

A SIMPLIFIED CALCULATION OF MAGNETIC FIELD STRENGTH
OVER THE MIDDLE OF THE GAP OF DOUBLE-POLE MAGNETIC IRON SEPARATOR

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The extraction of undesirable ferromagnetic pieces from various granular materials transported by belt conveyors is a most difficult task owing to thick layer of the material in the middle of the conveyor belt. The problem is related to derivation of the approximate formula for initial value of magnetic field strength at the points located over the middle of the gap between the inclined pole pieces of U-shaped magnetic system. The desired expression is obtained by the known formula for the plane-parallel field of two infinite plates in the same plane. The expression for calculation of the field between the inclined surfaces of the pole pieces is obtained by transformation of such formula. The experimental verification is performed by physical model and industrial specimen. As confirmed by experiments, the proposed formula can be used to calculate magnetic field in the suspended iron separators at preliminary stages. References 11, tables 2, figures 3.

Key words: calculation of magnetic field, electromagnetic iron separator, U-shaped magnetic system, plane-parallel field of infinite plates, inclined poles.

Introduction. Nowadays the extraction of undesirable ferromagnetic pieces from various granular materials transported by belt conveyors is realized by special direct current electromagnets – iron separators [1–3]. The suspended iron separators based on U-shaped double-pole magnetic systems are a common type of such electromagnets (Fig. 1).

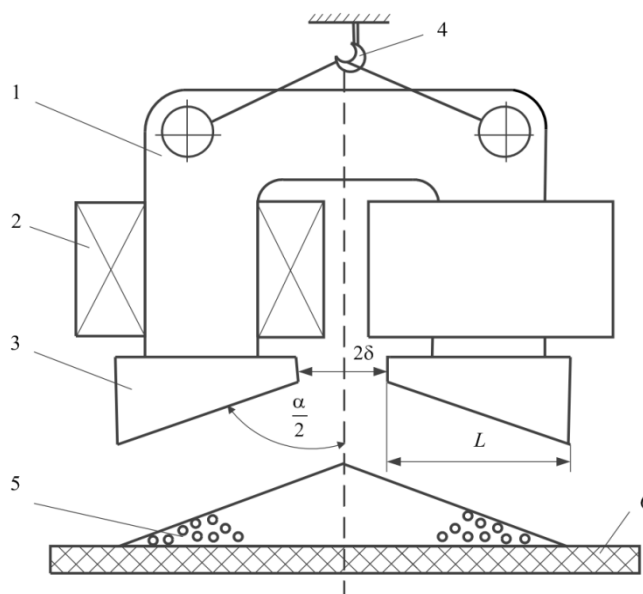


Fig. 1

One of the important stages in designing the electromagnets of suspended iron separators consists in the calculation of magnetic field in the inter-pole operating zone where the separated granular material is located. In this case the magnetic field strength and its gradient are the basic values to be calculated [1–4]. A number of methods with various degrees of accuracy are proposed in papers [5–7] to determine these values at all points of the inter-pole space of the suspended electromagnetic iron separators. However, they result in rather complicated formulae, which make it difficult to use them in direct engineering design practice. Besides, the calculation difficulties (e.g. the necessity to solve implicit equations) take place due to consideration of angle $\alpha \neq 180^\circ$ between the operating surfaces of the polar pieces that generate the main magnetic flux crossing the operating zone of the separator (Fig. 1). The following designations are used in Fig. 1: 1 is the magnetic core; 2 is the magnetization winding; 3 is the pole piece; 4 is the bracket; 5 is the granular material; 6 is the conveyor belt.

It should be noted that at the preliminary stages of iron separator designing, as a rule, only magnetic field

strength and its gradient in the vertical of the middle of the inter-pole gap is necessary to be known. It is very difficult to provide the extraction owing to the maximal thickness of purified material in this gap [8]. Moreover, at preliminary calculation, it is often not necessary to determine the magnetic field distribution in the whole inter-pole space.

Statement of problem. The purpose of the paper is to deduce the formula for magnetic field strength only at the points located over the middle of the gap between the inclined pole pieces of the U-shaped magnetic system. Moreover, this formula should be simple in practical calculations and provides sufficient accuracy for preliminary design solutions.

Problem solving. In order to solve the problem we take into account that, as shown in [6, 7, 9], the magnetic field of the pole pieces located in one plane ($\alpha = 180^\circ$) can be calculated as the plane-parallel field of two infinite plates (Fig. 2). The difference of magnetic potentials between these plates is equal to the magnetic potentials difference U_0 between the pole pieces. The geometric dimensions (width L and gap δ) are equal to the corresponding dimensions of the pole piece system. In the case of single-plane poles, the magnetic field strength in the middle of the inter-pole gap ($x = 0, y \geq 0$, Fig. 2) has only one (horizontal) component. On the basis of the formulae from [9, 10] (obtained by conformal transformation using Schwarz-Christoffel integral), this component in the adopted symbols (Fig. 2) can be written in the form

$$H_0(y) = U_0 \frac{0.5}{K(k)} \cdot \frac{(L + \delta)}{\sqrt{\delta^2 + y^2} \cdot \sqrt{(L + \delta)^2 + y^2}}, \quad (1)$$

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

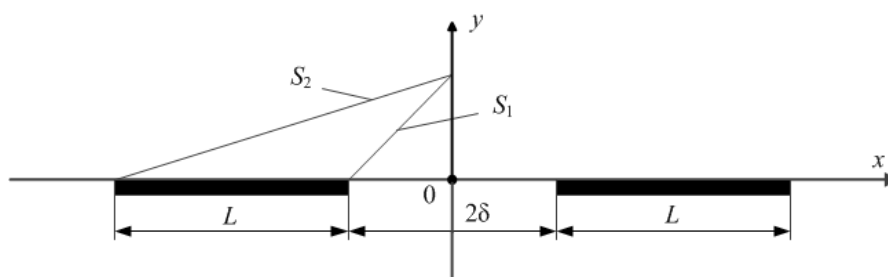


Fig. 2

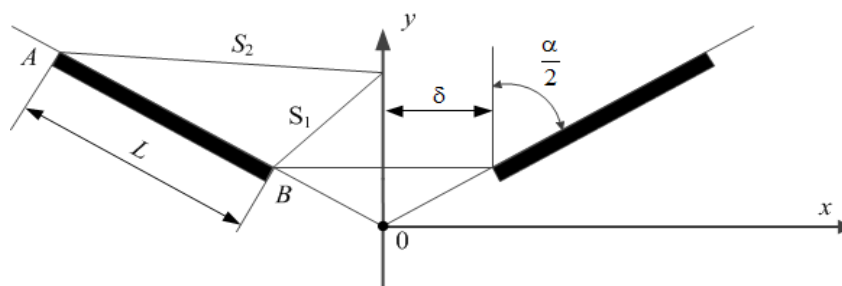


Fig. 3

If S_1 and S_2 are the distances to the point under consideration from the internal and external edges of the plate poles, respectively (Fig. 2) then

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

and formula (1) can be transformed as follows:

$$H_0(y) = U_0 \frac{0.5}{K(k)} \cdot (L + \delta) / (S_1 \cdot S_2). \quad (2)$$

The magnetic field in the inter-pole zone for the poles having the angle between the pole piece surfaces less than 180° can also be considered as plane-parallel field [5].

Let us assume that the magnetic field strength at the points over the middle of the inter-pole gap (axis y in Fig. 3) is determined by formula (2) in which S_1 and S_2 are the distances from the corresponding edges of the poles to the point under examination (Fig. 3)

$$\begin{aligned} S_1 &= \sqrt{\delta^2 + (y - \delta \cdot \text{ctg}(\alpha/2))^2}, \\ S_2 &= \sqrt{(\delta + L \sin(\alpha/2))^2 + (y - \delta \cdot \text{ctg}(\alpha/2))^2}. \end{aligned} \quad (3)$$

As to factor $(L + \delta)$ and module k in expression (2), the corresponding values for the inclined pole pieces can be determined by the distances obtained at the intersection of the upper plane (line ABO in Fig. 3) of the pole pieces with the vertical (axis y in Fig. 3) of the middle of the inter-pole gap (point 0 in Fig. 3). In this case the dimension $BO = \delta / \sin(\alpha/2)$ is taken as value δ , and $(L + \delta)$ is substituted by dimension $AO = [L + \delta / \sin(\alpha/2)]$. This gives

$$k = \frac{\delta / \sin(\alpha/2)}{L + \delta / \sin(\alpha/2)} = \frac{\delta}{\delta + L \cdot \sin(\alpha/2)}. \quad (4)$$

Thus, the magnetic field strength at the points over the middle of the inter-pole gap of the inclined poles is expressed as

$$H_{\alpha}(y) = U_0 \frac{0.5}{K(k)} (L + \delta / \sin \alpha / 2) / (S_1 \cdot S_2), \quad (5)$$

where S_1 , S_2 and k are found by (3) and (4), respectively.

At the known values L , δ and α the calculation by (5) is not difficult if the following recurrence formula from [11] is used for approximate determination of $K(k)$ (to four decimal places):

$$K(k) = \sum_{i=0}^{\infty} (1-k^2)^i \cdot [a_i + b_i \cdot \ln(1/(1-k^2))],$$

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 (5) it should be noted that qualitative dependences of $H_{\alpha}(y)$ depending on certain parameters (for the case of inclined pole plates) are identical with the analogous dependences for the case of single-plane poles. This identity is provided by assumed similarity of formulae for $H_0(y)$ and $H_{\alpha}(y)$. Note that when $\alpha = 180^\circ$ the formula (5) agrees with the expression (2).

Experimental verification. The verification of formula (5) was carried out by physical model of iron separator P160 (scale 1:5). The experimental data including magnetic field strength over the middle of the inter-pole gap of the physical model of iron separator P160 ($\delta = 24$ mm, $L = 106.5$ mm, $\alpha = 155^\circ$, $U_0 = 7695.34$ A) are given in Table 1. They show good coincidence of calculated results by the proposed formula with experimental results.

Table 1

Distance y , mm	Magnetic field strength, A/m		Error, %
	Calculation by formula (5)	Experimental data	
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	67611	-0.56
45	59278	60479	-1.99
50	52780	54113	-2.46
55	47390	48512	-2.37

Besides, the formula (5) was verified by comparison of experimental data for industrial specimen of iron separator P100M, given in [5], with the results calculated using (5) for corresponding dimensions (see Table 2 in column "Error", i.e. error of determination of magnetic field strength in the operating zone of iron separator P100M ($\delta = 85.4$, mm, $L = 350$ mm, $\alpha = 120^\circ$) over the middle of the inter-pole gap). For this case, there is no numerical value of U_0 for iron separator P100M and Table 2 includes calculated relative magnetic field strength $H^* = H_{\alpha}(y) / U_0$. The truth of the calculated data was proved by ratio of experimental value H_e^* from [5] to H^* , which is constant, independent of

y according to (5).

The analysis of data given in Table 2 reveals that the formula (5) provides an acceptable accuracy for practical calculations.

Table 2

y , mm	Magnetic field strength		Ratio H_e^* / H^* , A	Average value of H_e^* / H^*	Deviation from average value, %
	Calculation H^* , 1/m	Experimental data, absolute value, H_e^* , A/m			
42.7	4.46391	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	2.17151	7940	3656.38		-5.1
242.7	1.70315	6130	3599.22		-6.6

Conclusion. The approximate expression is obtained to calculate the magnetic field strength at the points over the middle of the inter-pole gap of inclined poles. The proposed formula (5) can be recommended for the preliminary design of suspended iron separators when it is required to determine the magnetic field strength at the points over the middle of the inter-pole gap of a U-shaped magnetic system.

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СПРОЩЕНИЙ РОЗРАХУНОК НАПРУЖЕНОСТІ МАГНІТНОГО ПОЛЯ НАД СЕРЕДИНОЮ ЗАЗОРУ ДВОПОЛЮСНОГО МАГНІТНОГО ЗАЛІЗОВІДОКРЕМЛЮВАЧА

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Видобування небажаних ферромагнітних предметів з різних сипучих матеріалів, що транспортуються стрічковими конвеєрами, найважче забезпечити через максимальну товщину шару очищеного матеріалу для ділянки середини конвеєрної стрічки. Визначено завдання отримання наближеної формули для вихідного проектного значення напруженості магнітного поля в точках, розташованих над серединою зазору між похилими полюсними наконечниками П-подібної магнітної системи. Шуканий розрахунковий вираз отримано за відомою формулою для розрахунку плоскопаралельного поля двох розташованих в одній площині нескінченних пластин. Виконане відповідним чином її перетворення дало змогу знайти вираз для розрахунку поля між похилими поверхнями полюсних наконечників. Експериментальна перевірка, проведена на фізичній моделі та промислового зразку, підтвердила прийнятність запропонованої формули для попередніх етапів розрахунків підвісних залізовідокремлювачів. Бібл. 11, табл. 2, рис. 3.

Ключові слова: розрахунок магнітного поля, електромагнітний залізовідокремлювач, П-подібна магнітна система, плоскопаралельне поле нескінченних пластин, похилий полюс.

УПРОЩЕННИЙ РАСЧЁТ НАПРЯЖЕННОСТИ МАГНИТНОГО ПОЛЯ НАД СЕРЕДИНОЙ ЗАЗОРА ДВУХПОЛЮСНОГО МАГНИТНОГО ЖЕЛЕЗОУДЕЛИТЕЛЯ

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Извлечение нежелательных ферромагнитных предметов из различных сыпучих материалов, транспортируемых ленточными конвейерами, наиболее трудно обеспечить ввиду максимальной толщины слоя очищаемого материала для области середины конвейерной ленты. Поставлена задача получения приближенной формулы для исходного проектного значения напряженности магнитного поля в точках, расположенных над серединой зазора между наклонными полюсными наконечниками П-образной магнитной системы. Искомое расчётное выражение получено на основе известной формулы для расчёта плоскопаралельного поля двух расположенных в одной плоскости бесконечных пластин. Выполненное соответствующим образом её преобразование позволило найти выражение для расчёта поля между наклонными поверхностями полюсных наконечников. Экспериментальная проверка, проведенная на физической модели и промышленном образце, подтвердила приемлемость предложенной формулы для предварительных этапов расчётов подвесных железозуделителей. Библ. 11, табл. 2, рис. 3.

Ключевые слова: расчёт магнитного поля, электромагнитный железозуделитель, П-образная магнитная система, плоскопаралельное поле бесконечных пластин, наклонные полюса.

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