# DEVELOPMENT OF BELT TYPE MATRIX PERMANENT HIGH GRADIENT MAGNETIC SEPARATOR ①

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**ABSTRACT** A belt type matrix permanent high gradient magnetic separator (BTMPHGMS) with middle field strength has been developed. The high gradient matrix belt circulates through the separating zone, thus providing continuous separation of magnetic minerals from nonmagnetic ones, which improves the process of the intermittent operation of common HGMS. The operating parameters are based on test work. The magnetic system consists of NdFeB permanent magnets with stored energy 255 kJ/$m^3$ and magnetizing induction intensity 1.1 T. A special magnetic circuit structure with iron-cladding is adopted to provide an optimal design, and a simple equation is derived to calculate the magnetic field strength on the basis of magnetic circuit law. The typical industrial scale tests show that the separating efficiency and performance of the BTMPHGMS are similar to those of the HGMS with electromagnetic field, but the manufacture and operating costs of the former are much lower.

**Key words** HGMS matrix belt permanent magnet kaolin purification

## 1 INTRODUCTION

With the development of permanent magnetic materials, the magnetic energy level of NdFeB magnets has approached 400 kJ/$m^3$. The evolution of high field strength permanent rare-earth magnets has made permanent magnetic system be applied widely, and has influenced the field of magnetic separation, creating various new type permanent magnet separators[1-2].

A permanent matrix producing high gradient combines the basic ideas of high gradient matrix with the permanent magnet system, and its structure is simple with innovative design providing a new approach to the development and application of permanent magnet separators. Research activities have shown that the background field strength magnetizing the steel wool matrix to saturation is feasible by use of a permanent magnetic system, which can provide a certain suitable separating space, meeting the need of the field gradient and the magnetic force required for minerals purification. The industrialization of permanent magnet separators can greatly reduce energy consumption, improve the flexibility of the production equipment and cut down the capital cost. This paper has developed a middle field intensity BTMPHGMS, and some good industrial results have been obtained.

## 2 BELT TYPE MATRIX PERMANENT HIGH GRADIENT MAGNETIC SEPARATOR (BTMPHGMS)

### 2.1 Structure

The BTMPHGMS is mainly composed of permanent magnetic system, an endless matrix belt, electromagnetic vibrating coils and a machine frame.

The magnetic system is iron-clad with NdFeB magnets forming a magnetic circuit. The magnetic induction in the magnetic field zone can reach 1.1 T. To meet the need of separating technology, the field strength in the working zone can be freely adjusted for particular application.

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The matrix belt is an endless belt woven by steel wool matrix and through two electromagnetic coils. The coils can produce a vibration of high frequency and low amplitude so that the materials to be processed are dispersed around the matrix and then captured selectively. The supporting wheel of the matrix belt is 200 mm in diameter, the distance between the two wheels is 727 mm and the separating length is 36 mm.

Fig. 1 shows the structure of BTMPHGMS.

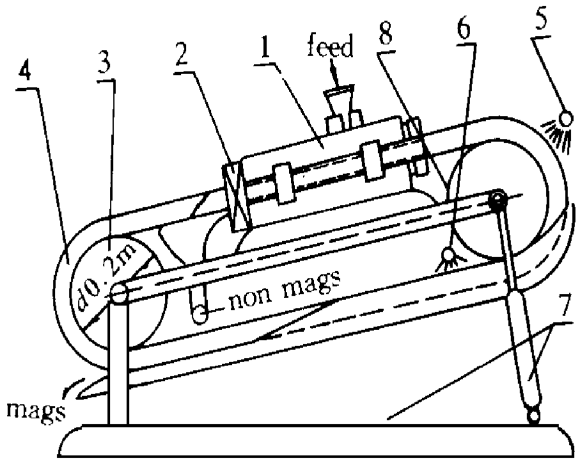


**Fig. 1 Structure of belt type matrix permanent high gradient magnetic separator**

1 —NdFeB magnetic system;
2 —electromagnetic vibrating coils;
3 —supporting wheel of the matrix belt;
4 —matrix belt;
5 —positive washing nozzle;
6 —negative washing nozzle;
7 —machine frame;
8 —driving wheel

### 2.2 Separating process

Under the motion of the driving wheel, the matrix belt circulates continuously through the separating zone. Minerals are fed onto the the matrix belt in the separating space; non-magnetic materials drop down as non-magnetic product along the inclined sluice due to gravitation action, and the magnetic materials attach to the matrix and leave the separating zone along the belt, being washed off as magnetic products by positive and negative washing of high-pressure water. The matrix belt with the collected magnetic products may be rinsed while in the magnetic zone to displace non-magnetic particles. The electromagnetic coils create vibrations to eliminate mechanical choke in the separating space and enforce the removal of magnetic materials from the matrix.

## 3 DESIGN OF MAGNETIC SYSTEM

The magnetic system of BTMPHGMS consists of NdFeB magnets with high stored magnetic energy. NdFeB magnets have the advantages of high coercivity, high remanence and linear demagnetization curve, thus simplifying the design and analysis of the permanent magnet circuit. On the basis of the magnet circuit law, the magnetic system is designed with two parts as upper and lower magnet blocks, and the distance between them can be adjusted to change the field strength. Because NdFeB magnets possess larger magnetic resistance, soft steel of engineering purity is selected as polar shoes, which are clad by iron to avoid magnetic flux leaking. The two magnet blocks form a closed circuit magnetic system. The field strength in the separating zone is homogeneous. The two dimensional model of the field strength can be expressed as:

$$B_g = \eta \frac{2B_r}{\pi} \tan^{-1} \frac{ab}{2l_g \sqrt{4l_g^2 + a^2 + b^2}} \quad (1)$$

where $B_r$ is the remanence of the magnet; $a$, $b$ are the width and length of cross-section of the magnet block along its magnetizing direction ( $a < b$ ) respectively; $l_g$ is the gap width; $\eta$ is the coefficient related to the ratio of magnet height to $a$.

## 4 SEPARATING PERFORMANCE

### 4.1 Iron removal from Liling glaze material

The presently adopted electromagnetic iron removers or manual permanent magnets soaked in mineral pulp to remove iron contaminants from glaze materials of Liling, Hunan Province, have a lower iron removing efficiency. But with the help of the BTMPHGMS, it can be improved obviously. The operating parameters are as follows: with steel wool No. 2 and No. 4 at a matched ratio of weight 1∶1 as the separating matrix, pulp density 32.3%, pulp flowrate 1.2 cm/s, matrix filling factor 3%, magnetic induction for separation 0.38T. After separating operation, the final concentrate contains $Fe_2O_3$ 0.13% with accumulated iron removal 50%. The feed glaze material contains $Fe_2O_3$ 0.21%, not only affecting the whiteness of the porcelain product, but forming stains on the surface due to coarse mechanic iron in it. After separation, not only is the whiteness improved, but the stain factor of the product can be decreased from 30% to 0.

4.1.1 Effect of dispersant dosage on the magnetic separating performance

In order to improve the separating efficiency and increase the concentrate yield, the dispersant dosage test was conducted with the pulp density up to 45.8%. Under the conditions of pulp flowrate 1.2 cm/s, matrix filling factor 2% and $Fe_2O_3$ content in the feed glaze material 0.21%, after one pass of operation, the separating result was got shown as Table 1.

**Table 1 Effect of dispersant dosage on the separating result**

| Dispersant dosage / $kg \cdot t^{-1}$ dry ore | Product | Yield / % | $Fe_2O_3$/ % | |
|---|---|---|---|---|
| | | | Content | Distribution |
| 0 | Concentrate | 97.46 | 0.19 | 89.6 |
| | Tailings | 2.54 | 0.84 | 10.4 |
| 0.5 | Concentrate | 98.82 | 0.15 | 71.9 |
| | Tailings | 1.18 | 4.91 | 28.1 |
| 1.0 | Concentrate | 98.96 | 0.14 | 67.7 |
| | Tailings | 1.04 | 6.50 | 32.3 |
| 2.0 | Concentrate | 99.06 | 0.13 | 62.5 |
| | Tailings | 0.94 | 8.23 | 37.5 |

Note: $Fe_2O_3$ contents in the feeds are all 0.21%.

4.1.2 Effect of pulp density on the magnetic separating performance

In order to meet the needs of industrial production, pulp density tests were carried out. In the absence of dispersant, under the conditions of pulp flowrate 1.2 cm/s and matrix filling factor 1.5%, the separating result is shown in Table 2. From Table 2 it can be seen that the separating result deteriorates with increasing pulp density, which is because the increase of the pulp density results in the deterioration of pulp rheologic behavior. The separation is still effective when the pulp density increasing up to 45.3%.

**Table 2 Effect of the pulp density on the separating result**

| Pulp density / % | Product | Yield / % | $Fe_2O_3$/ % | |
|---|---|---|---|---|
| | | | Content | Distribution |
| 45.3 | Concentrate | 96.98 | 0.19 | 88.7 |
| | Tailings | 3.02 | 0.78 | 11.3 |
| 39.9 | Concentrate | 97.98 | 0.18 | 84.8 |
| | Tailings | 2.02 | 1.56 | 15.2 |
| 35.6 | Concentrate | 98.22 | 0.17 | 80.3 |
| | Tailings | 1.78 | 2.30 | 19.7 |
| 31.0 | Concentrate | 98.45 | 0.16 | 75.8 |
| | Tailings | 1.55 | 3.24 | 24.2 |

Note: $Fe_2O_3$ contents in the feeds are all 0.21%.

## 4.2 Iron removal from Liling kaolin

Liling area, in Hunan Province, China, has rich kaolin reserve and abounds in porcelain. But kaolin in this place can not be utilized due to its high $Fe_2O_3$ content and low quality[3]. Kaolin used to produce porcelain in Liling has to be purchased and transported in from other places. In this case the developed BTMPHGMS was used to study iron removal, which has made Liling kaolin become the high quality kaolin that can be used to produce extra-fine porcelain.

Liling kaolin has original $Fe_2O_3$ content more than 0.77%. Using CL*d* 500 vibrating and pulsating HGMS to remove iron from Liling kaolin can meet the quality requirement. But the machine with great energy consumption and high manufacture cost can only run in a low field strength. Substituting BTMPHGMS for it can reach the same efficiency.

Comprehensive tests were carried out with the BTMPHGMS: at the pulp density 35%, after 4 passes of operation, $Fe_2O_3$ content in the concentrate was reduced to 0.6% with a concentrate yield of 92.79%. At pulp density 20%, one pass of operation reduced $Fe_2O_3$ content in the concentrate to 0.66% with a concentrate yield of 98.71%.

## 4.3 Effect of different matrices on the sepa-

**rating performance**

In order to investigate the matched relation between the matrix size and the material particle size, iron removing tests were carried out by use of different matrices. In the case of pulp density 35%, different separating results have been obtained (see Table 3).

From Table 3, it can be seen that when only steel wool No. 2 is used, the concentrate yield is low and $Fe_2O_3$ content is high; when only coarse steel wool No. 4 is used, the concentrate yield is improved and $Fe_2O_3$ content in the magnetic product becomes high, but $Fe_2O_3$ content in the concentrate can not reach the optimal point; when both steel wool No. 2 and No. 4 are used as matched matrix in the test, the best results are obtained at the matched ratio 1∶2.

**Table 3 Effect of different matrices on the separating result**

| Matrices | Product | Yield / % | $Fe_2O_3$ / % | |
|---|---|---|---|---|
| | | | Content | Distribution |
| No. 2 | Concentrate | 90.45 | 0.71 | 83.4 |
| | Tailings | 9.55 | 1.34 | 16.6 |
| No. 2+ No. 4 (3∶4 in mass) | Concentrate | 93.37 | 0.68 | 82.5 |
| | Tailings | 6.63 | 2.04 | 17.5 |
| No. 2+ No. 4 (1∶2 in mass) | Concentrate | 94.97 | 0.68 | 83.9 |
| | Tailings | 5.03 | 2.47 | 16.1 |
| No. 4 | Concentrate | 96.68 | 0.69 | 86.6 |
| | Tailings | 3.32 | 3.10 | 13.4 |

Notes: Specification of steel wool No. 2 is (60~ 90) μm × (30 ±5) μm; specification of steel wool No. 4 is (120~ 150) μm × (40 ±5) μm; $Fe_2O_3$ contents in the feeds are all 0.77%.

### 4.4 Comparison between the separating results of the permanent and the electromagnetic HGMSs

In the case of pulp density 35%, the separating results of kaolin by the permanent and electromagnetic HGMSs are listed in Table 4. It can be seen that the BTMPHGMS can reach the same separating level as electromagnetic HGMS, if not better. This means that permanent HGMS can be substituted for electromagnetic HGMSs. But the application of the former can greatly cut down operation cost, improve the flexibility of the equipment and reduce the manufacture cost of the equipment. It is specially suitable for the purification of porcelain materials in medium-sized and/or small-scale kaolin factories.

**Table 4 The separating result of kaolin by different HGMSs**

| Test equipment | Magnetic induction / T | $Fe_2O_3$ / % | | Iron removal / % |
|---|---|---|---|---|
| | | Feed | Concentrate | |
| Belt type separator | 0.35 | 0.77 | 0.69 | 13.40 |
| CL $d$500 HGMS | 0.35 | 0.77 | 0.70 | 12.10 |

## 5 CONCLUSION

Using iron-cladding technique, a new homogeneous magnetic field is designed on the basis of magnetic circuit laws.

The medium field strength BTMPHGMS possesses the advantages of simple structure, reliable performance, convenient operation, low capital and reliable operation. It adopts matrix vibration arrangement, making magnetic particles attach to the matrix and excluding mechanical choke of matrix[4]. Magnetic materials can be completely discharged under the action of positive and negative washing of high-pressure water.

Industrial tests showed that the medium field strength BTMPHGMS can replace electromagnetic HGMS to remove iron from raw porcelain materials and has wide prospects of application.

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