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Magnetic field characteristics analysis of a single assembled magnetic medium using ANSYS software

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ABSTRACT

The section shape of an assembled magnetic medium is the most important structural parameter of a high gradient magnetic separator, which directly affects the induction distribution and magnetic field gradient of the magnetic separator. In this study, equilateral triangle, square, hexagonal, octagon, dodecagon, and round shape sections of the assembled magnetic medium are chosen to study their influence on magnetic field distribution characteristics using the ANSYS analysis. This paper utilizes a single assembled magnetic medium to understand the relationship between the geometry of the assembled magnetic medium and its magnetic field distribution characteristics. The results show that high magnetic field, regional field, magnetic field gradient, and magnetic force formed by the different sections of the assembled magnetic medium in the same background magnetic field reduce in turn based on the triangle, square, hexagonal, octagon, dodecagon, and round. Based on the magnetic field characteristics analytic results, the magnetic separation tests of the ilmenite are carried out. The results indicate that the section shape of the toothed plate compared with the section shape of cylinder can improve the recovery of ilmenite up to 45% in the same magnetizing current condition of 2 A, which is consistent with magnetic field characteristics analysis of different assembled magnetic medium section shapes.

1. Introduction

The high gradient magnetic separation (HGMS) technology uses an assembled magnetic medium, which can produce a high magnetic field gradient in obtaining a high magnetic force to realize a collection of the fine grain of a weak magnetic material [1,2]. The technology is one of the primary methods of processing the fine grain of weak magnetic materials and has a number of advantages [3–9]. The magnetic medium is an important factor that influences the magnetic field gradient. Therefore, studying the magnetic properties of a magnetic medium in improving the performance of a high gradient magnetic separator is highly significant.

The assembled magnetic medium is the most important structural parameter of the high gradient magnetic separator. The magnetic trapping force, separation efficiency, production capacity, and other factors are relevant to the assembled magnetic medium. The materials, shape, size, and arrangement of the assembled magnetic medium play decisive influences in obtaining optimal recovery and concentrate grade [10,11]. Therefore, numerous scholars have conducted in-depth researches on the magnetic field distribution characteristics of various magnetic mediums [12]. Li studied the magnetic field characteristics of a rectangle magnetic medium using finite difference method and found that the magnetic field characteristics depend on the geometry size of the cross section when the cross section is a rectangular surface and the steel wool is not saturated magnetization [13]. Others studied the magnetic field characteristics of steel wool and the steel plate medium with different cross sections using the special function, conformal mapping, and finite element methods and obtained significant results [14–16].

Two experimental methods can be used to research the magnetic field of the assembled magnetic medium: measured method and simulation method. The magnetic simulation method can directly simulate the magnetic field distribution of the real equipment and can study the influence of magnetic medium characteristics, including the material, shape, and arrangement structure, on the magnetic field distribution. The simulation method can answer the deficiency of the measured method and is a good way to study the magnetic field distribution of a small or tiny space [2]. After nearly 40 years of development, the computer can be used as a

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numerical method to solve the problem of the electromagnetic field [17–21]. In the early 1970s, the Finite Element Method (FEM) was referenced in the design of the electromagnetic field by Silvester and Chari [22]. The FEM has been rapidly developed and widely applied in electrical engineering.

In this paper, the electromagnetic field problem is converted to an initial and boundary value problem of the partial differential equation in the field of mathematics using Maxwell's equations. The finite element method is used to establish a finite element model of the assembled magnetic medium. The ANSYS software is used to analyze the magnetic field characteristics of a single assembled magnetic medium. Further research on the magnetic field characteristics of the assembled magnetic medium is conducted based on the earlier research using the magnetic simulation method to improve the overall efficiency of the HGMS equipment.

2. Methodology

2.1. Variational formulation of electromagnetic field

The boundary value problem of the Poisson equation can be described in Eq. (1). The corresponding relations of the amount are shown in Table 1.

$$\begin{cases} \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = -f \ldots (x, y) \in \Omega \\ \Gamma_1 : u = 0 \end{cases} \tag{1}$$

As shown in Table 1, Φ_m is the scalar magnetic potential; Φ_{m0} is the known value of scalar magnetic potential on the border; μ is the magnetic permeability of material; B_n is the known value of the medial component of magnetic flux density inside the border; A_z is the vector magnetic potential of the Z direction; A_{z0} is the known value of vector magnetic potential on the border; Jz is the current density; r is the magnetic reluctivity; and H_i is the known value of the tangential component of magnetic field intensity inside the border.

The function $J(u)$ can be defined as follows:

$$\begin{aligned} J(u) &= \frac{1}{2}(-\Delta u, u) - (f, u) \\ &= \frac{1}{2}\int\int_\Omega (-\Delta u) \cdot u dxdy - \int\int_\Omega f \cdot u dxdy \end{aligned} \tag{2}$$

where Δ is the Laplace operator, $\frac{\partial u}{\partial x^2}^2 + \frac{\partial u}{\partial y^2}^2$.

Eq. (3) can be obtained using Green's theorem as follows:

$$\int\int_\Omega (-\Delta u).u dxdy = \int\int_\Omega \left(\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}\right)^2 \right) dxdy - \int_\Gamma \frac{\partial u}{\partial n} u d\Gamma \tag{3}$$

where n is the outer normal direction of the curved boundary.

If u meets the boundary value condition: $\Gamma_2 : \frac{\partial \phi}{\partial n} = -\frac{B_n}{\mu}$ (B_n is the normal vector of the magnetic flux density and is a known value), Eq. (4) can be obtained as follows:

$$\int\int_\Omega (-\Delta u).u dxdy = \int\int_\Omega \left(\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}\right)^2 \right) dxdy \tag{4}$$

Table 1
Corresponding relations between boundary value of Poisson equation and physical quantity.

Method	u	u_0	f	β	q
Solution by Φ_m	Φ_m	Φ_{m0}	0	μ	$-B_n$
Solution by A_z	A_z	A_{z0}	Jz	r	$-H_i$

The bilinear form can be defined in Eq. (5).

$$a(u, u) = \int\int_\Omega \left(\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}\right)^2 \right) dxdy \tag{5}$$

Given Eqs. (3)–(5), the function $J(u)$ can be written as Eq. (6):

$$J(u) = \frac{1}{2} a(u, u) - (f, u) \tag{6}$$

where $u \in H^1(\Omega)$ and $f \in L^2(\Omega)$. $J(u)$ is meaningful. $H_0^1(\Omega)$ shows the subspace of $H^1(\Omega)$ to meet Eq. (1). The solution of the boundary value is simplified to solve the conditional variation. Substitution of $u_+ \in H_1(\Omega)$ yields the Eq. (7):

$$J(u_+) = \min J(u)_{u_+ \in H_1(\Omega)} \tag{7}$$

2.2. Division of region Ω

The Ω of the curved edge area is generally divided into the sum of a finite number of triangular or quadrilateral. The different triangular or quadrilateral is made without an overlap inside. Any vertex of a triangular or a quadrilateral does not belong to the other internal triangular or quadrilateral. Therefore, the Ω is divided into a triangular or quadrilateral mesh, known as the triangle subdivision or the quadrangle. Each triangular or quadrilateral is called unit with a peak referred to as a node. Two vertices are called adjacent nodes that belong to the same unit. The two triangular and quadrilateral that have a public side are called adjacent units. All elements and nodes are numbered based on a certain order after the regional subdivision.

2.3. Structure of base function

A typical trilateral unit is taken as an example (see Fig. 1). An fully polynomial is structured in the trilateral unit $\Delta(1, 2, 3)$, as shown in Eq. (8):

$$p_n = \sum_{i+j=0}^{n} cjx^i y^i \tag{8}$$

Interpolation and approximation are used to reach $u(x, y)$. This polynomial contains the undetermined coefficients of $(n+1)$ and $(n+2)$. Therefore, the same number of the interpolation node should be taken in the $\Delta(1, 2, 3)$.

When $n = 1$, $p_1(x, y)$ is a first-order polynomial. The number of the interpolation node is 3. Three peaks of $\Delta(1, 2, 3)$ are chosen for the interpolation nodes. Eq. (9) is obtained using the method of undetermined coefficients.

$$p_n = L_1 u_1 + L_2 u_2 + L_3 u_3 \tag{9}$$

where (L_1, L_2, L_3) is the area coordinate of (x, y).

When $n = 2$, $p_2(x, y)$ is a quadratic polynomial, and the number of the interpolation node is 8. Four peaks of (1, 2, 3, 4) and the quadrilateral midpoints are chosen for the interpolation nodes.

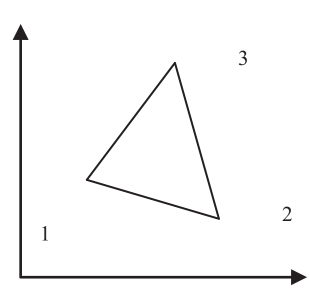

Fig. 1. Triangle cell.