm. The relative error of the sand body height measurement as per formula h_{PT}=3200-l_P does depend on the height. The lowest accuracy of the sand body height measurement, with the working parts unworn, corresponds to the initial values of the circulating load range, where the relative error stands at ± 2%. At the end of the range, where the sand body height is the largest, the relative error of the parameter is ± 1.0%. When the spiral is unworn, the sand body height can be determined with sufficiently high accuracy.

Given the fact that the wear of the spiral's working parts makes the sand body height measurement more complicated (7), the accuracy check should be conducted separately. The wear of the spiral's working parts proceeds from 0 to a certain maximum value. Normally, the biggest wear degree is Δh_{ed}=40 mm. As the wear of the spiral's working parts grows bigger, the value of l_P in function (7) remains unchanged with the measurement conditions being the same while l_B increases. That being the case, the third component of function (7) increases and, respectively, so does the sand body height measurement error. The error will be the highest when the wear of the spiral's working parts is maximal. So the accuracy check is appropriate when Δh_{ed}=40 mm. Then the third member of function (7) will be equal to 37.932 mm. Let us assume it is 38 mm. Under those conditions, equation (7) takes the form of h_{PT}=3162-l_P. The calculations based on the above equation and maintaining the previous measurement conditions are shown in Table 3.

Table 3. The error range of the inter-turn space sand body height measurements for a mechanical single-spiral classifier, with varying values of the sand body height and with the working parts being worn by 40 mm

Basic values of the sand body height h_{PT}, mm	*Measured distance from the locating device to the horizontal surface of the sand l_P, mm*	*Measured values of the sand body height h_{PT}, mm*	*Absolute error of the sand body height measurement, mm*	*Relative error of sand body height measurement, %*
112	3050±3	112±3	±3,0	±2,68
162	3000±3	162±3	±3,0	±1,85
212	2950±3	212±3	±3,0	±1,42
262	2900±3	262±3	±3,0	±1,0

The Table 3 and Table 2 data shows that the relative sand body height measurement error grows as the wear of the spiral's working parts nears its maximum. However, it stays within the process accuracy requirements of the information facilities. Its highest value is ± 2.68%, which is significantly lower than an allowable one of ± 3.0%. It should also be borne in mind that the circulating load does not really exist at h_{PT}=112 mm. The relative sand body height measurement error within the initial values of the range, when the spiral is fully worn, will therefore be much lower than ± 2.68%. The wear of the spiral's working parts does somewhat increase the relative sand body height measurement error, its absolute value stays, however, by a wide margin within the process accuracy requirements of the information facilities.

The analysis of function (10) also shows that, across the allowable range of the working parts' wear, the sand amount measurement error for the mechanical classifier's inter-turn space stays within the process requirements.

4. CONCLUSIONS

The accuracy of the mechanical classifier inter-turn space sand amount measurements relative to the sand body height depends on the wear degree of the spiral's working parts.

The wear of the spiral's working parts affects simultaneously both the amount of sand – with the sand body height staying the same – that amount being reduced, and the measurement accuracy of the height itself.

The relative error of varying the amount of sand, when the sand body height in the inter-turn space remains unchanged, with the allowable wear of the spiral's working parts, can reach 30%, while the systematic relative height measurement error can amount to 20%, which does not make it possible to directly assess the amount of sand relative to its body height when controlling the ore classification/crushing process.

The approaches that have been developed make it possible to neutralize the harmful effects of the wear of the classifier spiral's working parts on the measurements of the amount of sand in the inter-turn space relative to the sand body height ensuring the situation where the process parameter is determined within the accuracy requirements.

The prospect of further research is to develop techniques for direct sand amount measurements in the mechanical classifier's inter-turn space that are invariant to the impact of wear of the spiral's working parts.

REFERENCES

[1] Siqing L., Yang Z., Wanping W. and Shuming W., "Beneficiation of a low-grade, hematite-magnetite ore in China." Minerals & Metallurgical Processing 31 (2), 136-142 (2014).

[2] "European Commission. Sustainable process industry," Multi-annual roadmap for the contractual PPP under Horizon 2020. ,131 (2013).

[3] Delgadillo J.A., Lopez-Valdivieso A. and Tello A., "Optimization of a grinding and classification circuit of a magnetite ore processing plant through computer simulation." Minerals & Metallurgical Processing. 25 (4), 223-228 (2008).

[4] Gabets V.S., Aslamov A.A. and Gabets S.V., "Improving the efficiency of a spiral classifier and applying automated hydro-cyclone units at Norilsk concentrator plants." Bulletin of the Angarsk State Technical University 1 (1), 22-23 (2009).

[5] Vorobyov A. E., and Anikin A. V., "Improving the operation efficiency of the crushing and grinding division of a gold recovery plant.," Mining Bulletin of Uzbekistan. 2 (53), 39-43 (2013).

[6] Smetanin V.A., Putyato A.V., Ivaschenko V.V. and Lobanova V.P., "A method for improving the efficiency of hydraulic classification by spiral classifiers at Crushing and Concentrating Plant No. 5 of the Ore Concentration Division of the PJSC Magnitogorsk Iron and Steel Works." Steel 7, 10-11 (2015).

[7] Serbin V.M., "Enhancing wear resistance of working parts of small-size spiral classifiers." Mining Machinery and Electrical Engineering 6, 45-48 (2012).

[8] Wang X., Wang Y., Yang C., Xu D. and Gui W., "Hybrid modeling of an industrial grinding-classification process." Powder Technology. 279, 75-85 (2015).

[9] Chen X., Li Q. and Fei S., "Constrained model predictive control in ball mill grinding process." Powder Technology. 186, 31-39 (2008).

[10]Azaryan A.A., Krivenko Y.Y. and Kucher V.G., "Automation of the first stage of crushing, classification and magnetic separation – a real way to enhance the iron ore dressing efficiency." Bulletin of the Kryvyi Rih Technical University. 36, 275-280 (2014).

[11]Kupin A.I., "Smart identification and control in the context of beneficiation processes." Kryvyi Rih Technical University Publishers. Kryvyi Rih, 204 (2008).

[12]Vorobyov A. E., and Anikin A. V., "Improving the operation efficiency of the crushing and grinding division of a gold recovery plant.," Mining Bulletin of Uzbekistan. 2 (53), 39-43 (2013).

[13][13] Malyshev V.P., Turdukozhayeva A.M. and Kaykenov D.A., "Accounting for sand circulation in the probabilistic model of ore grinding." Ore Dressing 6, 29-33 (2012).

[14]Silva A.C., Silva E.M.S. and Rezende R.A., "Iterative calculation of circulating load in closed-circuits." Tecnol. Metal. Mater. Miner. 10 (3), 257-263 (2013).

[15]Silva A.C., Silva E.M.S. and Rezende R.A., "Circulating load calculation in grinding circuits." Revista Escola de Minas. 67 (1), 101-106 (2014).

[16]Matsui A.M., "Mathematical modeling of the sand body formation in the mechanical spiral classifier's inter-turn space." Automation of technological and business processes 7 (4), 9-17 (2015).

[17]Ivanova G.M., Kuznetsov N.D. and Chistykov V.S., "Process measurements and devices." Moscow Power Engineering Institute Publishers. Moscow, 460 (2005).

[18]"Ultrasonic level transmitter. Type 8175. Instruction manual.,http://www.burkert.com/en/type/8175", (2016).

[19]Podzharenko V.O., and Vasilevskyi O.M., "Diagnostics of technical condition of electromechanical systems for the logarithmic decrement." Proceedings of Donetsk National Technical University. Series: "Computers and Automation" 88, 138-144 (2005).

*matsuyan@mail.ru