Improving the control system of concentration plants based on express control of dissemination of magnetic minerals

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Abstract. One of the most important issues of the process control system is the quality control of the ore charge by averaging it over the material composition, which will improve the quality and quantity of the processing plant due to the stabilization of the properties of the raw materials. However, there are no methods for express control of the size of grains of productive minerals, which affect the extraction rates. Obtaining operational information on dissemination will increase the control of the technological process of ore preparation due to the operational control of the grinding process. Obtaining operational disseminated information can be achieved by measuring the electrical and magnetic properties of the ore. This article is devoted to express control of dissemination of magnetic minerals based on a comprehensive measurement of the magnetic characteristics of the ore flow. As the research part of the study was conducted within a training period, some remarks concerning educational value of joined research program are expressed in final remarks.

1. Introduction – the scope of the research

Researches on solving urgent problems in the field of mineral processing are carried out in many research centers and universities. There are many fundamental studies on this subject [1, 2]. In Russia, including the Mining Institute of NUST “MISiS”, for a long time, work has been ongoing to improve the quality of the raw materials obtained [3-8].

Today, one of the most important problems in the field of mineral processing is the unstable behaviour of the technological properties of ore material entering the processing plant. The main technological properties that have a direct impact on the processing of mineral raw materials (crushing, grinding, etc.) are the mineral composition of the ores, the chemical composition of the ores, the texture and structural features of the ores, and the physical and mechanical properties of the ores. The physical and mechanical properties of ores do not undergo significant changes within a single deposit, which makes the methods for studying these properties quite universal. Acoustic emission methods for studying the physical and mechanical properties of ores can be used to study ferruginous quartzites [9, 10].

This problem is solved by controlling the quality of the ore charge, stabilizing the properties of raw materials. The main criterion is the material composition of the source ore material. At the same time, such a parameter as dissemination of a productive mineral is not taken into account. This leads to the fact that the grinding complex with pre-set operating parameters for certain technological properties of the mixture will work less efficiently, the degree of under-grinding and over-grinding of grains of...
bearing minerals will increase. The difficulty in taking into account the grain size of useful minerals is quite sharp changes in dissemination even within the limits of one ore body under development.

Ore averaging is necessary to ensure the stable operation of the processing plant (PF). Averaging is carried out by mixing (batching) mined ores having various technological properties. Averaging can be carried out at various stages of production:

• at the ore warehouse (averaging sites) by transporting individual ores according to an appropriate schedule. In this case, the technological properties of each ore component are determined by analyzing drill cuttings obtained during drilling of the corresponding block before the explosion;
• at the stage of crushing by controlling ore flows and adjusting the composition of the charge. In this case, the technological properties of the current charge are determined by analyzing it;
• at the stage of enrichment by controlling ore flows (conveyor conveyance of feed to the mills) and adjusting the composition of the charge on the feed of each head mill.

The problem of the lack of operational information on the dissemination of magnetite in iron ores can be solved by integrating express control of the dissemination of magnetic minerals in the process control system of the mineral processing plant based on a comprehensive measurement of the magnetic characteristics of the ore flow at the three stages of enrichment.

2. Physical fundamentals
Ferromagnetism, antiferromagnetism and ferrimagnetism are observed in magnetically ordered substances. Internal interactions of atoms (ions) cause the appearance of spontaneous orientation of atomic magnetic moments, which, in turn, lead to the appearance of spontaneous magnetization. Three types of magnets are distinguished depending on the orientation of the moments: ferro-, antiferro- and ferrimagnets. It is logical to consider ferro- and antiferromagnetism as special cases of ferrimagnetism.

It is known that in all closed (filled) electronic shells of chemical elements for each electron with a spin of a certain sign there is a paired electron of the opposite sign. The total moment of such a pair is zero. The first condition of ferrimagnetism is the presence of uncompensated spins. This condition is fulfilled in transition elements with open shells. If this condition would be unique, then two classes - para- and ferrimagnets would merge into one. So, in an unfilled 3 d-shell of an iron atom there are six electrons, five of which have a positive spin and one negative. A constant moment is created by four uncompensated spins.

Natural magnetic minerals are inherently ferrimagnets. The values of their magnetic parameters lie between the values of ferromagnets (native magnetic metals) and antiferromagnets (metal oxides). So, for example, αFe₂O₃ (hematite) is an antiferromagnet, has low values of magnetization and magnetic susceptibility. Magnetite (Fe₃O₄), the structure of which is determined by the structure by the formula FeO · Fe₋₂O₃, is a ferrimagnet. Figure 1 shows a typical magnetite hysteresis loop, which characterizes the change in the magnetic properties of the material in fields of different intensities.

![Figure 1. The parameters determined during the construction of the hysteresis loop.](image-url)
The coercive force of polymineral ferromagnetic materials significantly depends on their structure. The theory of E.I. Kondorsky, known as the theory of stresses, is qualitatively confirmed in ferromagnetic materials with a small number of inclusions, which are characterized by a low value of coercive force (soft magnetic materials). M. Kersten considered the question of determining the coercive force with a large number of inclusions (inclusion theory). From the main qualitative principles of this theory it follows that the coercive force increases with increasing concentration of impurities.

Systematic studies show that the properties of soft magnetic materials are extremely structurally sensitive. Changes in the crystalline structure of magnetic materials do not significantly affect the saturation magnetic induction, but significantly affect the initial and maximum magnetic permeability, coercive force. However, knowledge in the field of structurally sensitive properties, in general, is not particularly complete. This is due to the difficulties in obtaining reliable information about the true physical state of the material (because the physical dimensions of impurities or any other cause of structural sensitivity are very small, often on the order of a micron or less).

Figure 2 shows the dependences of the coercive force on the magnetization of the sample: values calculated according to the dependence revealed by E.I. Kondorsky and theoretical, taking into account a large percentage of the correlation (over 80%) of the coercive force with the expression.

![Figure 2](image)

**Figure 2.** Theoretical and experimental dependences of the reduced coercive force $H_c$ on the value of the saturation magnetization of the sample $J_s$.

The influence of the size of a magnetic particle on its magnetic properties can be illustrated by the example of coercive force. Coercive force as one of the main applied characteristics of magnetic materials is actually a complex indicator that depends on a large number of factors (magnetic, crystallographic and other types of anisotropy, defectiveness, etc.). The effect of particle size on this indicator is illustrated in Figure 3.

![Figure 3](image)

**Figure 3.** Qualitative dependence of the coercive force on the particle radius:
- $R_0$ - critical radius of a single domain;
- $R_0'$ - radius of the absolute single domain;
- $R_0^*$ - critical radius of superparamagnetism.

The influence of the size of a magnetic particle on its magnetic properties can be illustrated by the example of coercive force. Coercive force as one of the main applied characteristics of magnetic materials is actually a complex indicator that depends on a large number of factors (magnetic, crystallographic and other types of anisotropy, defectiveness, etc.). The effect of particle size on this indicator is illustrated in Figure 3.
In connection with the foregoing, we can conclude that it is possible to construct a regression dependence between the grain sizes of magnetite and the values of its magnetic properties, which are determined when constructing a magnetic hysteresis loop.

3. Materials, methods and results

To construct a graph of the magnetic hysteresis loop and determine the values of the magnetic properties, a laboratory hardware complex of the Ferrograph type was used. The test material was 120-gram samples of ferruginous quartzite from the Kursk Magnetic Anomaly (KMA) deposits: after crushing in a crushing and screening complex in the amount of twenty pieces; drill cuttings in the amount of twenty pieces. For measurements, the samples were divided into three samples of 40 g. Each sample was placed inside the hardware complex, in an external magnetic field with gradually increasing intensity. At the same time, the values of the magnetic field induction in the test sample were recorded. Based on these data, a magnetic hysteresis loop was plotted and its parameters were determined, such as: coercive force, saturation magnetization, remnant magnetization, saturation field strength.

Previously, during the optical-mineralogical analysis, the dissemination of magnetite in the samples of ferruginous quartzite was determined. By means of a regression analysis, a relationship was established linking the parameters of the magnetic properties with the size of the inclusions of the magnetic mineral, type. The type of regression dependence, the selected variables and the calculated coefficients are a trade secret, their reduction in this article is impossible.

The results obtained during the experiment were processed, for clarity, graphs of the actual fluctuations were constructed, determined by optical-mineralogical analysis, and calculated from the obtained model of magnetite particle sizes relative to the average value (Figures 4 and 5). The x-axis represents the sample number. The y-axis is the particle size in the sample minus the average value of particle size (for all samples). The mean absolute and relative errors of determining the impregnation were also determined, which amounted to: 1.39 μm and 4.53% for the material after the crusher, respectively; for drill cuttings, 0.92 microns and 3.03%, respectively.

![Figure 4](comparison.png)

**Figure 4.** Comparison of actual and estimated values of impregnation sizes for material after crusher.

![Figure 5](comparison.png)

**Figure 5.** Comparison of actual and estimated impregnation sizes for drill cuttings.
4. Discussion and conclusions
An analysis of the magnetic properties of ferruginous quartzites of the Kursk magnetic anomaly shows the presence of prerequisites for the integration of express methods for controlling dissemination of magnetite in process control systems of concentration plants. The relationship between the coercive force of the ore material and the size of the magnetite particles that make up the ore is experimentally established. This creates the basis for determining the size of magnetite grains in the incoming ore.

Moreover, a feature is the fact that it is possible to install this complex in an ore stream with a continuous supply of material for analysis. It is worth noting that for the ore material that was studied in this work, the relative error in determining the impregnation of magnetite was 4.53% for ore after crushing and 3.03% for drill cuttings. This control method will improve the efficiency of the ore preparation process control by obtaining operational information on dissemination. Thus, the described complex can be considered a qualitative express method for controlling the dissemination of magnetite in ferruginous quartzites.

5. Final remarks
This study was conducted as part of the fifth-year student internship. The Mining Institute of NUST “MISIS” pays great attention to the practical training of civil and mining engineers [11] and to transfer of their findings to the final client in mining industry [12]. In the future, work is planned to continue as part of graduate studies. The wider, multidisciplinary context of practical training was emphasised by various authors worldwide [13-15]. The importance of Research and Development projects in the field of geotechnology may be measured by means of number of conferences held within that area of Civil Engineering and Earth Sciences [16, 17].

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