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THE SUSPENDED MAGNETIC SEPARATOR WITH LARGE BLOCKS FROM NdFeB MAGNETS AND ITS LONG TERM TECHNOLOGICAL TESTS

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ABSTRACT

The article presents a separator whose magnetic circuit is comprised of large blocks from permanent NdFeB magnets and the knowledge gained from its assembly. In the separation zone of this separator, significantly higher values of magnetic induction were reached in comparison with a similar circuit with ferrite magnets. The results of the long-term comparative technological tests are provided of this separator when used in an industrial plant for the separation of undesirable ferromagnetic admixtures and objects (tramp iron) from raw materials for tile production. Throughout these tests, the fundamental influence of the value of magnetic induction in the separation zone on the amount of the captured magnetic fraction was confirmed and high efficiency of the new separator proven.

KEYWORDS: magnetic separation, magnetic separators, magnetic circuits, permanent NdFeB magnets, technological innovation

1. INTRODUCTION

Permanent magnets on the basis of rare earths (particularly NdFeB) have been placed in various types of magnetic separators for a number of years already. Their use for example in cylindrical and drum separators has enabled an increase in efficiency and economical feasibility of high-intensity magnetic separation (Arvidson and Henderson, 1997), (Arvidson, 2001). They have also been used in magnetic filters, grates and rods, as well as in suspended magnetic separators. The new types of industrially produced permanent NdFeB magnets are characterized by the ever-growing values of the maximum energy product $(BH)_{max}$ achieved (currently already higher than 400 kJ/m^3) and simultaneously constantly growing dimensions. Manipulation with them in the magnetized state is therefore substantially more difficult than in the case of ferrite magnets with $(BH)_{max}$ reaching roughly 30 kJ/m^3. This arises from the rapidly growing great force with which these magnets act on themselves mutually as well as on the surrounding ferromagnetic objects. A prerequisite for use of these large magnets (or even much larger blocks consisting of such large magnets) in any equipment is safe managing of these large forces throughout the magnetic circuit assembly.

By assembling small blocks of permanent magnets, it is possible to build up larger wholes, allowing the creation of static or variable, uniform or non-uniform magnetic fields (Coey and Mhíocháin, 2001). The questions of creating a strong static magnetic field by using magnets from rare-earth elements have been dealt with by Marble (Marble, 2008). He derives an ideal magnetization pattern, leading to the strongest possible stray field, and proposes designs for the magnet assemblies that approximate the ideal 2-D magnetization model in a practical implementation. For application in equipment for magnetic separation, the successful management of further consequential work, resolving the problem of creating this strongest magnetic field in a sufficiently large separation zone, is however indispensible.

Suspended magnetic separators above conveyor belts are intended for the capture of undesirable ferrous objects randomly appearing in various transported materials. They are used primarily as protection of the subsequent technological equipment from damage – for instance in treating plastic or glass wastes, etc. They can, however, also significantly contribute to increasing the purity of the transported material or input raw material, because undesirable ferromagnetic admixtures, contained for example in input raw materials for tile production, negatively affect the quality of the final products. For the capture of these admixtures, converted in the course of further raw-material treatment into a form of fine ferrous abrasions, e.g. discontinuous high-gradient magnetic filters with ferrite or NdFeB magnets are used, inserted in various places in the technological line. It is apparent that capturing the greatest share of ferromagnetic admixtures possible right at the beginning of the line still before the entry of the raw materials for further treatment is more effective than the substantially more demanding capture of these admixtures after their pulverization. It thus lowers the burden on the mentioned magnetic filters and opens a path to increasing the quality of the production.

If the transported material contains only small amounts of occasionally appearing ferrous objects, it is possible to use a simple suspended magnetic separator with manually periodically controlled cleaning mechanism above the conveyor belt. If there is a greater amount of this tramp iron in the transported material, belt suspended magnetic separators are used, enabling a continuous automatic removal of the captured magnetic admixtures and objects from the area of the magnetic field. In both of the mentioned cases, the magnetic field can be created by permanent magnets or an electromagnet.

For effective magnetic separation, both a strong magnetic field and a high value of its gradient are equally important (Gerber and Birss, 1983). Suspended separators with permanent magnets achieve lower values of magnetic induction in the separation zone in comparison with electromagnets. Magnetic force is proportional to the product of the magnetic induction of the outer magnetic field and its gradient and has the direction of the gradient (Svoboda and Fujita, 2003). This force is too little particularly with the suspended separators with ferrite magnets, so far most used, and often does not allow the capture of ferromagnetic objects or elements. As is stated in Theory of the Magnetic Separation of Elements by a Suspended Magnet (Svoboda, 2004), in the case of a body at rest the vector of the minimum magnetic force necessary for moving an object is determined by the sum of the vectors of the gravitational force and the force of the load of the material above the body. It is precisely this burdening by the material determined by the depth of the layer and the type of material being transported on the conveyor belt that significantly influences the strength of the magnetic force necessary for the capture of the body. Especially in the case of a thicker layer of material that is difficult to separate, like wet sand or clay, it is practically impossible for the separator with ferrite magnets to capture an object lying directly on the belt under this layer. An increase in the effectiveness of the separation can be reached either through reducing the thickness of the layer of the material on the belt (which, however, results in a lowering of the performance of the technological line) or through bringing the magnets of the separator closer to the surface of the material being transported. In using a simple suspended separator without a discharging belt, bringing the magnets too close to the layer of the material can cause the objects that have already been captured to be pulled into the transported material.

For completeness, it is necessary to state that the method of work and results achieved, which are presented below in this article, build directly on the results of previous work in assembling a smaller trial magnetic circuit for suspended magnetic separators (Žežulka, 2010). Just like before with magnetic filters, the use of large magnetic blocks from NdFeB magnets also in this case provided significantly higher values of magnetic induction in the separation zone in comparison both with the circuit with ferrite magnets and with the circuit with only one layer of large NdFeB magnets.

2. AIM OF THE WORK

On the basis of the results achieved in the previous development, it was decided to propose and assemble using large blocks from NdFeB magnets a larger magnetic circuit for a functional model of a suspended magnetic separator with a high value of magnetic induction in the separation zone. It was further decided to install this functional model above the conveyor belt in the technological line in an industrial plant for long-term tests, allowing a comparison of the capability of capturing undesirable ferromagnetic admixtures from the transported raw materials of this new separator with a similarly sized, currently used separator with ferrite magnets.

3. WORK METHODOLOGY

3.1. *THE MAGNETIC CIRCUIT AND THE MEASUREMENT OF MAGNETIC INDUCTION B = f(x)*

The magnetic circuit for a functional model of a suspended separator was equipped with the same twelve magnetic blocks with ground-plan dimensions of 0.16 x 0.107 m and a height of 0.09 m. Each block of an overall weight of approximately 11 kg was assembled from three compact plates placed on top of one another with the same ground-plan dimensions as the block and with a height of 30 mm. The individual compact plates consisted of six pieces of NdFeB magnets with dimensions of 0.05 x 0.05 x 0.03 m, inserted in the perimeter frame from non-magnetic stainless steel. After each plate was sealed with epoxy resin and it hardened, it was magnetized as a whole. All plates were magnetized in the same direction.

In the whole circuit, thirty-six compact plates were hence inserted with a total of 216 magnets from the N45 material with the following parameters: remanence B_r = 1.354T, coercivity H_{cb} = 956 kA/m, H_{cj} = 992 kA/m, energy product $(BH)_{max}$ = 348 kJ/m^3.

For the assembly of the magnetized compact plates into blocks, the method (Žežulka et al., 2010) making it possible to control the speed of attraction of the magnets in their assembly in the direction perpendicular to the future common contact surface was used again. The magnetic plates in this case are gradually inserted in the tube of the equipment, filled with a liquid (e.g. hydraulic oil), with the mutually adjacent surfaces of the magnets having the opposite polarity. This method also makes it possible to eliminate partial demagnetization of the magnets (or magnetic plates) during their assembly (Žežulka and Straka, 2008). All blocks were the same polarity after assembly.

The magnetic blocks were gradually inserted in the steel circuit, composed of an iron base plate of a thickness of 0.034 m and of attached side plates from non-magnetic stainless steel. The completely assembled magnetic circuit having a ground-plan area of all twelve magnetic blocks of ca 0.43 x 0.48 m is shown in Fig. 1. In this case, the circuit is in the position for a subsequent measurement of magnetic induction after its assembly is completed; in the working position, it is then turned with the surface of the magnets towards the conveyer belt.

In the next stage of the work, the magnetic induction B_{max} was measured in dependence on the distance from the surface of the magnets x. The maximum magnetic induction, achieved at some point on the surface parallel to the surface of the magnets at distance x above the surface of the magnets, was determined using a method similar to that employed in the previous work (Žežulka, 2010).

3.2. THE SUSPENDED MAGNETIC SEPARATOR

By complementing the magnetic circuit with further parts (a stainless-steel cover sheet, a bottom stainless-steel slide-out plate, the bearing construction), the functional model of the new magnetic separator above a conveyor belt with the DMON 43/48 type label (see Fig. 2) was created, similar to the DMO 40/45 type separator with ferrite magnets, introduced in recent years in diverse plants in the Czech Republic.

The new separator including the magnetic circuit and technology of assembling magnetic blocks was developed at the Institute of Rock Structure and Mechanics, ASCR, v.v.i.

3.3. THE LONG-TERM TECHNOLOGICAL TESTS

These tests were conducted at the factory of Lasselsberger, s. r.o. in Chlumčany intermittently for a period of approximately six months. The new DMON 43/48 separator was mounted on the central conveyor belt of the Dlaždice (Tile) II production plant for separating undesirable ferromagnetic admixtures and objects from the raw materials for the production of tiles. In the first stage of the trials, it was placed in a series after the existing DMO 40/45 magnetic separator with ferrite magnets (see Fig. 3, the DMON 43/48 separator on the left as the second in the direction of movement of the raw material). The individual raw materials (sand, clay, feldspar, kaolin) were gradually dosed from the bunkers at the beginning of the technological line to the central conveyor belt in the required proportion for the type of tiles being produced and further transported as selected into one of two mills with continuous or discontinuous operation. In the course of the trials, the fed raw materials were often damp or wet (sand, clay, the clay moreover in the form of lumps), hence in a state not very suitable for magnetic separation. However, since the same raw material always passed gradually under both magnetic separators, it was possible to rule out the influence of the type of raw material and its state in a mutual comparison of both separators. For the same reason, it was possible to exclude also other variables – the influence of the depth of the layer of the raw material on the conveyor belt, the grain size of this raw material and a possible change of the speed of the belt's movement.

In each test (by extracting the magnetic fraction) the data of the amount of raw material passed for the period from the previous extraction (or from the beginning of the first stage in the first test) was subtracted from the belt scales. This period of the length of the individual tests differed and depended on the amount of admixtures captured on the separators and time possibilities for conducting the extraction. In this context, it is necessary to bear in mind that the described tests took place under normal production operation, to which it was necessary to adjust also the conduct of the tests. The detail of the tramp iron (of the magnetic fraction), captured on the slide-out plate of the DMON 43/48 separator before conducting the extraction is depicted in Figure 4. The actual extraction took place such that all falling magnetic fraction was captured independently from each separator after the extraction of the slide-out plate and its net weight was determined by weighing.

In the second stage of the tests, the order of the separators was changed and the DMON 43/48 separator was placed first on the conveyor belt in the direction of the movement of the raw material. The method of the trials was like in the previous stage.

4. RESULTS AND DISCUSSION

4.1. THE MEASUREMENT OF MAGNETIC INDUCTION

The values of magnetic induction of the new magnetic circuit with NdFeB blocks measured in dependence on the distance from the surface of the magnets $B_{max}=f(x)$ are listed in Table 1. For comparison, it also provides the earlier measured values of similar circuits in terms of the construction and dimensions with ferrite magnets, used in the case of DMO separator. A graphic depiction of both dependencies is shown in Figure 5.

After the installation of DMON separators above the conveyor belt, the magnetic induction of both separators was measured again, always under their centre on the surface of the belt and for all of the settings of the height of the slide-out plate above the belt. From Table 1 and Figure 5, it is clear that these measured values are still higher in all these cases than the values of magnetic induction at the corresponding distances from the surface of the magnets measured on the magnetic circuits alone. It is caused by the fact

Table 1 The measured and reference values of magnetic induction B_{max}=f(x).
*) The values of the setting of the height of the slide-out plate above the conveyor belt (a total of five data) and the corresponding magnetic induction during technological tests (see Tables 2 and 3).

Distance from the surface of the magnets x [mm]	The height of the slide-out plate of the separator above the surface of the conveyor belt [mm]	Magnetic induction B_{max} [T]			
		DMO 40/45 magnetic separator with ferrite blocks		DMON 43/48 magnetic separator with NdFeB blocks	
		Magnetic circuit measured without the bearing construction	Measured at the site of installation	Magnetic circuit measured without the bearing construction	Measured at the site of installation
0		0.151		0.573	
4		0.138		0.441	
10				0.377	
20				0.324	
30		0.104		0.281	
40		0.091		0.253	
50		0.082		0.235	
60		0.073		0.223	
70		0.065		0.207	
80		0.056		0.194	
100		0.046		0.173	
120		0.036		0.154	
140				0.136	
160				0.121	
180				0.107	
184	175*)				0.113
193	187		0.036		
200				0.095	
209	200				0.098
216	210		0.031		
234	225				0.084
250				0.069	
300				0.051	
350				0.039	
400				0.029	

that both the additionally attached bearing construction of the magnetic separator and the conveyor frame are produced from common ferromagnetic steel and as a result of a substantially lower magnetic resistance as against the air make it possible to reduce losses caused by stray partially and thus strengthen the magnetic field at the place of measurement.

It is evident from the measured values that in the case of the new DMON magnetic separator it was possible to reach in the operative range of the settings of the height of the separator above the conveyor belt more than three times greater values of magnetic induction in the separation zone as compared with the separator with ferrite magnets.

4.2. THE RESULTS OF THE FIRST AND SECOND STAGES OF THE TECHNOLOGICAL TESTS

The data acquired during the first stage of the technological tests are shown in Table 2 and the data from the second stage in Table 3.

4.3. THE EVALUATION OF THE TECHNOLOGICAL TESTS

For the evaluation of the tests, it is necessary to bear in mind that in this specific case it is the separation of various raw materials with the random appearance of ferromagnetic admixtures, whose content in the raw materials being separated is not constant but on the contrary quite variable over time. During the tests, diverse components and parts,

Table 2 The first stage of the technological tests of the DMON 43/48 magnetic separator mounted on the central belt after the existing DMO 40/45 separator in the direction of movement of the transported material.

Test Number	Amount of material passed [t]	The height of the slide-out plate above the conveyor belt [mm] in the case of the separator		Magnetic induction [T] on the surface of the belt in the centre under the separator		The weight of the magnetic fraction [kg] captured by the separator		The percentage share of the total weight of the magnetic fractions captured by both separators [%] in the case of the separator		The weight of the magnetic fraction, recalculated to 1000 t of passed raw material [kg/1000 t] captured by the separator	
		DMO 40/45	DMON 43/48	DMO 40/45	DMON 43/48	DMO 40/45	DMON 43/48	DMO 40/45	DMON 43/48	DMO 40/45	DMON 43/48
1	3 300	210	225	0.031	0.084	0.453	1.768	20.4	79.6	0.137	0.536
2	2 680	210	225	0.031	0.084	0.75	1.6	31.9	68.1	0.28	0.597
3	4 105	210	200	0.031	0.098	0.619	0.862	41.8	58.2	0.151	0.210
4	4 010	210	200	0.031	0.098	0.665	2.199	23.2	76.8	0.166	0.548
5	861	187	200	0.036	0.098	0.784	0.313	71.5	28.5	0.911	0.364
6	1 389	187	200	0.036	0.098	1.647	2.49	39.8	60.2	1.186	1.793
7	3 500	187	175	0.036	0.113	0.351	0.751	31.9	68.1	0.1	0.215
8	1 369	187	175	0.036	0.113	0.306	0.352	46.5	53.5	0.224	0.257
9	3 864	187	175	0.036	0.113	0.487	0.984	33.1	66.9	0.126	0.255
10	3 772	187	175	0.036	0.113	0.444	1.356	24.7	75.3	0.118	0.359
The Total [kg]	-	-	-	-	-	6.506	12.675	-	-	-	-
The Share [%]	-	-	-	-	-	33.9	66.1	-	-	-	-

Table 3 The second stage of the technological tests of the DMON 43/48 magnetic separator mounted on the central belt before the existing DMO 40/45 separator in the direction of movement of the transported material.

Test Number	Amount of material passed [t]	The height of the slide-out plate above the conveyor belt [mm] in the case of the separator		Magnetic induction [T] on the surface of the belt in the centre under the separator		The weight of the magnetic fraction [kg] captured by the separator		The percentage share of the total weight of the magnetic fractions captured by both separators [%] in the case of the separator		The weight of the magnetic fraction, recalculated to 1000 t of passed raw material [kg/1000 t] captured by the separator	
		DMON 43/48	DMO 40/45	DMON 43/48	DMO 40/45	DMON 43/48	DMO 40/45	DMON 43/48	DMO 40/45	DMON 43/48	DMO 40/45
11	2 922	175	187	0.113	0.036	1.321	0.0341	97.5	2.5	0.452	0.012
12	2 593	175	187	0.113	0.036	1.318	0.0738	94.7	5.3	0.508	0.028
The Total [kg]	-	-	-	-	-	2.639	0.1079	-	-	-	-
The Share [%]	-	-	-	-	-	96.1	3.9	-	-	-	-

screws, washers, wires, the remnants of welding electrodes etc. were captured along with for example also fine ferrous abrasions, which were apparently created during a previous treatment of feldspar. The size, shape and position of these admixtures with respect to the direction of the magnetic field in the separation zone of the separator are thus also very varied. It is possible to mention as an example Test 2 in the first stage (Tab. 2), when one small steel plate, captured already by the DMO separator, substantially influenced the mutual proportion of the magnetic fractions captured by both separators. The position of this small plate in the raw material being transported was such that it could be captured by the weaker magnetic field of the DMO separator. However, if such a plate had lain directly on the surface of the belt, burdened by the transported material, it would not have been captured until by the substantially stronger magnetic field of the DMON separator and the proportion of captured magnetic fractions would have significantly changed in favor of DMON. A similar situation appeared also with some other tests, to the greater extent in Test 5 (Tab. 2), which was the only one where the weight of the magnetic fraction captured by the DMO separator was greater than with DMON. It is therefore not possible to draw conclusions from a single extraction of the magnetic fractions captured in one test, but it is necessary to analyze a greater number of tests in long-term operation.

The whole course of the tests clearly confirmed the determinant influence of the magnitude of magnetic induction on the results of the separation and the high efficiency of the new separator. Although it was placed second in order in the first stage (in the direction of movement of the raw material), it captured on average roughly twice the weight amount of the magnetic fraction in comparison with the DMO separator.

After changing the order of the separators in the second stage, only two tests were conducted for time reasons. It was claimed that the DMON 43/48 separator captured an average of 96.1 % of the total weight of the magnetic fractions on both separators and the DMO separator as the second was thus practically unnecessary.

From the results of the first stage of the tests, it arises that the existing DMO separator with ferrite magnets captured only 33.9 % of the total weight of the magnetic fractions captured on both separators (the range of the results of individual tests ran from 20.4 to 71.5 %). In the original setting of the DMO at a height of 210 mm above the belt, used in the long term during the operation of the line, this relative value is even lower and is approximately 27.9 % (the results of four tests being between 20.4 and 41.8 %). Based on the results presented, it can thus be stated that more than two-thirds of the total weight of the admixtures captured at the present time on both separators had passed without being captured into the technological line with all of the negative effects before the usage of DMON 43/48.

What was also monitored with both separators was the influence of their height setting above the conveyor belt, which determines for the given type of magnetic circuit (with ferrite or NdFeB magnets) the magnitude of magnetic induction in the separation zone. The separator (its slide-out plate) should be set as close above the belt as possible without however hindering the passage of the material being separated and also the captured objects must not be pulled by the transported material. Because of its being necessary to maintain a relatively narrow range of setting of both separators for technological reasons, the increase of the magnetic induction in the separation zone was however not so significant (in the case of DMO from 0.031 T to 0.036 T, in the case of DMON from 0.084 T to 0.113 T). The influence of the corresponding relatively low increase of the attractive force on the results of the tests was thus overshadowed by the more important distinctive difference in the content of random ferromagnetic admixtures in the raw materials, which influenced these results substantially more.

The application of the new separator and the results of the tests also made it possible to acquire a more precise picture of the real content of undesirable ferromagnetic admixtures in the raw material. In the individual tests in the first stage, the total captured amount of admixtures on both separators was in the range of approximately 0.3 to 3 kg/1000 t of passed raw material, whereas the average value from all twelve tests was 0.79 kg/1000 t.

5. CONCLUSIONS

It has been proven that the proposed technology of the assembly of a magnetic circuit using large magnetic blocks from NdFeB magnets is safe and implementable also in the case of a circuit design of a larger size suitable for industrial application. In the separation zone of a suspended magnetic separator with this circuit, the value of magnetic induction attained was more than three times greater in comparison with a circuit of a similar size and construction with ferrite magnets.

The results of the long-term comparative technological tests of magnetic separators clearly confirmed the fundamental importance of the magnitude of magnetic induction on the separation results. The magnetic separator with large blocks from NdFeB magnets showed directly in industrial operation a substantially higher capability to capture ferromagnetic admixtures from raw materials for tile production in comparison with the existing separator with ferrite magnets.

The area of the possible application of the described new magnetic separator with permanent magnets and with high magnetic induction in the separation zone is very broad. It is apparent from the very satisfying results of the technological tests that its implementation would with great probability allow without demands for electrical energy consumption the achievement of distinctly more efficient capture of undesirable ferromagnetic admixtures also from various other materials or raw materials on a conveyor belt and thus also an increase in their purity for further use.

Another significant possibility for the application of a magnetic circuit with large blocks from NdFeB magnets is, for example, the area of the separation of materials with a high content of ferromagnetic admixtures in the separated material on the conveyor belt. The placement of this circuit in the suspended belt magnetic separator, discharging automatically the captured tramp iron continuously, or discontinuously, from the area of the activity of a strong magnetic field would make it possible to exclude periodical manual operation, indispensible in the case of the separator described above.

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REFERENCES

Arvidson, B.R. and Henderson, D.: 1997, Rare-earth magnetic separation equipment and applications development. Minerals Engineering, 10, no. 2, 127–137.

Arvidson, B.R.: 2001, The many uses of rare-earth magnetic separators for heavy mineral sands processing. International Heavy Minerals Conference, Fremantle.

Coey, J.M.D. and Mhíocháin, T.R.: 2001, Encyclopedia of Materials: Science and Technology. Permanent Magnet Assemblies, Elsevier Science Ltd., 6798–6805.

Gerber, R. and Birss, R.: 1983, High Gradient Magnetic Separation. Research Studies Press, John Wiley and Sons Ltd., Chichester, 37.

Marble, A.E.: 2008, Strong, stray static magnetic field. IEEE Trans. Magn., 44, no. 5, 576–580.

Svoboda J. and Fujita T.: 2003, Recent developments in magnetic methods of material separation. Minerals Engineering, 16, no. 9, 785–792.

Svoboda J.: 2004, Magnetic techniques for the treatment of materials. Kluwer Academic Publishers, Dordrecht, 172–181.

Žežulka, V. and Straka, P.: 2008, Methods of assembling large magnetic blocks from NdFeB magnets with a high value of $(BH)_{max}$ and their influence on the magnetic induction reached in an air gap of a magnetic circuit. IEEE Trans. Magn., 44, no. 4, 485–491.

Žežulka V.: 2010, Magnetic circuit with large blocks from NdFeB magnets for suspended magnetic separators. Acta Geodyn. Geomater., 7, No. 2 (158), 227–235.

Žežulka, V., Straka, P. and Soukup, V.: 2010, Method of forming magnetic blocks and equipment for carrying out that method. United States Patent No: US 7,796,001 B2, Date of Patent: Sep. 14. (In the USPTO Patent Database it is necessary to search it according the number of the patent).

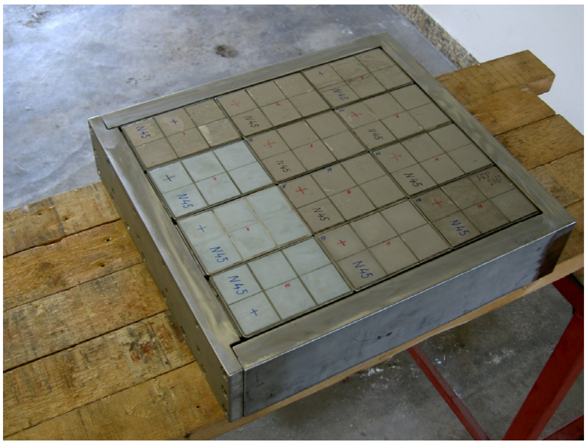

Fig. 1 A complete magnetic circuit of a separator.

Fig. 2 A suspended magnetic separator of the DMON 43/48 type.

Fig. 3 The usage of the DMON 43/48 separator (in the picture on the left) in the first stage of the technological tests.

Fig. 4 The tramp iron captured by the DMON 43/48 separator.

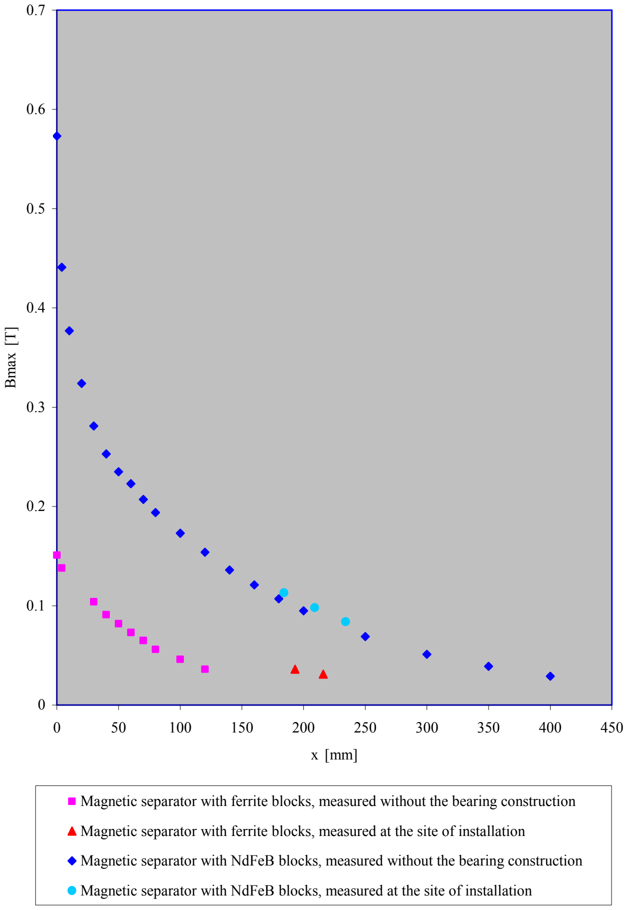

Fig. 5 A graphic depiction of the dependence $B_{max}=f(x)$.