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AUTOMATION OF ORE QUALITY MANAGEMENT IN QUARRIES

Purpose. Formation of a realistic assessment of the prospects for the introduction of automated ore extraction systems and quality control in the activities of modern mining enterprises.

Methodology. The basis of the methodological approach in this study is a combination of system analysis of various aspects of automation of management processes of ore quarrying, with an analytical investigation of the prospects for optimising ore mining processes in quarries using modern methods of automation and digitalisation.

Findings. A systematic analysis of various aspects of automation of ore mining management processes by quarry method was performed. The most promising areas of quarry development in order to obtain ore raw materials of the highest quality were identified. A scheme showing the systems of methods for managing the quality of ore mined by the mining method at the mining enterprises was presented. In addition, the scheme of automation of ore quality management processes extracted in quarries was presented and analysed.

Originality. A real assessment of the prospects for the introduction of automated systems of ore mining and quality control in the activities of modern mining enterprises has been formed.

Practical value. The results of the research can be used as a basis for training specialists in the field of mining industry, whose professional responsibilities include solving issues of ore mining in a quarry way.

Keywords: *mining, ore quality, ore quarries, automated design*

Introduction. The current state of a number of mining enterprises in the post-Soviet countries, in particular, Russia and Kazakhstan, is characterised by a sharp drop in ore mining volumes conditioned by the collapse of numerous geological structures, which led to a gradual cessation of the growth of reserves of this type of minerals [1]. The situation is also considerably aggravated by the gradual deterioration of the mining and geological conditions of ore extraction, which leads to an extensive depletion of ore reserves and necessitates the creation and implementation of a quality management system for extracted crude ore. The fact that there are no effective technological schemes for ore quality management at mining enterprises commonly becomes the main reason for a considerable increase in losses during ore extraction, a decrease in extraction volumes, and an increase in prime-cost and energy costs for concentrate production. In conditions of instability of ore flow on a global scale, considering all aspects of the activities of the mining industry of Russia and Kazakhstan, such a situation causes disruption of planned deliveries for a given volume of extracted ore and difficulties in creating forecasts of ore extraction indicators for its subsequent processing [2].

The creation and practical application of a system for managing the quality of mined ore at the mining enterprise imply the timely attraction of investments for the organisation of the activities of these enterprises and the ore mining process in compliance with all quality standards of the mined raw materials. Active quality management of the extracted ore ensures a gradual increase in the quality standards of its extraction and volumes, a reduction in total losses of useful components, and reduces overall production costs. All the above, over time, leads to the development of the necessary prerequisites for the real planning of the volumes of mined ore and key technological parameters of mining production [3].

The purpose of this study is to investigate the current stage of development of automation of ore quality management in quarries, a realistic assessment of the prospects for the introduction of

automated ore extraction systems, and quality control over the activities of mining enterprises. The quality of the extracted ore is essential from the standpoint of the prospects for its subsequent processing and ensuring the high quality of the products obtained.

Literature review. The quality of the extracted crude ore is largely determined by the mineralogical and material composition of the ores and the degree of its stability. This establishes the level of end-user requirements for the quality of the extracted raw materials, for their subsequent storage and processing [4]. In general, the quality of the extracted ore is largely conditioned by the final level of concentration of useful and harmful elements in it, their percentage ratio, the possibility of reducing the deviations of the ore flow components to the minimum parameters and achieving maximum uniformity of the composition of the extracted ore mass within a specific batch or at specified time intervals. The heterogeneity of the ore mass implies its variability in the concentration of the main constituent components, and this parameter is essential, primarily for large volumes of ore, including many different components [5]. The requirements for the quality of crude ore vary due to considerable differences in the assessment criteria and the main methods for achieving the required quality parameters of the extracted ore. The development and practical implementation of an automated quality management system for mined ore in quarries contribute to the systematisation of all ore extraction processes and the determination of the quality of extracted crude ore at the early stages of its extraction, to optimise its subsequent processing and use [6].

The theoretical basis of this study is available publications of researchers devoted to the issues of ensuring proper quality standards for mining raw materials, the creation and implementation of an automated control system and quality control of mined ore. To create the most objective and qualitative picture of the research and to facilitate the perception of the information provided in it, all the borrowed achievements of authors from other countries presented in this study have been translated into English.

Materials and methods. The basis of the methodological approach in this study is a combination of system analysis of various aspects of automation of management processes of ore quarrying, with an analytical investigation of the prospects for

optimising ore mining processes in quarries using modern methods of automation and digitalisation. The development of a qualitative theoretical basis contributes to the optimal use of a combination of methods to create an objective picture of research and search for answers to all the questions raised.

This research consists of three main stages. At the first stage of this research, a qualitative theoretical base is created, necessary for further study on the prospects for the development and practical implementation of a modern automation system for the quality management of ore mining in quarries. Moreover, at this stage, based on the created theoretical base, a systematic analysis of various aspects of automation of management processes of ore quarrying is conducted.

At the second stage, an analytical investigation of the prospects for optimising ore mining processes in quarries is conducted along with an analysis of the prospects for the practical application of modern methods of automation and digitalisation of these processes using a schematic representation of the automation of ore mining in quarries. In addition, at this stage, an analytical comparison of the preliminary results obtained with the results and conclusions of other researchers regarding the considered issues or related to them is conducted to develop the most objective picture of this research and obtain results that maximally reflect its essence.

At the final stage, based on the results obtained, the conclusions are formulated, displaying and summarising the entire complex of studies. In general, the results obtained and the conclusions formulated on their basis can subsequently serve as a qualitative methodological basis for further research on the issues of automation of ore quality management in quarries to expand existing ideas about the prospects of ore mining and improve the quality of raw materials extracted for the needs of various sectors of the economy.

Results. In the course of the study, the following results are obtained. Automation of ore quality management in quarries involves considering a number of factors that have a direct impact on the ore extraction process itself and its transportation to the place of processing and storage. Most commonly, these factors can be reduced to the following:

1. Identification of the most promising quarrying sites to obtain the highest quality crude ore.

2. Implementation of an automated accounting system for the volumes of extracted ore crude ore and its delivery to the surface during open-pit mining.

3. Automated accounting of crude ore storage before it is sent for processing.

4. Construction of a system for delivering ore to the places of its subsequent processing.

To date, metallurgical processing enterprises have consistently high requirements for the quality of the extracted ore since the stability of the granulometric and chemical composition of the ore masses guarantees the stability of the ore smelting processes, allowing it to be accelerated if necessary, and contributes to an increase in the productivity of blast furnaces, combined with a reduction in the prime cost of metal smelting processes [7]. Stabilisation of the quality of quarried ore ensures the achievement of a considerable beneficiating effect. In addition, an increase in the technological indicators of beneficiation is observed if ore of a homogeneous composition is supplied to the ore-processing plant for a long time since this allows clearly adhering to the selected technological regime of beneficiation.

Fig. 1 is a diagram presenting the systems of methods for managing the quality of quarried ore at mining enterprises in Russia and the Republic of Kazakhstan. According to the data presented in Fig. 1, there are two main types of methods for managing the quality of quarried ore: organisational and technological. The use of organisational methods of ore quality control involves mandatory planning of the sequence of quarry work performed divided into months, quarters, or half-years. Moreover, constant quality control of the quarried ore is ensured, regardless of the method of extraction and delivery of raw materials to the surface.

Technological methods for managing the quality of quarry ore extracted involve constant monitoring of the quality of compliance with the technology of ore mining operations in quarries. In this context, it is mandatory to control the processes of crushing ore masses during mining and their delivery to the surface using modern ore lifting technologies. Technological methods for managing the quality of extracted ore have a close relationship with production processes of ore extraction, pursuing the tasks of blending ore layers to obtain a uniform granulometric composition and distributing the monitored component in the final volume [8]. Therewith, the choice of the method for blending ore masses for the subsequent identification of the quality of the mixture is determined by the blending volumes and the placement of mixers in the quarry.

Fig. 2 shows an approximate diagram of the automation system for the quality management of ore mined in quarries.

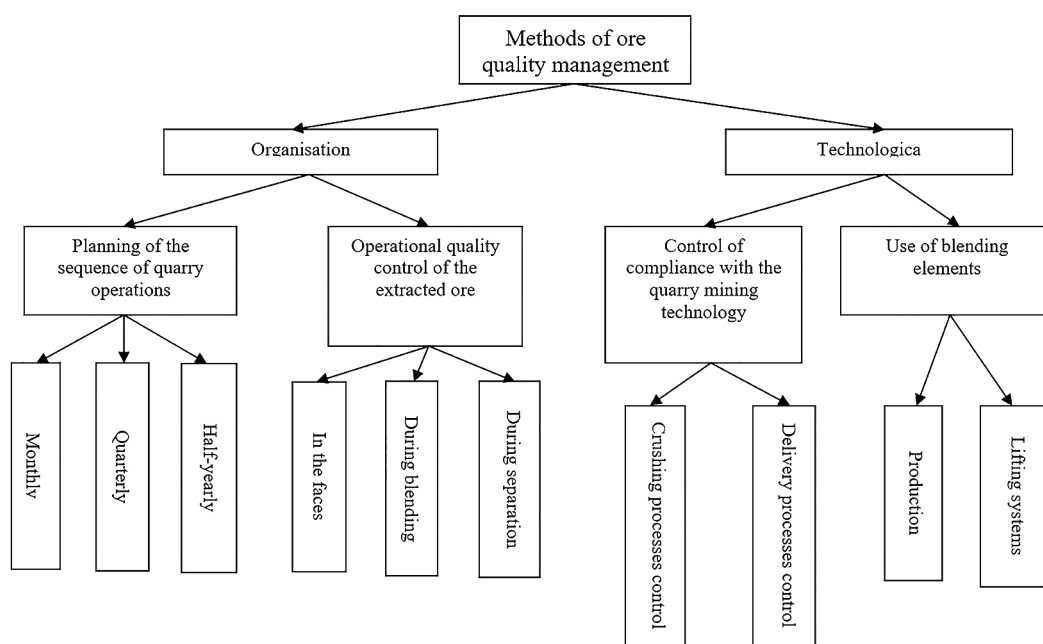


Fig. 1. Methods of quarried ore quality management at mining enterprises in Russia and Kazakhstan

As of 01.11.2021, the introduction of automation processes for ore quality control in quarries has become one of the reasons for the increase in monthly iron ore extraction in South Africa by 15 % compared to the same period in 2020. A relative increase is also observed in the extraction of manganese and nickel ores. Table presents data on the increase in the annual volume of ore extraction at the mining enterprises of South Africa in comparison with 2020.

Automation of ore quality management in the quarries of the Republic of South Africa has successfully solved a number of issues related to determining the prospects for the development of the country's mining industry. The main issues include:

1. Development and implementation of innovative solutions in the processes of extraction and beneficiation of ore mined in quarries.

2. The introduction of energy-saving and labour-saving technologies in the development of ore deposits to improve labour productivity.

3. Improvement of ore mining conditions through the introduction of automated systems of ore quality management.

The current situation at mining enterprises of Russia, Kazakhstan, and South Africa is similar in the context of the impossibility of effective management of ore extraction operations and ensuring the preservation of the required quality parameters of ore processing products without obtaining accurate and timely information about the quality of the initial crude ore. At the enterprises of these countries, such information is obtained through geological exploration, which includes methods for obtaining samples of the source material with its subsequent crushing, drying, and grinding [9]. After that, a chemical analysis is performed, which summarises the results of the entire complex of studies. Since the number of preparatory operations is quite large and takes a considerable amount of time, the usual methods of quality control of crude ore do not have proper efficiency, which necessitates the development and implementation of automated systems for this process.

Automation of ore quality management in quarries involves organisation of processing of data obtained at various stages of drilling, crushing, extraction, and beneficiation of raw materials and during chemical analysis; so, in this context, it is mandatory to consider the time of sampling and preparation of samples at each stage of the technological operations performed. It should be considered that to timely and qualitatively adjust the ore quality management processes, all data regarding the performance of certain technological operations should be submitted and processed in a timely manner to avoid inconsistencies and delays in the execution time of the technological process. The results, as a rule, are losses in the quality of crude ore, a decrease in the quality of beneficiation from the standpoint of a drop in the technical and economic indicators of this process, and failures in the operation of automated quality control systems of the extracted ore.

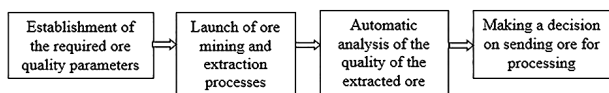


Fig. 2. Automation of quality management of ore mined in quarries

Table

Annual increase in ore extraction at mining enterprises of the Republic of South Africa

Ore	Growth volumes in %
Iron	42.5
Manganese	15.8
Nickel	4.4

In general, a qualitative solution to the issues of automation of ore quality management in quarries requires the creation of complex systems for timely quality control of crude ore, with the possibility of making additional changes to various aspects of the functioning of these systems at the stage of their practical application in the activities of mining enterprises.

Discussion. In the CIS (Commonwealth of Independent States) countries, up to 2015, it was planned to achieve the intensity of iron ore extraction at the main mining plants up to 540 million tonnes of mining raw materials. Such plans could be implemented only with the qualitative modernisation of the existing fleet of quarry and mining equipment, optimisation of logistics schemes, and with the introduction of complex components of quality management of extracted raw materials [3]. The ongoing research in the field of improving the technologies of excavation and loading of raw materials raised to the surface concerns various aspects of optimising this process, with the improvement of a number of indicators, namely, logistical, economic, and energy-economic.

The development of industrial deposits of solid minerals usually involves drilling and blasting operations. During explosions, mass crushing of the mined rock takes place with the formation of an extremely heterogeneous mass in terms of its granulometric composition, as well as large fractions with particle sizes from 300 to 400 mm, which causes difficulties in delivering raw materials to the surface with a conveyor. In this context, the development and practical implementation of an effective system for automating ore quality management in quarries, involving the establishment of control over the mining of ore in the quarry, its extraction, and transportation to places of subsequent processing and practical use, is essential [10].

The modern terminology implies some averaging of certain actions aimed at stabilising the overall quality of minerals, which does not quite correctly reflect the very essence of the process. Stabilisation of the composition of the extracted ore is a complex combination of a number of factors related to various aspects of ore extraction and its subsequent processing to obtain high-quality products. In general, the stabilisation of ore quality implies a set of factors during production processes to bring the crude ore in line with the specified state parameters under which there is a gradual increase in the uniformity of their composition and the provision of an average level of the quality index over the entire range of work performed [11].

The basis of the quality management of the extracted ore should be certain quantitative and qualitative dependencies affecting the constituent elements of the entire mass of crude ore. This process can be initiated from the current planning of all works performed at various stages of quality management to the final implementation of the entire sequence of actions aimed at optimising the ore extraction process and sending it to the end-user.

All technological operations for blending and separating specific volumes of crude ore are performed in strict accordance with established management principles, which involve both the division of the entire volume of ore mass into separate parts and the unification of individual ore layers of different quality to obtain an optimal ore composition. In this case, the goals are to consistently increase the concentration of useful elements in the ore mass and to divide the entire mass into certain grades of ore, depending on the final chosen method for controlling the described processes [12]. In this context, it should be noted that blending the entire mass of ore leads to an averaging of quantitative and qualitative indicators, which generally conforms to certain dependencies in cases of using relatively small volumes of ore. Moreover, the lumpiness of the ore mass is decisive from the standpoint of the gradual reduction of ore batches. Therefore, the maximum allowable averaging of a mine is determined by the lumpiness index of the ore mass: the smaller the conditioned ore fragment is, the more opportunities the mine has in terms of averaging the quality of the products produced. The most profound averaging process is at the beneficiation plant, where there

is a gradual grinding of the ore mass to particles with the lowest dispersion, which causes the development of a physically more active (pulp-like) medium [13].

Ore quality management during quarry mining necessarily involves the stabilisation of the ore composition, which can be achieved by both organisational and production-technological methods of influence. Organisational methods of stabilisation include the organisation of mining production and its management, planning operations for averaging the quality of the extracted ore mass in the technological scheme of the ore quarry. Compliance with the specified stages of operations plays a crucial role in this context since the specific order of planning operations and managing the sequence of their implementation ensures the achievement of the final effect, which is expressed in increasing the overall efficiency of the quality management system of the extracted ore. All organisational measures are aimed at ensuring an average level of ore quality in the total volume of its extraction.

The main quantitative and qualitative dependences of the parameters of the extracted ore are the key tools of organisational impact on the quality management of the extracted ore. Based on these dependencies, the amount of ore mass extraction and the degree of its compliance with the required quality standards are determined for specific time periods [14]. The operational control over the process involves a decrease in the volumes of ore mass of various qualities that take part in the stabilisation along with a consistent averaging of the composition of the mixture, which gradually leads to a decrease in the amplitude of oscillatory processes.

All production and technological works from the standpoint of the organisation of the full functioning of the quality management system of the extracted ore are production operations and processes, whose main task is to mix the specified volumes of ore mass to obtain a uniform distribution of the controlled element in the final volume. The differences between the production and technological processes, in this case, consist in the types of mixers, which in the conditions of mining production can be represented by both mechanical devices and mining structures.

The specific methods for blending ore masses are determined by the blending volumes and the areas of installation of the mixer in the technological scheme of the mine which is being mined. As the technological scheme of the mine is completed, there is a gradual decrease in unit volumes and lumpiness of the ore mass due to gradual mutual penetration of masses of different quality and their deeper blending [15].

After the completion of the main organisational averaging processes, a partial blending of components of different quality may be noted, with their subsequent combination into a common volume. Therewith, when blending ore mixture of different compositions and qualities, certain actions for averaging the composition of the mixture and its individual parameters are not excluded. In particular, the method for regulating the composition of the mixture and the volume of ore extraction at specific points and when applying the averaging mode, the total ore flow can be developed through the main ore pass, while there will be a considerable impact on the mixer. In addition, the downward transfer of ore directly from its purification unit conducted in the averaging mode, involves the sequential blending of ore masses that come from auxiliary production [16]. Notably, the averaging of ore masses by increasing the number of functioning faces takes place amidst a decrease in the overall volume of ore extracted by the total indicator of its quality.

Improving the overall efficiency of ore deposit development involves the use of automated ore quality management systems in quarries directly during open-pit mining. Therewith, to ensure the high quality of the extracted raw materials with overall growth in the volume of their extraction, it is necessary to use transport and extraction-and-loading equipment, since, without practical resolution of the issues of delivery of the extracted ore to the destination, it is impossible to

maintain the high quality of the extracted ore in general. For that purpose, it is imperative to build a transport logistics system that assumes the necessary conditions for the export of mined ore and its delivery to the end-user [17].

In Russia, Kazakhstan, and a number of other countries from the former USSR, ore is mined, generally, by an open, quarrying method. With an increase in the depth of ore pits, there is considerable growth in the volume of extracted ore mass, and, consequently, the costs of its delivery to the destination. Therewith, the steady increase in the costs of transporting the extracted ore mass causes an urgent need for qualitative optimisation of the functioning of quarry transport during open-pit mining and the transportation of raw materials from the place of their extraction to the places of processing [18]. A number of mining enterprises are gradually transitioning to the development of technologies for the non-explosive extraction of ore, which allows achieving high quality of the raw materials obtained while reducing the cost of their production. Such technologies are based on the practical use of bucket-wheel, compact excavators, earthmoving and milling machines, quarry-type combines. The use of such machines in quarrying to extract high-quality ore almost completely eliminates the possibility of obtaining large, unprocessed fractions, which allows completely excluding coarse crushing from the production process.

To date, Russia has a considerable amount of explored mineral reserves, among which ore reserves occupy a notable place. Notably, the total contribution of the mineral resource complex to the revenue item of the state budget is approximately half of the total volume, which provides revenue from the sale of mineral resources in the amount of approximately 65–70 % of the total foreign currency receipts to the state treasury [19]. Currently, the state of the Russian mineral resource complex is extremely important for maintaining stability in the Russian economy, it allows achieving appropriate conditions for ensuring high-quality technological development of the main branches of the processing industry in the future.

The open-pit mining is characteristic of modern Russia and a number of other states with the developed mining industry. In recent decades, the appearance of new types of mining machines and transport, lifting, and drilling equipment has led to forced optimisation of transport systems and a considerable increase in the depths of open-pit mining operations. All the above necessitates the optimisation of the functioning of quarry transport systems and the introduction of fundamentally new types of transport systems, in particular, skip and steeply inclined hoists and the technology of lifting mined ore masses with a conveyor.

Issues of automation of ore quality management in quarries often require the development and implementation of the latest methods for delivering extracted raw materials to the end-user, which is expected to considerably reduce the total delivery time [20]. This issue can be solved comprehensively by introducing the latest technological accounting systems for extracted raw materials, along with using quality management techniques for extracted ore, its transportation to processing sites and subsequent shipment to the consumer. Delivery time plays a key role in this context, determining the efficiency of the entire system and the area of the quality management of ore mined in open pits.

Conclusions. The conducted study on the prospects for the automation of ore quality management during its extraction in quarries in the activities of enterprises of the mining sector led to the following conclusions. The development and implementation of modern ore quality management systems in quarries involve a comprehensive analysis of the enterprise's activities, in the context of studying the main features of the organisation of ore mining, its extraction, shipping for subsequent processing, and receipt of finished products. In general, the quality control system adopted in the past at most mining enterprises does not meet modern requirements for ensuring the cyclicity and timeliness of technological operations performed. Automated quality management systems for the quar-

ried ore are designed to ensure timely receipt of reliable information about the quality of the extracted ore by fully automating the processing of data regarding its granulometric composition, chemical properties, and a number of auxiliary parameters that determine the quality of crude ore and prospects for its subsequent processing to obtain quality products.

The system of automated ore quality control in quarries in the structure of the mining industry enterprise allows conducting comprehensive management of ore extraction and its subsequent processing, ensuring reduction of technological losses and ore dilution. Moreover, the system increases the technological and economic performance indicators of the entire enterprise due to the reduction in the cost of a number of processes, which indicates the achievement of a positive economic effect from the introduction of the system under study. Thus, the development of automation systems for ore quality management in quarries and the subsequent introduction of such systems into the operation of mining enterprises contribute to the overall increase in their economic efficiency and the achievement of high-quality standards of the ore produced, which has a positive effect on the organisation of the entire ore mining process, including all its stages, from the discovery of mineral deposits to their development, including the extraction of ore, lifting it to the surface, and its shipment for further processing to obtain finished products.

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Автоматизация процесів управління якістю руди в кар'єрах

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Мета. Формування реальної оцінки перспектив запровадження автоматизованих систем видобутку руди й контролю за її якістю в діяльність сучасних гірничодобувних підприємств.

Методика. Основу методологічного підходу становить поєднання системного аналізу різних аспектів автоматизації управлінських процесів видобутку руди кар'єрним методом з аналітичним дослідженням реальних перспектив оптимізації процесів видобутку руди в кар'єрах з використанням сучасних методів автоматизації та цифровізації даних процесів.

Результати. Виконано системний аналіз різних аспектів автоматизації управлінських процесів видобутку руди кар'єрним способом. Визначені найперспективніші ділянки кар'єрної розробки з метою отримання рудної сировини найвищої якості. Представлена схема, що відображає системи способів управління якістю руди, яка видобувається кар'єрним методом на гірничодобувних підприємствах. Крім того, представлена та проаналізована схема системи автоматизації процесів управління якістю руди, що видобувається в кар'єрах.

Наукова новизна. Сформована реальна оцінка перспектив запровадження автоматизованих систем видобутку руди й контролю її якості в діяльність сучасних гірничодобувних підприємств.

Практична значимість. Результати дослідження можуть бути використані як база для підготовки фахівців у сфері гірничодобувної промисловості, до професійних обов'язків яких належить вирішення питань видобутку руди кар'єрним способом.

Ключові слова: видобуток корисних копалин, якість руди, рудні кар'єри, автоматизоване проєктування

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