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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.*

***Streszczenie.** Artykuł prezentuje obliczenia pola magnetycznego i sił w szczelinie separatora magnetycznego jednowałkowego przeznaczonego do separacji minerałów z zanieczyszczeń ferromagnetycznych. Do obliczeń zastosowano metodę sieci reluktancyjnych w przestrzeni trójwymiarowej z uwzględnieniem nieliniowości rdzenia. Obliczenia zweryfikowano pomiarami uzyskując dobrą zgodność wyników teoretycznych i doświadczalnych. (**Pole magnetyczne i siły w szczelinie separatora magnetycznego**).*

Keywords: magnetic separator, magnetic field, magnetic forces, reluctance method
Słowa kluczowe: separator magnetyczny, pole magnetyczne, siły magnetyczne, metoda sieci reluktancyjnych

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 main part of the separation unit is a screw shaft placed vertically. The coil is supplied from a dc source. 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 The magnetic concentrate is withdrawn from the separation zone by turning round screw shaft.

A significant influence on the separation process has a magnetic field distribution in the separation chamber. Due to the presence of the screw-shaft the calculations of magnetic field should be carried out in a 3-D space. It was done by using the reluctance network method (RNM) [1]. The mathematical model of the separator which is applied takes into account saturation of the iron core. In the paper the calculation results of the magnetic field and magnetic forces are presented. Some of them are verified by the measurement results.

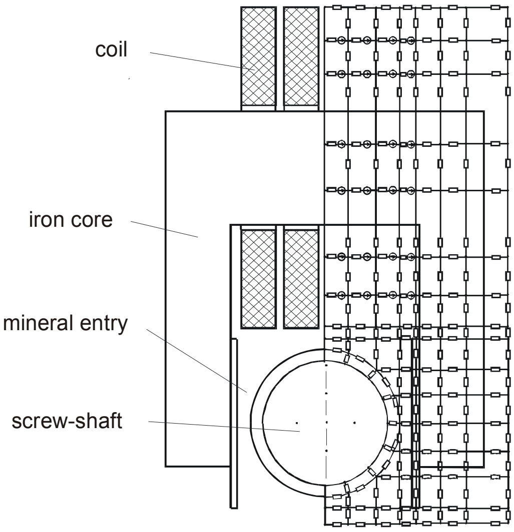


Fig.1. A scheme of the magnetic separator with the reluctance network

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 ($F_{\mu i}$) and reluctances shown in Fig.1. Due to a symmetry the calculations were carried out for the one quater of the separator. A three-dimentional view of the network in a separation chamber is shown in Fig. 2.,

2) The U-shaped core and the screw-shaft have a finite magnetic permeability μ_{Fe} related to the ***B-H*** curve, which was approximated by the equation *B=1,172* arctg *0,05H*,

3) The rotation of the screw-shaft and the presence of the ferromagnetic particles do not influence the magnetic field in the air-gap. That means that the calculations of magnetic field are carried out at the stationary screw-shaft without the presence of the magnetic particles.

The elementary MMFs of the excitation coil in the separator network are expressed by the equation:

$$F_{\mu i} = z_i I \tag{1}$$

where z_i is the number of turns of the elementary coil and I is the current flowing in this coil.

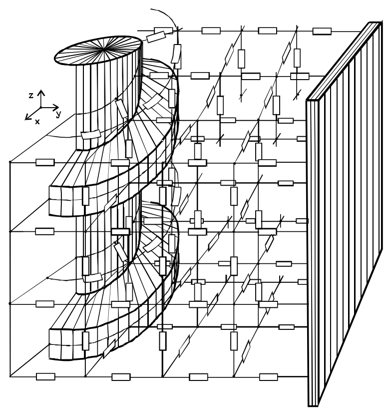


Fig. 2. A reluctance network in the separator gap.

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

$$R_{\mu ix} = \frac{l_{ix}}{\mu_0 S_{iyz}}, \quad R_{\mu iy} = \frac{l_{iy}}{\mu_0 S_{ixz}}, \quad R_{\mu iz} = \frac{l_{iz}}{\mu_0 S_{ixy}} \tag{2}$$

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:

$$R_{\mu p} = \frac{r_2 - r_1}{\mu_0 h_i \dfrac{2\pi r_{sr}}{p}} \qquad R_{\mu o} = \frac{\dfrac{2\pi r_{sr}}{p}}{\mu_0 h_i \left(r_2 - r_1\right)} \tag{3}$$

where: μ_0 = 4p10^{-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 μ was found from the equation [1]:

$$f = \frac{\mu - \mu_0}{2\mu_0 \mu} \nabla \left|\boldsymbol{B}\right|^2 \tag{4}$$

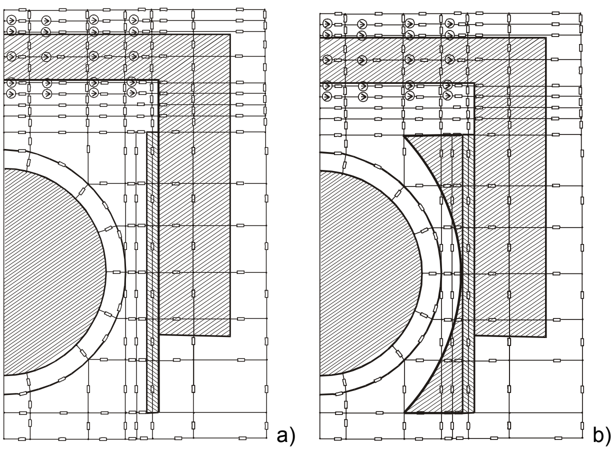


Fig. 3. A reluctance network: a) W1 separator, b) WK separator .

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.

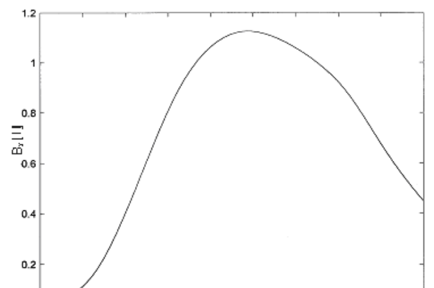


Fig. 4. A distribution of B_y magnetic flux of the cross-section.

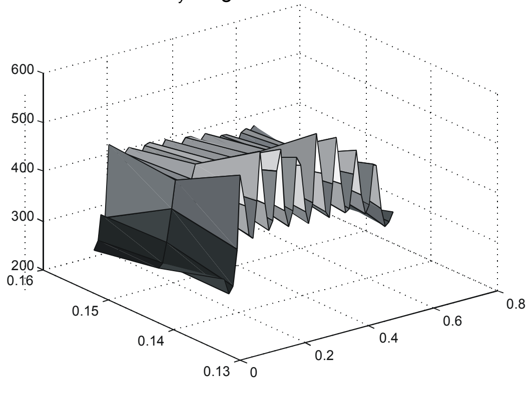


Fig.5. Experimental distribution of magnetic flux density in the separator W1 along the screw-shaft.

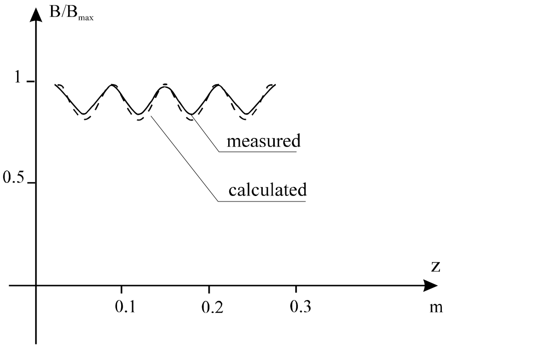
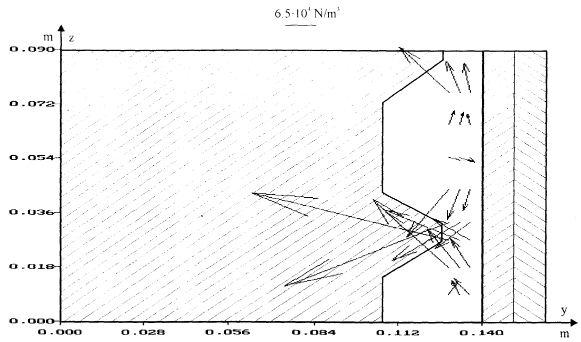


Fig.6. Theoretical and experimental curves of magnetic flux density in the separator gap along the screw-shaft.



Rys. 7. The forces in the WK separator along the shaft.

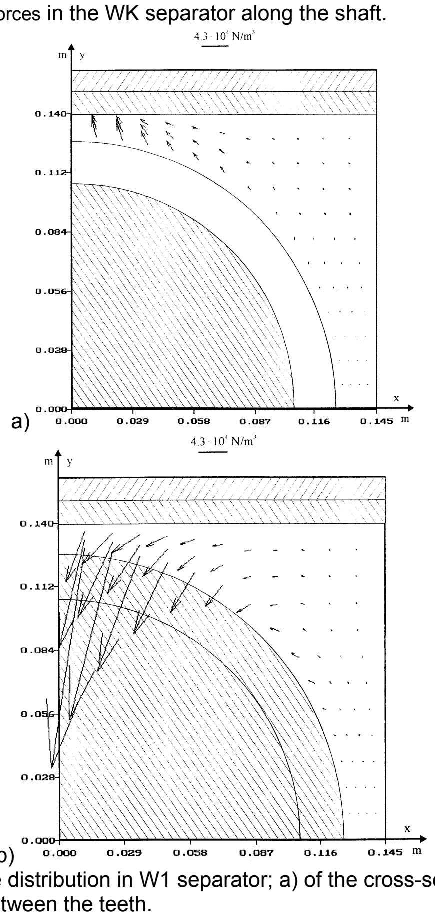
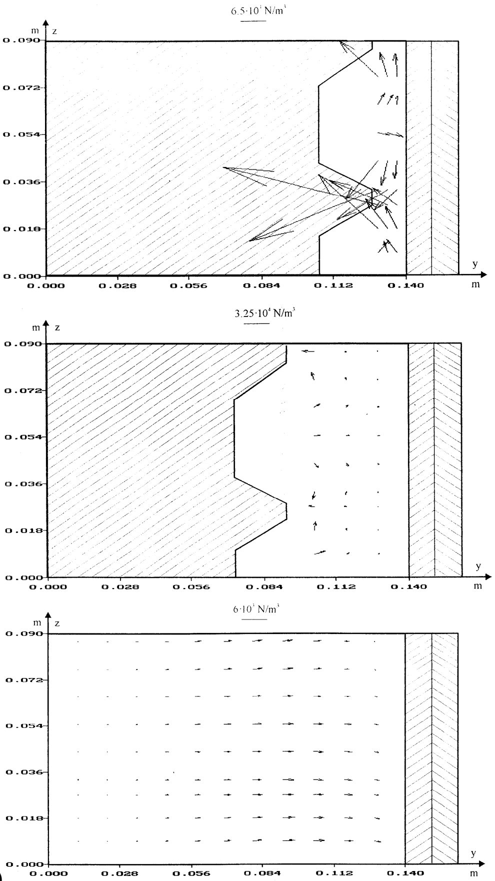


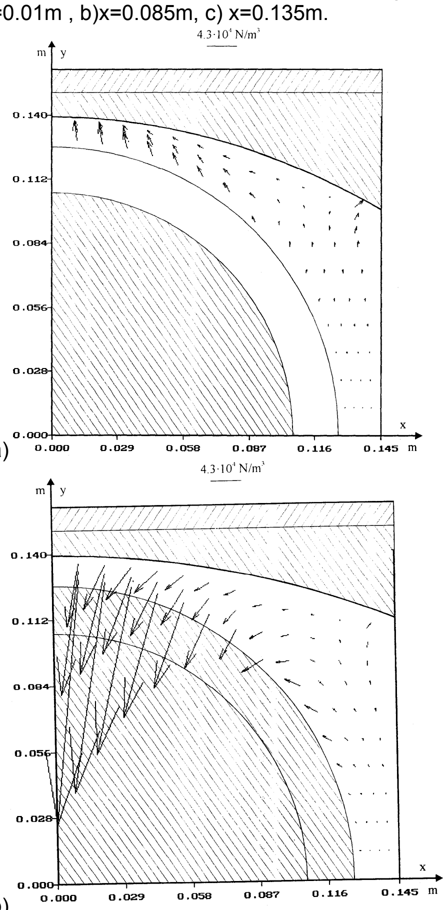
Fig. 8 A force distribution in W1 separator; a) of the cross-section ofteeth, b) between the teeth.

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.



a) b) c)

Fig. 10. A force distribution in the WK separator along the screw-shaft; a) x=0.01m , b)x=0.085m, c) x=0.135m.



a) b)

Fig. 9. A force distribution in WK separator , r=0.365m; a) of the cross-section of teeth, b) between the teeth.

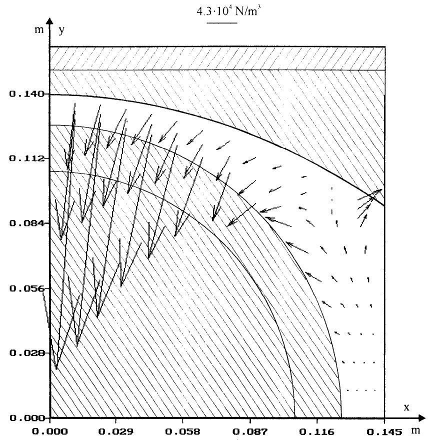


Fig.11. A distribution of forces in the WK separator, r=0.235m.

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 = 0.365m and r = 0.235m 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

1. Ciosk K., Gierczak E.,.Mendrela E.A : Pole magnetyczne i pole sił w szczelinie separatora magnetycznego śrubowego: Wiadomości Elektrotechniczne, No 6,1994, str.236-238