DESIGN OF RECIPROCAL VIBRATING HGMS AND ITS MAGNET SYSTEM①

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ABSTRACT

The present paper gives the design of a new HGMS for magnetic separation of sulphides. The main characteristics of this HGMS are using iron-cladding saddle shaped magnetic coil for instead of the ordinary magnet, and combining reciprocal-linear motion with vibration to actuate the separation box, and the magnetic field intensity is high up to 2T as well. For improving the magnet system design, a modified finite element method is used to calculate the distribution of magnetic field intensity of separation space of the magnetic coil, and according to the calculation results the magnetic leakage coefficient can be determined easily, thus making designers apart from the empirical way.

Key words: HGMS, Reciprocal motion and vibration, Finte element method, Saddle shaped coil.

Magnetic separation of sulphides is a new separation technology found in the 1970's. However this technology is still at the stage of laboratory experiment due to the lack of a suitable pilot separator. Because of that, this paper studies the design of a new pilot HGMS called CQD–1 separator. Major types of HGMS developed so far are cyclic solenoid horizontal ring, vertical ring and pulsating HGMS, although, no one is fit for the magnetic separation of sulphides.

Principally sulphide bulk concentrates which can be treated by magnetic separation contain much more magnetic minerals. Therefore the optimal magnetic separator designed would be the continuous HGMS, and its separation box should be moved in a separate space of the saddle shaped magnet with both reciprocally linear and vibration motion for achieving very high background magnetic intensity and increasing separation response. Such type of HGMS possesses the characteristics of both horizontal ring magnetic separator using saddle shaped magnet and pulsating magnetic separator with high separation response, and is different from the ring magnetic separator with lower separation response and pulsating magnetic separator at lower background magnetic intensity. Morever, in comparision with horizontal ring magnetic separator, the optimal magnetic separator is much simpler in structure and lighter in weight. It also occupies a smaller space and its trasmission power is lower.

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1 THE STRUCTURE AND SEPARATION PRINCIPLE OF THE SEPARATOR

The structure of CQD–1 HGMS is shown in Fig. 1.

During separating the separation box with matrices repeatly recieves feed through the hopper and the upside holes of the magnet steel at a static state, then it moves forword quickly and reset automatically under the combine action of the reciprocal-linear motion mechanism and the horizontal vibration. As a result the non-magnetic particles cross the separation box and pass through the downward holes in the magnet steel into tailing tank. The magnetic particles captured by matrices move with separation box to washing place where entrapped non-magnetic particles are washed off and then move to magnetic washing place outside the magnetic field where they are washed into concentrate tank.

2 MAGNET DESIGN

From Fig. 1 and the separation principle, it can be seen that the key of the separator and the design is the magnet assembly, especially the saddle shaped coil. So far the magnet design of HGMS has been limited in the scope of conventional magnetic circuit design. Says, during the design of an iron-cladding saddle shaped magnetic coil the following formula is often used for calculating magnetic potential, i. e. the number of Ampere-turn:

$$IN = \sigma H \delta / 0 \cdot 4\pi$$

where H is magnetic intensity required; δ is the height of separation space and σ is the magne- tic leakage coefficient .

From theoretical analysis, it can be understood that σ is not only relative to magnetic leakage but also to magnetic potential consumed in iron-clad. So it is very difficult to determine the magnetic leakage coefficient σ. At present, designers choose σ only by their

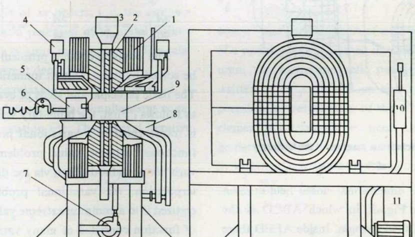

Fig.1 The structure of CQD–1 separator

1–Saddle shaped coil; 2–Magnet steel; 3–Feed hopper; 4–Washing control valve; 5–Vibrator; 6–Transmision device; 7–Pump; 8–Receiving tank; 9–Separation box.

experience. If σ is smaller, the magnetic intensity would not meet the requirement. If σ is greater, the manufacture cost and operating energy consumption would be increased.

On the basis of field theory, the finite element method is used to calculate the distribution of magnetic intensity of the air gap of iron-cladding saddle shaped coil in advance, and satisfactory results are obtained.

Under the condition of the accuracy requirement of engineering design we may only study the middle cross section of the separation space without considering the edge effect and simplify the field domain to a two dimensional flat one. Because of the symmetric distribution of the magnetic field, we can calculate only half of the cross section.

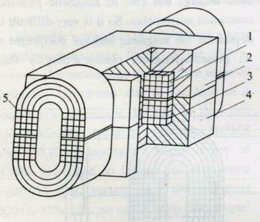

Fig.2 Schematic diagram of the boundary of field domain

The two dimensional closed field domain is shown in Fig. 2, in which ABCD is the boundary of field domain. Inside AFED there is the magnetic coil. BC is the mid-line of the cross section. AB, CD and DA are interfaces between the air gap or the coil and the iron-clade. From the field theory, it is known that all points in the field domain meet the Possion equation, $\nabla^2 A = \rho$, where A is a vector magnetic potential and ρ the electric current density. As mentioned above, boundary BC is a symmetry mid-line. So it must be a part of the magnetic induction strength lines, i. e. B lines. From electro-magnetism it is known that an equi-vector magnetic potential line is a magnetic induction strength line, so there is a constant value A on the boundary BC. Since magnetic potential has only relative significance, we suppose $A|_{BC} = 0$. Boundary AB and CD and DA as well can be regarded as the interface between air and ferromagnetic meterial, iron-clade, so there is

$$\frac{\partial A}{\partial n}\Big|_{AB} = \frac{\partial A}{\partial n}\Big|_{CD} = \frac{\partial A}{\partial n}\Big|_{DA} = 0,$$

where n is the coordinate perpendicular to the interface.

Based on mentioned situation, we can give the boundary value problem:

$$\left.\begin{array}{l} \nabla^2 A = \rho \\ A|_{BC} = 0 \\ \frac{\partial A}{\partial n}\Big|_{AB} = \frac{\partial A}{\partial n}\Big|_{CD} = \frac{\partial A}{\partial n}\Big|_{DA} = 0 \end{array}\right\} \qquad (2)$$

The boundary value problem above can be solved by finite element numerical method. The basic principle and steps of evaluation are as follows: First, the boundary value problem is transformed to a variational problem, i. e. functional extreme value problem from the variational method; Then via the dissection interpolation, the variational problem is discretized into a common extreme value problem of function consisted of many variabless. The dissection interpolation is performed as follows: The field domain is dissected into a number of triangular elements. In every triangular element, the values of the unknown function on nodal points are used as interpolation of the unknown function. This interpolation function is substituted for the unknown function. Thus, the functional function is converted into a common function dependent on the unkown values of the nodal points. Via the dissection interpolation, the extreme problem of the functional function is discretized into a common extreme value problem of function consisted of many variables. The later, after derivation generally becomes a linear simultaneous equations. Adopting suitable algebraic method and solving the equations with electronic computer, the numerical solutions of the unknown function on any nodal points can be obtained.

According to above principle and steps, the following linear equations are obtained in the light of series derivations for the boundary problem.

$$[K][A]=[P] \quad (3)$$

where $[K]$ is a square matrix of m orders, m the total numbers of the nodal points, $[A]$ a column matrix of m orders, i. e. the unkown vector magnetic potential of m nodal points; and $[P]$ also a column matrix of m orders relative to the current density.

The overrelaxation iterative method is used to calculate the linear simultaneous equations, i. e. equation (3). The general iterative formula is

$$A_i^{(m+1)}=(1-\alpha)A_i^{(m)}+\alpha\,[(-\sum_{j=1}^{i-1}k_{ij}A_j^{(m+1)}-\sum_{j=i+1}^{M}k_{ij}A_j^{(m)})/k_{ij}] \quad (4)$$

where α is the factor of accelerating convergence.

If the dissection of field domain is very small and dense and the numbers of nodal points are too much, the equation (4) is not suitable for the calculation with medium or mini-computer due to the limit of internal storage capacity of the computer, even if the method of equi-band and variable band are used.

With the analysis and derivation to the general coefficient matrix $[k]$ and the non-zero elements in the matrix, the following iterative formulas can be obtained:

$$A_{i,j}^{(m+1)}=(1-\alpha)A_{i,j}^{(m)}+\alpha\,[(k_1A_{i-1}^{(m+1)}+k_2A_{i,j-1}^{(m+1)}+k_3A_{i+1,j}^{(m)}+k_4A_{i,j+1}^{(m)}/k_0 \quad (5)$$

$$k_0=\sum_{n=1}^{6}\frac{1}{4\mu_n\triangle_n}(b^2_{ij}+c^2_{ij}) \quad (6)$$

$$k_1=\sum_{n=1}^{2}\frac{1}{4\mu_n\triangle_n}(b_{ij}b_{i-1,j}+c_{ij}c_{i-1,j}) \quad (7)$$

$$k_2=\sum_{n=1}^{2}\frac{1}{4\mu\triangle}(b_{ij}b_{ij-1}+c_{ij}c_{ij-1}) \quad (8)$$

$$k_3=\sum_{n=1}^{2}\frac{1}{4\mu_n\triangle_n}(b_{ij}b_{i+1,j}+c_{ij}c_{i+1,j}) \quad (9)$$

$$k_4=\sum_{n=1}^{2}\frac{1}{4\mu_n\triangle_n}(b_{ij}b_{ij+1}+c_{ij}c_{ij+1}) \quad (10)$$

where i and j are numbers of each nodal point. If a nodal point is located on i line and j column, the vector magnetic potential on it is written as $A_{i,j}$; Δn and μn are the area and permeability respectively of the nth triangular element in n triangular elements associated together; and if the numbers of the nodal points in a triangular element are i and j and m, then

$$b_i=y_j-y_m \qquad b_j=y_m-y_i$$
$$b_m=y_i-y_j \qquad c_i=x_m-x_j$$
$$c_j=x_i-x_m \qquad c_m=x_j-x_i$$

where x and y are coordinate values of the nodal point.

Calculating non-zero elements with equstion (6)–(10) and the linear simultaneous equations with equation(5), the internal storage capacity of computer are sharply reduced and the calculation process of forming the general coefficient matrix is simplified because there is no zero element entering the calculation process. Thus it may calculate linear simultaneous equations of high orders in finite element method with mini-computer.

If the vector magnetic potentials obtained, the magnetic induction strength B of all nodal points in the middle cross section of the saddle shaped coil can be obtained also with computer according to the relationship between magnetic induction strength and vector magnetic potential, i. e.

$$B_x = \frac{\partial A}{\partial y} \qquad B_y = -\frac{\partial A}{\partial x}$$

$$B = \sqrt[2]{B_x^2 + B_y^2}$$

Based on the above studies a so-called predicating calculation finite element method is used to design the iron-cladding saddle shaped coil magnet of the CQD−1 separator as follows:

1 Predicating the magnetic leakage coefficient σ

According to practical experience the value of σ can be predicated between 1. 0 and 1. 5. In fact any value in this range is feasible.

2 Calculating preliminarily the magnetic potential according to formula (1).

3 Determinating the specification of wires

According to that the height of the magnet must be greater or equal to the height of the working gap,the axial wire turns N_z and the total wire turns N can be determined and then the radial wire turns is $N_r = N / N_z$. Above all gaps must be left between two wire turns for isolation and winding. Thus, the filling ratio of the coil can be calculated.

4 Calculating the excitation current I using $I = IN / N$, and the current density j according to $j = I / S_c$,where S_c is the effective cross section of the wire.

5 Calculating the distribution of magnetic field of the coil working gap and the magnetic intensity of middle point H_o according to the current density and the dimension of the coil.

6 Calculating the actual magnetic leakage coefficient of the magnet using $\sigma = 0.4\pi IN / H_0\delta$

7 Amending the parameters designed and redesigning if necessary

Firstly substituting the actual magnetic leakage coefficient σ into formula (1) to calculate the potential needed actually. If it is equal or approach to the magnetic potential calculated before, the remained conventional design of the magnet can be conducted directly. However, the magnetic potential calculated is often not equal to the actual one and there is a great different between the two. In this case the current density determined formerly would be corrected according to the formula:

$$j = \frac{IN}{NS_c} \qquad (11)$$

where IN is the ampere turn required in fact and N the total wire turns of the coil.

If the current density corrected is also suitable the remained conventional design of the magnet can be conducted continuously with the corrected current density; Otherwise redesign is needed. If the current density is too large either the turns of coil or the dimension of wire should be increased, and then the dimension of the coil is determined and the magnet is redesigned with the predicating calculating method; On the contrary if the current density is too small, the turns of coil or the dimension of wire should be reduced.

8 Determing the geometrical and electrical parameters as follows:

(1) Magnetic potential

$$IN = \frac{\sigma H \delta}{0.4\pi} = \frac{1.15 \times 2{,}000 \times 20}{1.25}$$

$$= 3.68 \times 10^5 \text{ Ampe-return}$$

(2) Effective cross section area of the wire

Since hollow square copper pipe of a cross section of 10 × 10 × 2mm is used as wire, Its effective cross section area

$$S_c = 10^2 - 6^2 = 64 \text{ mm}^2$$

(3) Turns of the coil

The axial length of saddle shaped coil is equal to the total length of the wires side length plus the thickness of isolation coat and winding gaps. The axial turn of coil should make the axial length of the coil equal to the height of separation space and the thickness of the magnetic poles. It is known that the height of separation space is 20 cm, the thickness of the magnetic poles is 13. 6 cm, the thickness of isolation coat and the winding gap is 0. 2 cm and the side length of wire is 1 cm. So, the axial turn of the coil N_z should be 28. The total turn of the coil N is 784. Thus the radial turn of the coil $N_r = N / N_z = 28$.

(4) Excitation current I and current density j

$$I = IN / N = 3.68 \times 10^5 / 784 = 469 \text{ A}$$

$$j = I / S_c = 6.34 \text{ A} / \text{mm}^2$$

(5) Total length of the wire

According to the total turn and geometrical shape and the fashion of winding, the total length of wire L is 1,706 m.

(6) Total resistance of the wire

$$R = \rho \frac{L}{S_c} = 0.020{,}005 \frac{1{,}706}{74} = 0.461 \ \Omega$$

where ρ—resistivity of wire , $\Omega \cdot \text{mm}^2 / \text{m}$

(7) Excitation power W and voltage V

$$W = I^2 R = 469^2 \times 0.461 = 101.4 \text{ kW}$$

$$V = \frac{W}{I} = \frac{101.4 \times 10^3}{469} = 216 \text{ V}$$

The stereogram of the iron-cladding saddle shaped coil magnet designed follow the steps mentioned above is shown in Fig. 3. The design and calculation of the steel and the cooling device of the coil and the checking of working tempreture of the wire are conducted with common method.

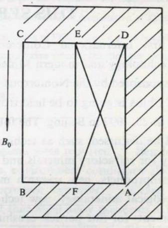

Fig. 3 Stereogram of the magnet

1—Upside saddle shaped coil; 2—Upside magnetic steel; 3—Downward saddle shaped coil; 4—Downward magnetic steel.

3 CONCLUSION

(1) The main characteristics of the reciprocal vibrating HGMS designed are that, its magnet is an iron-cladding saddle shaped magnetic coil, its separation box is activated by a reciprocal-linear mechanism and horizontal vibrator simutaneously. Its magnetic field intensity and operation response are high. Its structure is simple and does not occupy much space. Its transmission power is lower.

(2) The predicting calculation finite element method adopted to design the iron-cladding saddle shaped coil magnet is feasible, simple and exact and reliable, it is helpful to the designers for depart from dependence only on experience.

(3) The new iterative formula and a calculation formula to determine the elements of the coefficient matrix proposed can be used to reduce the internal storage capacity required by computer and simplifies the calculation process.

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THE FIRST INTERNATIONAL CONFERENCE ON MINERAL TECHNOLOGY AND ENGINEERING IS GOING TO BE HELD THIS SEPTEMBER IN BEIJING

The first International Conference on Mineral Technology and modern Mineral Engineering sponsored by the Nonferrous Metals Society of China is going to be held from September 20 to 25, 1992 in Beijing. The following topics will be discussed, such as technological mineralogy for refractory minerals and metallurgical semiproducts, new research methods for technological mineralogy, new technology and equipments for fine particle crushing and grinding, new method of physical mineral processing, theory and practice of flotation, simulation and processes control, solid-liquid seperation technique and technological economy as well. It is a good opportunity for us to make international academic exchange, to learn advanced foreign technique and to exhibit our new results in technological mineralogy and mineral engineering in China. This conference will make far and deep influences in technological level for technological mineralogy and mineral engineering and in promoting the four modernizations in China.

The organization of this conference is composed of organzing committe, academic committee and working committee. The organizing committee sent the first circular call for to the attendants at home and abroad in August and September in 1991 and at the same time the first expanding conference was held in Beijing at which vice manager of the Nonferrous Metals society of China, He Boquan, presented and made an important speech. Through the first appreciation the received papers were finally approved in November, 1991 by the academic committee of this conference as well as the academic committee for mineral processing of the Nonferrous Metals society of China. 72 representatives abroad coming from 21 regions and countries and more representatives coming from China have registered. This conference is sponsored and supported by the following units: Mining Association of China, the Nonferrous Metals Society of China, Gold Society of China, Division of science and technology Information for Mineral Processing of China, the Nonmetal Mineral Society of China.

(Written by Qiu, Guan zhou. Translated by Baifan)