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FORMULA FOR CALCULATION OF MAGNETIC FIELD STRENGTH OVER THE MIDDLE OF THE GAP OF A BIPOLAR SUSPENDED IRON SEPARATOR

ENAČBA ZA IZRAČUN JAKOSTI MAGNETNEGA POLJA PO SREDINI REŽE BIPOLARNIH SUSPENDIRANIH SEPARATORJEV ŽELEZA

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Abstract

A formula providing the possibility of calculating with sufficient accuracy the strength of the magnetic field over the middle of the inter-polar gap formed by sloping surfaces of pole pieces of U-type electromagnets of suspended iron separators is presented.

Povzetek

Predstavljena je enačba, ki zagotavlja možnost dovolj točnega izračuna jakosti magnetnega polja po sredini reže med poloma, ki ga tvorijo nagnjene površine delov polov elektromagnetov U-tipa suspendiranih separatorjev železa.

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1 INTRODUCTION

At present, the extraction of foreign ferromagnetic objects from various bulk materials transported by belt conveyers is carried out by dedicated direct current electromagnets (suspended iron separators), [1, 2]. Suspended iron separators based on U-type bipolar magnetic systems are a common type of such electromagnets (Figure 1).

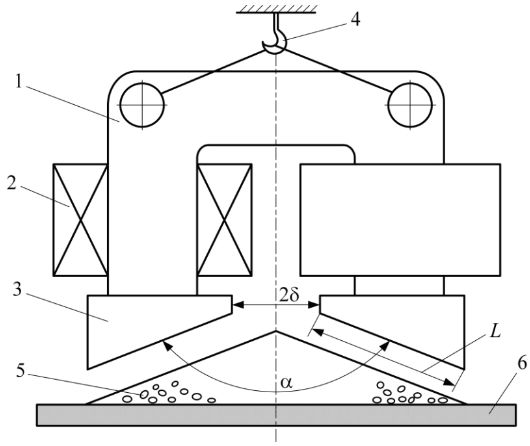

Figure 1: *Suspended electromagnetic separator*

One of the critical stages of designing suspended iron separators is the calculation of the magnetic field in the inter-polar zone, where the separated bulk material is located. In this case, field strength and its gradient, [2–6], are the basic calculation values. A number of methods of different degrees of accuracy are offered in Smolkin and Sayko's paper, [7], to determine these values at all the points of inter-polar space of suspended electromagnetic separators. However, these methods result in rather complicated calculation formulas, which make their use in practical design difficult. Calculation difficulties (e.g. necessity of solution of equations of an implicit form) occur due to taking into account the angle $\alpha \neq 180^{\circ}$ (Figure 1) between the operating surfaces of pole pieces forming the basic magnetic flux through the working zone of the suspended iron separator. The following designations are assumed in Figure 1: 1 – magnetic circuit; 2 – magnetizing winding; 3 – pole pieces; 4 – suspension; 5 – bulk material; 6 – conveyer belt.

It should be mentioned that at the preliminary stages of designing suspended iron separators, as a rule, the knowledge of magnetic field strength and its gradient is required only for the points of the vertical of the middle of the inter-polar gap. Obviously, it is the most difficult place for extraction due to the maximum thickness of the layer of the separated material, [1–3], i.e. there is often no necessity to calculate the strength distribution across the whole inter-polar space during preliminary calculation. This is why the problem of this paper consists of obtaining the formula of magnetic field strength for the points situated over the middle of the gap between sloping pole pieces of U-type magnetic system. This formula should be simple for practical calculation and to provide accuracy sufficient for preliminary design calculations.

2 INVESTIGATION MATERIAL

With the aim of solving the posed problem, it should be taken into consideration that, as shown in [8], the calculation of magnetic field of pole pieces lying in the same plane ($\alpha = 180^\circ$) can be reduced to the calculation of a plane-parallel field of two infinite plates (Figure 2); the magnetic potential difference between them equals U_0 ; the magnetic potentials difference between pole pieces and their geometry (width L and gap δ) equals to the corresponding dimensions of the magnetic system. In the case of the same-plane poles, the field strength in the middle of inter-polar gap ($x = 0, y \geq 2$, Figure 2) has one component (horizontal) that can be recorded on the basis of corresponding formulas from [8, 9], with the assumed dimensions designation (Figure 2), in the form:

$$H_0(y) = U_0 \frac{0{,}5}{K(k)} \cdot \frac{(L+\delta)}{\sqrt{\delta^2 + y^2}\sqrt{(L+\delta)^2 + y^2}} \tag{2.1}$$

where y is the vertical distance from the poles plane to the point at which the strength is determined; $K(k)$ is the first-type complete elliptic integral with module $k = \delta/(L+\delta)$.

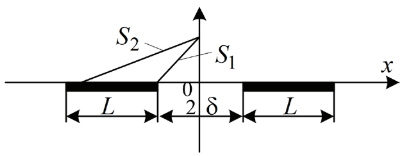

Figure 2: *Two infinite plates*

If values S_1 and S_2 , i.e. distances to the analyzed point from the internal and the external edges, respectively, of pole-plates are introduced (Figure 2):

$$S_1 = \sqrt{\delta^2 + y^2}, \qquad S_2 = \sqrt{(L+\delta)^2 + y^2},$$

then formula (2.1) can be converted to the form:

$$H_0(y) = U_0 \frac{0{,}5}{K(k)} \cdot \frac{(L+\delta)}{(S_1 \cdot S_2)} \tag{2.2}$$

The magnetic field in the inter-polar zone can also be considered plane-parallel for poles having an angle between the pieces surfaces of less than 180° , [7]. Let us assume that in this case the magnetic field strength at the points over the middle of the inter-polar gap (axis y in Figure 3) is also determined by formula (2.2) in which, analogously to the previous one, S_1 and S_2 are presumed to be distances from corresponding pole edges to the analyzed point (Figure 3):

$$S_1 = \sqrt{\delta^2 + \left(y - \delta\, ctg(\alpha/2)\right)^2}\ ,$$

$$S_2 = \sqrt{\left(\delta + L\sin(\alpha/2)\right)^2 + \left(y - \delta\, ctg(\alpha/2) - L\cos(\alpha/2)\right)^2}\ , \tag{2.3}$$

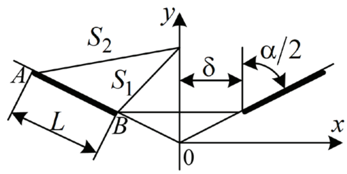

Figure 3: *Two plane-parallel plates having the angle* α *between their surfaces*

As to multiplier ($L + \delta$) and module k , contained in (2.2), corresponding values for sloping pole pieces can be determined by distances obtained when the upper plane of pole pieces crosses the vertical of the middle of inter-polar gap (line AB0 in Figure 3), i.e. in this case, dimension $B0 = \delta/\sin(\alpha/2)$ represents value δ , and dimension $A0 = [L + \delta/\sin(\alpha/2)]$ is taken instead of ($L + \delta$), which yeilds

$$k = \frac{\delta/\sin(\alpha/2)}{L + \delta/\sin(\alpha/2)} = \frac{\delta}{\delta + L\sin(\alpha/2)} \tag{2.4}$$

Thus, taking the above said into consideration, the following can be recorded for magnetic field strength at the points over the middle of the inter-polar gap of sloping poles

$$H_\alpha(y) = U_0 \frac{0{,}5}{K(k)} (L + \delta/\sin\alpha/2)/(S_1\, S_2) \tag{2.5}$$

where S_1, S_2 and k are taken from (2.3) and (2.4), respectively.

When parameters L, δ, α are known, calculation according to (2.5) does not present any difficulties if the following relation from [10] is used for an approximate calculation of $K(k)$ (true with accuracy up to the fourth decimal):

$$K(k) = \sum_{i=0}^{2} \left(1 - k^2\right)^i \left[a_i + b_i\ \mathrm{h}\left(1/\left(1 - k^2\right)\right)\right] \tag{2.6}$$

,

where $a_0 = 1.3862944$; $a_1 = 0.1119723$; $a_2 = 0.0725296$; $b_0 = 0.5$; $b_1 = 0.1213478$; $b_2 = 0.0288729$.

To substantiate formula (2.5), it should be noted that qualitative dependences $H_\alpha(y)$ on certain parameters (the case of sloping plates of poles) are to be identical to analogous dependences for the case of single-plane poles. This identity is provided by the assumed similarity of formula structures for $H_0(y)$ and $H_\alpha(y)$. It should also be mentioned that in the case of $\alpha = 180^\circ$, formula (5) transforms into an accurate formula (2.2).

3 EXPERIMENTAL VERIFICATION

Experimental verification of formula (2.5) was carried out with a physical model of a suspended iron separator P160 (scale 1:5). Corresponding data are given in Table 1; they show good coincidence of the results of calculation according to the proposed formula with the results of the experiment. Furthermore, formula (2.5) was verified by means of comparison of the experimental data for a suspended iron separator P100M given in [7] with the results of the calculation according to (2.5) for corresponding dimensions (Table 2). As [7] does not contain a numerical value U_0 for suspended iron separator P100M, the calculated reduced strength $\overset{*}{H} = H_\alpha(y)/U_0$ is included in Table 2. As to the degree of certainty of the calculation, it was determined according to the ratio of the experimental value of magnetic field strength from [7] to $\overset{*}{H}$, which, according to (2.5), is to be a constant value not depending on y. Analysis of the corresponding results shows that formula (2.5) provides acceptable accuracy for practical calculations.

Table 1: *Magnetic field strength over the middle of inter-pole gap of a physical model of suspended iron separator P160* ($\delta = 24$ mm, $L = 106.5$ mm, $\alpha = 155^\circ$, $U_0 = 7695.34$ A)

Distance y, mm	Field strength, A/м		Error, %
	calculated according to formula (5)	Experimental	
15	159174	153585	+3.64
20	129938	128120	+1.42
25	107234	105838	+1.32
30	90209	89127	+1.21
35	77293	77190	+0.13
40	67261	67641	–0.56
45	59278	60479	–1.99
50	52780	54113	–2.46
55	47390	48542	–2.37

Table 2: *Error of the calculation of magnetic field strength in the operating zone of suspended iron separator P100M* ($\delta = 85.4$ mm, $L = 350$ mm, $\alpha = 120^\circ$) *over the middle of the inter-polar gap*

y, mm	Strength values		Ratio $H_ý / \overset{*}{H}$, A	Mean value of ratio $H_ý / \overset{*}{H}$, A	Deviation from the mean value, %
	given according to calculation $\overset{*}{H}$, 1/м	absolute, from experience $H_ý$, A/м			
42.7	4.46394	1880	4229.44	3852.16	+9.8
92.7	3.8699	1530	3953.59		+2.6
142.7	2.8701	10970	3822.16		–0.8
192.7	2.17154	7940	3656.38		–5.1
242.7	1.70315	6130	3599.22		–6.6

4 CONCLUSIONS

The proposed formula can be recommended for preliminary stages of the calculation of suspended iron separators, when it is necessary to determine the magnetic field strength at the points over the middle of the inter-polar gap of a U-type magnetic system.

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