Features of industrial use of magnetic pulse processing of sulfide copper-nickel ores*

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The article is devoted to the development of an effective technology for beneficiation of sulfide ores. The article refers to the issue of increasing the recovery rate of flotation concentrate when working with copper-nickel ores. The effectiveness of ore pre-treatment using magnetic pulse action has been proven based on the technological effect and mineral analysis of concentrate. The article addresses the peculiarities of adaptation of industrial magnetic pulse equipment (MPP) to the features of the technological process of beneficiation of sulfide copper-nickel ores. When adapting the equipment, technological effects obtained during laboratory testing, certain ranges of rational technological modes of the MPP, geometric characteristics of units of the beneficiation apparatus and the speed of ore flows were taken into account.

Key words: recovery rate, mineralogical studies, energy efficiency, magnetic pulse processing, beneficiating plant, equipment adaptation, flotation, sulfide ores, pulse current generator, inductor.

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Introduction

The quality of mining and processing of minerals is one of the main indicators of the level of development of the country's mining and metallurgical complex. This implies not only the use of advanced technologies for exploration, extraction and benefication of minerals. It is also mandatory to ensure environmental, social and economic aspects. This implies not only the use of advanced technologies for exploration, extraction and beneficiation of minerals. It is also mandatory to ensure environmental, social and economic aspects. These aspects include energy efficiency [1] and resource conservation [2]. Sustainable development of the mining industry is impossible without the introduction of digital technologies and automation. Ore beneficiation processes are, as a rule, both energy-intensive and environmentally problematic. And improving beneficiation technologies is a very important and urgent task [3, 4]. Including by studying the mineralogical composition of the ore [5]. Particular attention is paid to the process of ore preparation [6–8].

Under present-day conditions, the main trend in the development of the beneficiation process is its intensification by increasing the rate of extraction of useful components from ore [9, 10]. This is due to a decrease in the quality of original ores. This pattern also applies to sulfide copper-nickel ores, the extraction from which into commercial concentrate tends to reduction due to a decrease in the copper and nickel content in the original ore, as well as a decrease in the size of dissemination of minerals such as pentlandite and chalcopyrite [11].

The main method of beneficiation of sulfide copper-nickel ores is the flotation process, which is focused on the stage-by-stage extraction of copper-nickel minerals. At the same time, increasing the local extraction of useful components at this stage is an urgent technological and economic task. The main trends in improving flotation beneficiation technology are the use of innovative reagents and pneumatic separation, which helps to increase the recovery rate by reducing losses in sludge (over-ground material). The payback period for such innovations is several years.

Magnetic pulse processing is a fundamentally new technology that provides control of the technological properties of ores at the dislocation level [12]. Its use makes it possible to soften boundaries of the intergrowth of mineral grains in ore or control flotation activity due to a directed change in the surface charge [13]. The specific energy intensity of the MPP does not exceed 0.2 kW·hour/1m^3 of ore (or pulp). This provides a payback period of less than one year.

Materials and methods

Magnetic pulse processing (MPP) of ore materials can help solve a fairly wide range of problems [14], such as:

- MPP at the stage of ore preparation before grinding for selective destruction of the boundaries of intergrowth

*The article is published as a platform for discussion.

of useful minerals and non-metallic phase, in order to increase productivity, while maintaining the qualitative and quantitative indicators of the resulting concentrates;

- MPP at the stage of ore preparation before grinding for selective destruction of the boundaries of intergrowth of useful minerals and non-metallic phase, in order to increase the qualitative and quantitative indicators of the resulting concentrates while maintaining productivity;
- MPP of pulp feed to beneficiating apparatuses to increase the physical and chemical activity of sulfides, in order to improve flotation performance.

The basic physical principles that ensure ore preparation for further selective grinding are based on: generation at the boundaries of the phases of dislocations motion and their concentration, the occurrence of magnetic-strictive and piezostrictive effects in individual minerals [15]. This, in turn, contributes to the occurrence of microdefects at phase boundaries and selective disintegration along the boundaries of intergrowth ore and non-ore phases [16].

Magnetic pulse activation of a mineral surface during subsequent flotation involves changing the zeta potential, which is often the only available way to assess the surface electric charge (properties of the electric double layer).

The effect of changing the technological properties of ore during magnetic pulse processing is of a dislocation nature, associated with the interaction of the magnetic field with charged dislocations.

When additional dislocations are generated due to the use of MPP under different impact modes, two mutually exclusive processes occur simultaneously:

- Combination of dislocations into larger defects, which reduces the charge.
- Mutual obstacle to the movement of dislocations in their ensemble, which leads to strengthening (Cottrell effect) and an increase in the charge density on the surface.

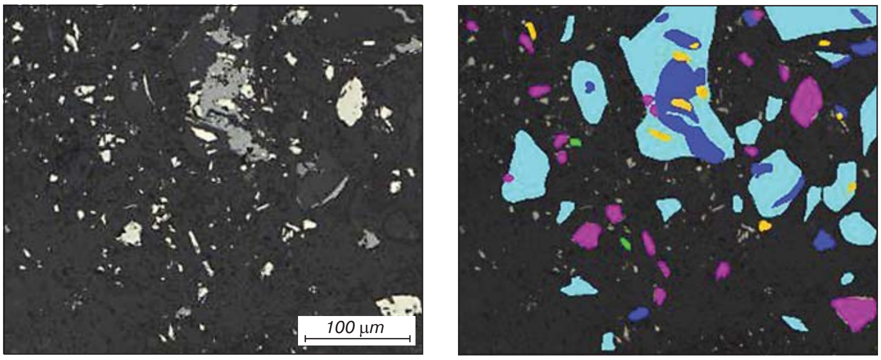

Fig. 1. Micrograph of flotation concentrate in reflected light (left) and the result of identification of mineral phases (right): purple color – pyrrhotite, orange – pentlandite, green – chalcopyrite, dark blue – "magnetite", blue – "quartz

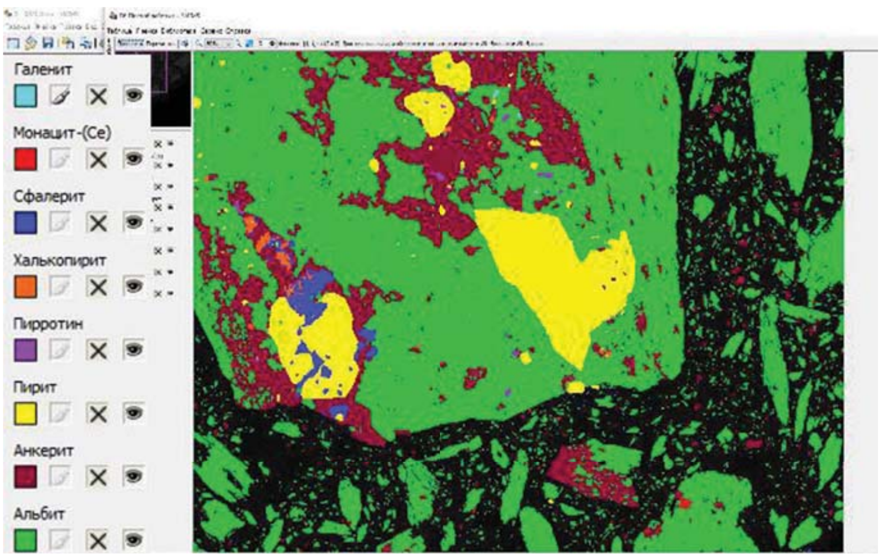

Fig. 2. An example of ore image identification by EBSD in the Mineral S7 program. above is a micrograph in reflected electrons, below are identified phases: галенит — galenite; монацит-(Ce) — monacite-(Ce); сфалерит — sphalerite; халькопирит — chalcopyrite; пирротин — pyrrhotite; пирит —pyrite; анкерит — anchorite; альбит — albite

Results and discussion

During laboratory tests of the MPP technology, the MPP mode (pulse power, pulse energy, impact duration) was selected, which provides control of the surface charge of mineral particles.

The result of laboratory tests of the MPP technology on KMMC`s ores in 2022 was a potential increase in nickel extraction in industrial conditions into concentrate of more than 0.9%, confirmed by KMMC`s specialists. This forecast was made using a number of reduction factors that take into account the peculiarities of the technological process of beneficiation at the KMMC [17].

In order to physically substantiate the obtained physical effect, additional studies were carried out on the mineralogical nature of the beneficiation products obtained without the use of MPP and using MPP on a stage of flotation feed.

Mineralogical studies were carried out to identify the following mineral phases: pyrrhotite, chalcopyrite, pentlandite, oxides of iron and titanium (magnetite, ilmenite, less commonly rutile), designated as "magnetite", nonmetallic minerals, designated as "quartz" **(Figs. 1, 2).**

As a result of statistical processing of the measurement results, many parameters were calculated, of which the most informative for the project were the following: the number of analyzed mineral grains, mass fraction of the mineral, percentage of fully released grains in mineral phases, the quality of intergrowths (in mass percent) in the following classes: 0–30%, 30–60%, 60–95% and more than 95% (fully released phases).

The effect of using MPP technology is shown in **Fig. 3** in the form of a diagram.

Analysis of comparative results on the content of various minerals in the concentrate obtained using MPP and without the use of MPP shows that the proportion of useful minerals such as pentlandite and chalcopyrite increases significantly when using MPP, which creates the basis for increasing the recovery rate and quality of the concentrate.

A feature of the industrial use of magnetic-pulse processing is the need to adapt its units to the industrial conditions of a particular production, such as pulp productivity on flotation feed, diameters of pulp pipelines, etc.

To adapt industrial equipment, it is necessary to ensure the previously established required parameters of the MPP modes [18, 19]:

1. Specific energy intensity of one discharge. The specific energy intensity of one discharge is defined as the ratio of the energy stored by the capacitor bank to the inductor`s volume. This means that if the volume of an industrial inductor is increased several times relative to the volume of a laboratory inductor, the stored energy on the current pulse capacitors (CPC) in the industrial installation must be increased by the same number of times (no less) than the stored energy of the laboratory CPC. In the industrial installation, the value of the specific energy intensity of one discharge can be controlled by changing the charging voltage of the capacitors. The indicated similarity between laboratory and industrial installations should be taken into account when adapting equipment and when developing recommendations for this MPP mode in industrial conditions.

2. Pulse duration. The pulse duration is determined by the product of the time period of the sinusoidal discharge and the number of waves of the sinusoidal discharge. The period of the sinusoidal discharge is determined by the selected circuit-technical and design characteristics of the equipment. The number of half-waves can be changed, making it possible to control the duration of the discharge.

3. Number of pulses. Creating the required number of pulses during laboratory tests is not difficult, since the sample being processed is stationary in the laboratory inductor. During the industrial use of MPP, the pulp flow moves at a certain speed. Therefore, providing the required number of pulses per portion of pulp requires synchronizing the pulse repetition rate with the ore flow rate, taking into account the working length of the inductor. This pattern should be taken into account when adapting equipment and when developing recommendations for this MPP mode in industrial conditions.

In industrial conditions, two units of single-circuit pulse current generators (PCG) of the TNM 1-2/1 and TNM 1-2/2 types were used **(Fig. 4)**, two units of inductor systems of the TNM I-1 type, placed in series on the flotation pulp pipeline **(Fig. 5)**, as well as connecting cables for inductor systems and PCGs.

A diagram of the MPP installation at the ore flow of the 3rd ore flotation feed section is shown in **Fig. 6.**

To ensure the required MPP mode in industrial conditions, it is necessary to fulfill the appropriate conditions for the similarity of parameters of industrial and laboratory equipment, namely:

- the ratio of the stored energy of the capacitor bank of an industrial installation to the stored energy of the

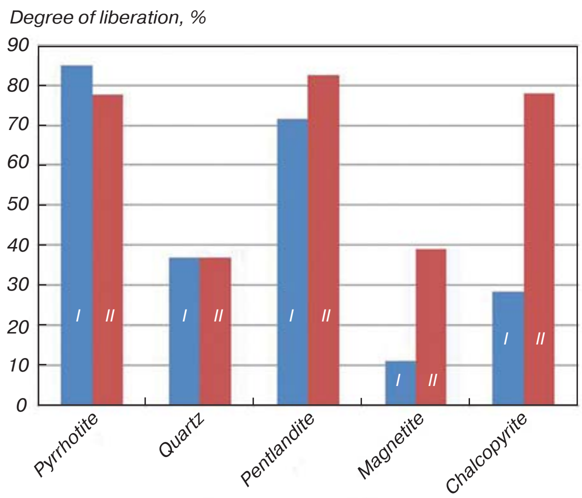

Fig. 3. Comparison of the concentrate in the baseline experiment and after the MPP application:
I – flotation concentrate basic test; *II* — flotation concentrate MPP before flotation

Fig. 4. Single-circuit pulse current generator (*photo by authors*)

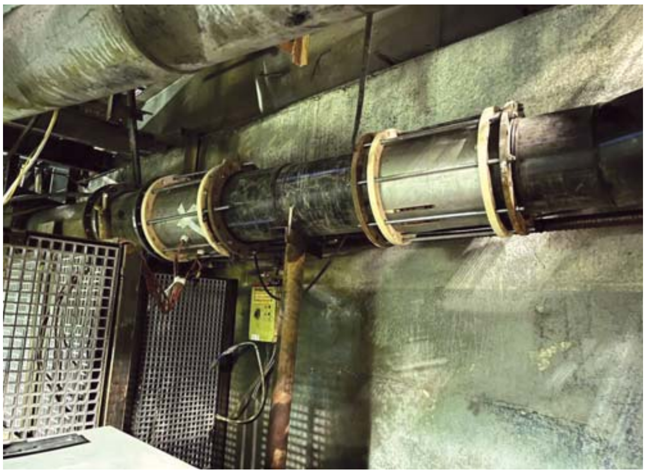

Fig. 5. Two units of inductor systems placed in series on the flotation pulp pipeline (*photo by authors*)

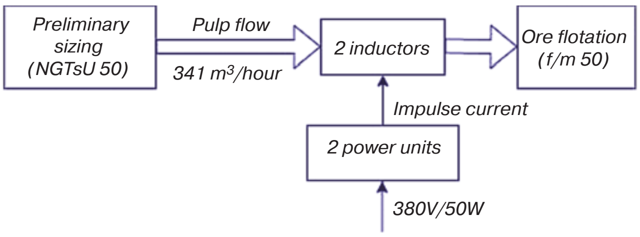

Fig. 6. Scheme of MPP installation at the ore flow of the 3rd ore flotation feed section

Fig. 7. MPP supervision installation (*photo by authors*)

capacitor bank of a laboratory installation should be equal to the ratio of volumes of inductors of the industrial and laboratory installations, respectively. This condition ensures that the specified field density amplitude is obtained;

- the ratio of the inductance of an industrial inductor to the inductance of a laboratory inductor should be inversely proportional to the ratio of the capacitances of capacitor banks of industrial and laboratory equipment. This condition ensures that the specified discharge frequency is obtained (the period of a daMPPd sinusoid);
- the required number of pulses N for each "portion" of ore must be equal to the product of the pulse repetition

Fig. 8. Typical oscillograms of a discharge with different pulse durations on GIT TNM 1-2

rate and the ratio $l_{cat.ind.}/V_{flow}$, where V_{flow} is the linear speed of the ore flow, determined from the productivity and cross-section of the inductor.

Based on the obtained flow rate, the pulse repetition rate is calculated.

The supervision installation was carried out in accordance with the design documentation, with the participation of specialists from TNM Ltd. and the KMMC`s processing plant **(Fig. 7)**.

The implementation of commissioning work involved a comprehensive testing of the equipment, including detailed adjustment of the MPP modes before its commissioning.

During commissioning, before the installation of inductor systems on the pulp pipeline, parameters of the pulse field in the inductor were measured using an induction sensor and oscilloscope. The purpose of these tests was to check the performance of the equipment in the possible range of MPP regulation, including the mode corresponding to the optimal combination of parameters, which was selected on the basis of previously conducted laboratory tests.

Typical oscillograms of a discharge with different pulse durations (number of half-waves) are shown in **Fig. 8.**

Conclusion

The following tasks were solved:

- a technological effect to increase the extraction of copper and nickel into flotation concentrate when using MPP was obtained;
- mineralogical studies of flotation concentrates obtained with and without the use of MPP were carried out in order to physically substantiate the obtained technological effect, while a significant increase in nickel- and copper-containing minerals in the flotation concentrate when using MPP was revealed;
- calculations were carried out for adaptation of MPP, demonstrating the possibility of industrial implementation of the MPP mode using the theory of similarity of energy and time characteristics.

Testing of MPP industrial equipment showed its performance under the selected optimal mode, corresponding to obtaining the required technological result, according to the results of laboratory tests.

The possibility of adjusting the operating parameters of MPP in the vicinity of the optimal mode has been confirmed.

References

1. Rzazade U., Deryabin S., Temkin I., Kondratev E., Ivannikov A. On the Issue of the Creation and Functioning of Energy Efficiency Management Systems for Technological Processes of Mining Enterprises. *Energies*. 2023. Vol. 16, Iss. 13. 4878.

2. Plotnikova A. V. Resource-Saving Technology of Processing Difficult Benefication Ores on the Basis of Magnetic-Impulse Impacts. *Izvestiya Vuzov. Chernaya Metallurgiya*. 2013. Iss. 9. pp. 69–70.

3. Sannikov D. O., Orlov I. V., Berveno A. V., Gavrilov A. I. A Review of Innovative Development Areas, Novel Materials and Rsearch Techniques in Metallurgical Industry. *Tsvetnye Metally*. 2023. No. 9. pp. 8–13.

4. Chumakov A., Prischepov V., Melekhina K., Ivannikov A. Improving the Control System of Concentration Plants Based on Express Control of Dissemination of Magnetic Minerals. 2021. *IOP Conf. Series: Earth and Environmental Science*. Vol. 684. 012005.

5. Ananyev P. P., Gridin O. M., Samerkhanova A. S. Interrelation of Properties and Electromechanical Sensitivity of Natural Minerals. *MIAB*. 2008. Iss. 5. pp. 184–189.

6. Melekhina K. A., Ananyev P. P., Plotnikova A. V., Timofeev A. S., Shestak S. A. Modeling and Optimization of Complex Ore Pretreatment by Disintegration in Autogenous Mills. *MIAB*. 2020. Iss. 5. pp. 95–105.

7. Osipova N. V. Selecting Parameters of Feed Control Algorithm for Wet Autogenous Mill for Grinding Iron Ore. *MIAB*. 2021. Iss. 10. pp. 146–156.

8. Ananiev P. P., Plotnikova A. V., Meshcheryakov R. V., Belyakov K. O., Adamyan E. V. A Method of Electromagnetic Pretreatment of Ore and a Unit for Implementing It. Patent RU, No. 2739274. Applied: 27.12.2019. Published: 22.12.2020.

9. Yushina T. I., Chanturia E. L., Dumov A. M., Myaskov A. V. Modern Trends of Technological Advancement in Iron Ore Processing. *Gornyi Zhurnal*. 2021. No. 11. pp. 75–83.

10. Osipova N. V. Investigation of the Possibility of Obtaining Concentrate Production Targets Based on a Mathematical Model of an Ferrum Ore Processing Site. *CIS Iron and Steel Review*. 2023. Vol. 25. pp. 4–9.

11. Ivannikov A., Chumakov A., Prischepov V., Melekhina K. Express Determination of the Grain Size of Nickel-Containing Minerals in Ore Material. *Materials Today: Proceedings*. 2021. Vol. 38, Pt. 4. pp. 2059–2062.

12. Goncharov S. A., Anan'ev P. P., Datsko S. A., Bel'chenko E. L., Tomaev V. K. Usage of Electromagnetic Processing of Mineral Raw Material for Development of Resource-Saving Technology of Its Comminution. *Gornyi Zhurnal*. 2002. Iss. 3. pp. 21–25.

13. Turin A. I., Kupryashkin A. M., Ananiev P. P., Ermakov S. V., Plotnikova A. V. Softening of Interfaces Ferruginous Quartzite Under the Influence of Magnetic-Pulse Processing. *Bulletin of Tambov University. Natural and technical sciences*. 2013. Vol. 18, Iss. 4. pp. 1699–1700.

14. Chanturiya E. L., Vishkova A. A., Ananiev P. P., Tomskaya E. S., Koporulina E. V. Enhancement of Ore Grinding Under Energy Deposition. *Gornyi Zhurnal*. 2014. No. 12. pp. 63–69.

15. Aleksandrova T., Nikolaeva N., Afanasova A., Romashev A., Kuznetsov V. Selective Disintegration Justification Based on the Mineralogical and Technological Features of the Polymetallic Ores. *Minerals*. 2021. Vol. 11, Iss. 8. 851.

16. Ananyev P. P., Goncharov S. A., Gridin O. M., Samerkhanova A. S. The Influence of Physical, Mechanical and Dielectric Properties of Rocks on the Effect of Their Softening During Magnetic Pulse Processing. *MIAB*. 2010. Iss. 10. pp. 41–46.

17. Magaev M. A., Shorikov A. P., Brazyulis L. A., Klemyatov A. A. Step-by-Step Research and Scaling of Technological Solutions for the Copper-Nickel Ores Benefication of the Pechenga Ore Field. *Tsvetnye Metally*. 2022. No. 11. pp. 10–16.

18. Adamyan E. V. Apparatus for Performing Magnetic-Pulse Treatment of Mineral Material. Patent RU. No. 2716423 C1. Applied: 29.12.2018, Published: 11.03.2020.

19. Ananyeva A. V. Technique for Selecting Control Decisions in Optimizing Technological Modes of Processing Iron Ore Raw Materials Using Electromagnetic Influences. *Proceedings of the Southwest State University*. 2023. Vol. 27, Iss. 4. pp. 117–131.

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