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Analysis of material separation process performed in wet drum magnetic separators

Abstract. *Magnetic separators are widely used in both research and industry. The progress that has been made in magnetic separation technique resulted in some novel application as biotechnology and nanotechnology. The results of magnetic field modeling inside drum magnetic separators have been shown. The magnetic field source is the permanent magnet assembly. The performed simulation is the first step in designing more effective separating devices.*

Streszczenie. *Separatory magnetyczne znajdują powszechne zastosowanie zarówno w nauce jak i w przemyśle. Wieloletnie badania naukowe, a w szczególności postęp jaki dokonał się w ciągu ostatnich kilkunastu lat zaowocowały wykorzystaniem separacji magnetycznej w takich nowoczesnych dziedzinach jak biotechnologia czy nanotechnologia. W pracy zostały zaprezentowane wyniki symulacji numerycznych rozkładu pola magnetycznego w separatorze typu bębnowego. (**Analiza procesu separacji materiałów paramagnetycznych w magnetycznych separatorach bębnowych**).*

Key words: magnetic separator, drum separator, magnetic field distribution.
Słowa kluczowe: separator magnetyczny, separator bębnowy, rozkład pola magnetycznego.

Introduction

During the past fifty years many improvements have been made in order to develop innovative magnetic separation technology [1, 2, 3, 4]. The progress has resulted from advances in materials and understanding of the nature of magnetic forces. The performed research paved the way for applications of magnetic separation ranging from processing industrial minerals to biotechnology [5]. The Department of Measurement and Diagnostic Systems inquiries the possibilities of development of new methods of simulation and designing magnetic separators with neodymium magnets and superconducting electromagnets.

Theory

The physical principle at the basis of magnetic separation is the existence of magnetic force acting on particles with different susceptibilities. The externally applied field can select particles out of physically similar mixture particles based on their magnetic characteristics. The nonhomogeneous external magnetic field creates magnetic force that is expressed by [6]:

$$(1)\quad \vec{F} = \chi_m \mu_0 V(\vec{H}\cdot\nabla)\vec{H}_0 = \chi_m \mu_0 V \frac{3}{2+\mu} H_0 \nabla H_0$$

Where: $\vec{F}$ is the magnetic force; χ_m the magnetic susceptibility of the particle's material; $\mu_0 = 4\pi\times10^{-7}\,H/m$, V the volume of the magnetic particle; μ relative permeability and $\vec{H}_0$ is magnetic field strength.

There are several variables influencing the separation process in a wet drum magnetic separator: magnetic field strength, its gradient, hydraulic capacity, percent solids, magnetic content etc. The crucial role play here magnetic field strength H_0 and its gradient ∇H_0 since they are two main elements contributing to magnetic force. Clearly, the homogeneous magnetic field cannot produce separating force since its gradient is zero.

Drum magnetic separators are characterized by radial or axial pole disposition. The analytical expression for magnetic field strength in the radial magnet configuration can be obtained by the method of conformal mappings [6]:

$$(2)\quad H(r,\varphi) = \frac{U_\delta n}{2KR} \times \frac{1}{\xi\left[\begin{array}{l} C_1^2 - 2C_1(\xi^n + \xi^{-n})\cos(n\varphi) \\ + 2\cos(2n\varphi) + \xi^{2n} + \xi^{-2n} \end{array}\right]^{1/4}}$$

$$F_\varphi(r,\varphi) = -m\nu \frac{U_\delta^2 n^3}{8K^2R^3} \times \left(\frac{2\sin(2n\varphi) - C_1\left(\xi^n + \xi^{-n}\right)\sin(n\varphi)}{\xi^3\left[\begin{array}{l} C_1^2 - 2C_1(\xi^n + \xi^{-n})\cos(n\varphi) + \\ 2\cos(2n\varphi) + \xi^{2n} + \xi^{-2n} \end{array}\right]^{3/2}} \right)$$

where: $H(r,\varphi)$ is the magnetic field strength; $F_r(r,\varphi)$ radial component of magnetic force; $F_\varphi(r,\varphi)$ azimuthal component of magnetic force; χ_m magnetic susceptibility of the particle's material; $\mu_0 = 4\pi\times10^{-7}\,H/m$, V particle's volume; μ relative permeability ; $\vec{H}_0$ magnetic field strength; U_δ difference in the magnetic potentials applied to the ends of unlike poles, K complete elliptic integral, k absolute value of the complete elliptic integral, a is an arc length of the magnetic poles, m is the mass of the ball, ν parameter, δ is an arc length of an air gap; n is the number of poles, R radius of the magnetic system, φ polar angle,

$$\xi = \left((R+r)/R\right)$$

$$C_1 = 2\cos\left((\pi a)/(\delta + a)\right)$$

where *r* is the radial distance from the pole surface, and *a* size of an air gap.

Construction and operation principle

A typical drum magnetic separator consists of stationary magnet set, rotating drum, tank, feed box, magnetics and tailings discharge. The magnetic system plays here the most important role. Its design influences the magnetic field intensity and gradient. The axial type is characterized by sandwiching magnets between the poles to increase the magnetic depth beyond the drum shell.

The magnets here are called interpole magnets. The other type, radial section, is characterized by large size magnets to provide a very deep magnetic field in order to maximize the magnetic force. The schema of radial type section is presented in Fig. 1. The typical magnetic element consists of a series of agitating magnet poles that span an arc of 120 to 140°.

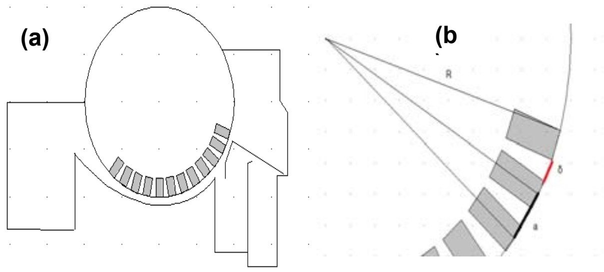

Fig.1. Multipole magnetic system of drum separator. Geometry of the radial type separator (a). *δ* is an arc length of an air gap, *a* is an arc length of the magnetic poles (b).

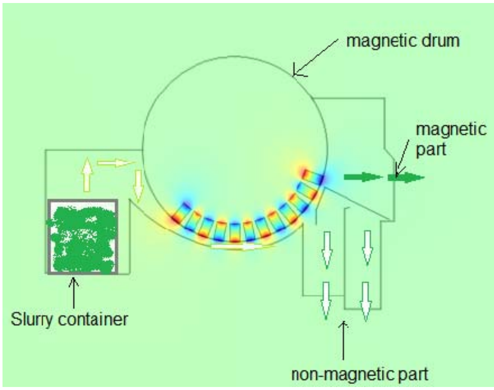

Fig.2. Schematic illustration of wet drum magnetic separator tank. The magnetic element consists of a series of poles that span an arc of 120°. The magnetic poles alternate from north to south in order to produce an agitating effect to magnetics as they are conveyed.

The other important element is rotating drum situated in a tank that receives the feed slurry which is the mixture some magnetic and nonmagnetic materials. The drum encloses the magnetic system and is mounted in a tank. The magnetic slurry is fed to the tank and then flows through the magnetic field generated by the drum. The magnetic particles are attracted to the drum shell by the magnetic circuit and rotated out of the slurry stream. Next, they discharge from the drum shell out of the magnetic field. There are two common types of tank designs. In the first type drum rotates in the same direction as the slurry flow in the concurrent tank style (Fig. 2). The slurry flows into the magnetic field generated by the drum. The magnetics are attracted by the magnetic field, collected on the drum surface, and rotated out of the slurry flow. In the other type - counter–rotation wet drum tank style drum rotates against the slurry flow. The slurry enters the feedbox and flows directly into the magnetic field generated by the drum. In comparison with the first type, the magnetic material is conveyed the shorter path that results in high magnetics recoveries.

In wet drum separator the magnetic force acting on a magnetic particle is predominately opposed by hydrodynamic drag force. However, the drag force helps to wash away the non-magnetic particles while the magnetic particles are collected in the magnetic field. As the flowrate increases, the slurry velocity and consequently the fluid drag force increases which tends to detach more magnetic particles from the opposing magnetic field. The percent solid of the feed directly affects the selectivity of the separation. As the percent solids increases, the slurry becomes more viscous minimizing the effects of the fluid drag to assist in the separation. Any given wet drum magnetic separator has the capability of removing a limited amount of magnetics based on the diameter of the drum, peripheral speed, and the magnetic field strength.

Most drum separators employ novel class neodymium-iron-boron (NdFeB) magnetic systems. Strong NdFeB magnets develop an extremely high surface force to allow the magnetic circuit to remove very fine or weekly magnetic contamination. Such high strength separators are extensively used by food, chemical and pharmaceutical processors requiring the highest levels of product purity [4].

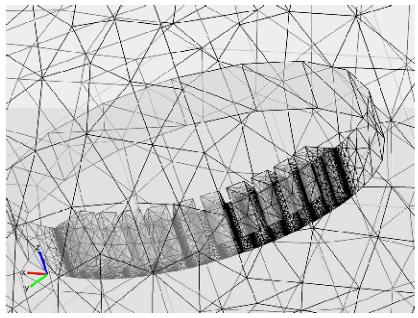

Fig.3. Mesh of the drum magnetic separator generated using Comsol Multiphysics Program

Magnetic field distribution in wet drum separators

The computation of magnetic field distribution inside wet drum separator has been performed using the Comsol Multiphysics software with AC/DC module that uses finite element method [7]. The geometry of the calculated model was concurrent tank style permanent magnet separator. The magnetic system consists of 12 alternating magnetic poles of magnetic flux density of 1T. Fig 3 shows a mesh generated prior to simulation. Fig 4 illustrates an agitating effect that is useful to transport magnetics along the drum. The symmetry of magnetic scalar potential is apparent. Figure 5 shows the magnetic field line distribution around the separator. The high symmetry is clearly visible.

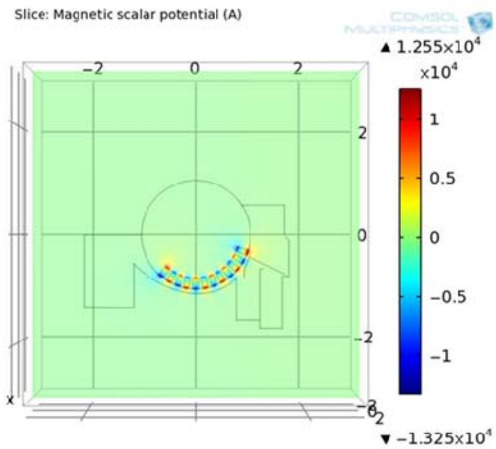

Figure.4. The distribution of magnetic scalar potential in wet rdum magnetic separator. The agitating effect of 12 alternating magnetic poles is apparent

The computed magnetic field distributions are the basis for determining magnetic forces using expression (2) and next particle's trajectory in the separation zone. It is possible to find out the efficiency of calculated separator's geometry.

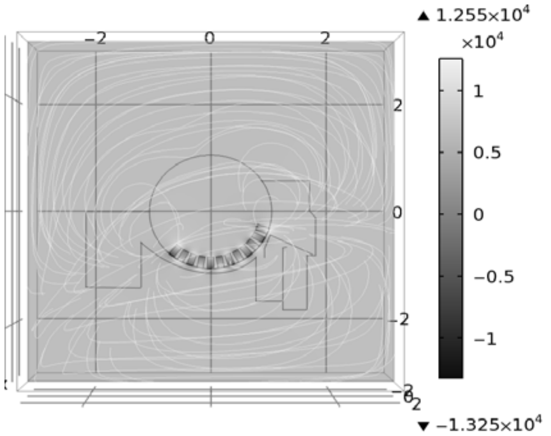

Figure.5. The distribution of magnetic field lines

Conclusions

The paper presents the analysis of the drum magnetic separators. The physical principle underlying separation is presented, that is magnetic force acting on magnetic particles. The analytical expression for magnetic field strength and magnetic force produced by drum separator characterized by radial magnet arrangement. The results of magnetic field modeling inside drum magnetic separators have been shown. The magnetic field source is the permanent magnet assembly. The performed simulation is the first step in designing more effective separating devices. The models under consideration are derived from practical limitations of their application. Due to modeling tools there is a possibility to optimize the specified parameters. The optimized model is going to be used as the solution of inverse problem that is determining of construction parameters, a prerequisite for designing a highly efficient magnetic separator.

REFERENCES

[1] Parker, M.R., Physics of magnetic separation. Contemporary Physics 18 (3) (1977), 279–306.
[2] Gerber, R., Birss, R.R., High Gradient Magnetic Separation. Research Studies Press (1983).
[3] Svoboda, J., Fujita, T., Recent developments in magnetic methods of material separation. Minerals Engineering 16 (9) (2003), 785–792.
[4] Moeser, G.D., Roach, K.A., et al., High-gradient magnetic separation of coated magnetic nanoparticles. A.I.Ch.E. Journal 50 (11) (2004), 2835–2848.
[5] Yavuz C. T, Prakash A., Mayo J. T., Colvin V., Magnetic separations: From steel plants to biotechnology, Chemical Engineering Science 64 (2009) 2510-2521.
[6] Smolkin M. R., Smolkin R. D., Calculation and Analysis of the Magnetic Force Acting on a Particle in the Magnetic Field of Separator. Analysis of the Equations Used in the Magnetic Methods of Separations, *IEEE Transactions on Magnetics*, vol. 42, No. 11 (2006).
[7] http://www.comsol.com/.

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