Magnetic field and forces in a magnetic separator gap

Abstract. Calculation results of magnetic field and forces in a 3-D space of magnetic separator, which is used for cleaning of fine-grain minerals from magnetic impurities are presented. Calculations are based on Network Reluctance Method and the nonlinearity of the iron core is taken into account. Some results are backed by the measurements and there a relatively good agreement was obtained.

Introduction

A magnetic separator which is discussed in the paper is used for minerals to clean them from magnetic impurities. The scheme of the separator structure is shown in Fig. 1. It consists of an U-shaped iron core, an excitation coil and a separation unit that is placed between the core plates. The minerals to be cleaned enter the gap between the screw-shaft and the iron plates at the top. The magnetic particles affected by the nonuniform magnetic field tend towards the thread of the screw-shaft while the clean mineral is falling down to an exit. The magnetic concentrate is withdrawn from the separation zone by turning round screw shaft.

Fig.1. A scheme of the magnetic separator with the reluctance network

Mathematical model of the separator

A mathematical model of the magnetic separator is defined by the following assumptions:

1) A magnetic separator is represented by the 3-D network of MMFs ($F_{\mu}$) and reluctances shown in Fig.1. Due to a symmetry the calculations were carried out for the one quarter of the separator. A three-dimensional view of the network in a separation chamber is shown in Fig. 2.

There are three types of reluctances in the separator network: the rectangular $R_{ix}$, radial $R_{iy}$ and circumferential $R_{iyo}$ ones, which are shown in Fig.2. The reluctances of the rectangularly shaped air-space are defined in the following way:

$$R_{ix} = \frac{l_{ix}}{\mu_0 S_{ix}} , \quad R_{iy} = \frac{l_{iy}}{\mu_0 S_{iy}} , \quad R_{iyo} = \frac{l_{iyo}}{\mu_0 S_{iyo}}$$

Fig. 2. A reluctance network in the separator gap.

There are three types of reluctances in the separator network: the rectangular $R_{ijx}$, $R_{ijy}$ and $R_{ijz}$, radial $R_{ijp}$ and circumferential $R_{ijo}$ ones, which are shown in Fig.2. The reluctances of the circularly shaped air-space are defined in the following way:

$$R_{ijx} = \frac{l_{ijx}}{\mu_0 S_{ijx}} , \quad R_{ijy} = \frac{l_{ijy}}{\mu_0 S_{ijy}} , \quad R_{ijz} = \frac{l_{ijz}}{\mu_0 S_{ijz}}$$

The reluctances of the air-space in a vicinity of the screw-shafts should take into account the curvature of the screw-thread. Because of that two types of reluctances: the radial and the circumferential ones (see Fig.2. (c) and (d)) are considered and are calculated as follows:

Słowa kluczowe: separator magnetyczny, pole magnetyczne, siły magnetyczne, metoda sieci reluktancyjnych

Keywords: magnetic separator, magnetic field, magnetic forces, reluctance method
where: $\mu_0 = 4\pi 10^{-7}$ H/m, is the vacuum permeability; $p$ is the number of elements on the shaft circumference; $l_i, h_i, d_i$ are linear dimensions of i-th element; $r_i$ is the radius of i-th element; $S_i$ is the cross-section area of i-th rectangular element. The magnetic force acting on the magnetic particle of the volume $V$ and of permeability $\mu$ was found from the equation [1]:

\[
f = \frac{\mu - \mu_0}{2\mu_0\mu} \sqrt{|\mathbf{B}|^2}
\]

Calculation results

The calculations were carried out for two versions of separator: with flat pole pieces (W1) and the curved pole pieces called WK. The results of the calculation of the $B_y$ component are shown in Fig. 4 and Fig.6.

![Fig. 3. A reluctance network: a) W1 separator, b) WK separator.](image)

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![Fig. 4. A distribution of $B_y$ magnetic flux of the cross-section.](image)

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![Fig. 5. Experimental distribution of magnetic flux density in the separator W1 along the screw-shaft.](image)

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![Fig. 6. Theoretical and experimental curves of magnetic flux density in the separator gap along the screw-shaft.](image)

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![Fig. 7. The forces in the WK separator along the shaft.](image)

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![Fig. 8 A force distribution in W1 separator; a) of the cross-section of teeth, b) between the teeth.](image)

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In order to verify the mathematical model measurements of the magnetic flux density were carried out in the air gap of separator. The results of measurements are shown in Fig.5. The theoretical and test characteristics of the magnetic force acting on the magnetic particles are shown in Fig.6. Small discrepancies between two curves illustrate a relatively good accuracy that can be reached using the RNM.
The force distributions in the gap of separators of the cross-section of 0.03 m (teeth), and between the teeth of the screw-shaft the shaft are shown in Fig.8 and Fig.9. Force field in the gaps along the screw-shaft are shown in Figures 7 and 10. Figures show, the use of curved pole in this type of separator has increased separation efficiency by increasing the forces acting on the ferromagnetic particles. The direction of this forces has also changed, causing the ferromagnetic particles move to the screw-shaft.

In order to optimally design the structure of the WK separator the calculations were carried out for the various radius of curvature of the poles. The cross-sectional force field for the two radii \( r = 0.365 \) m and \( r = 0.235 \) m on the tooth is shown in Figure 9 and Figure 11. The comparison of distributions of the forces acting on the ferromagnetic particles, pole radius \( r = 0.235 \) m gives a higher separation efficiency due to the higher force. The effectiveness of the separation is a function of the magnetic field formed respectively in the gap.

Conclusions

The RNM used to calculate the magnetic flux density and the forces acting on the ferromagnetic particles in the whole volume of magnetic separator is a relatively simple method, easy in use and gives a good enough accuracy. The short calculation time and a small PC memory it requires makes it competitive in some cases to the FEM and other numerical methods. These features make the RNM a very useful tool for designing of electromagnetic devices and in particular the magnetic separators. The effectiveness of the separation is a function of the magnetic field formed respectively in the gap.

REFERENCES