

## DEVELOPMENT AND APPLICATIONS OF A DRUM MEDIUM–INTENSITY PERMANENT MAGNETIC SEPARATOR

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### Abstract

This paper describes the development and testing of a drum medium–intensity permanent magnetic separator. The magnetic field strength on the drum surface can be increased to 0.8 T using a new magnet technology. Uniform distribution of a feed can be achieved with a two–stage feed system. Industrial tests were carried out using a manganese mineral from DouLan manganese mine. The results obtained show that good separation results can be obtained using the separator, with upper limit of the separation size being 30 mm.

### INTRODUCTION

In recent twenty years dramatic advances were made in mineral magnetic separation technology. Jones high–intensity magnetic separator and SALA high–gradient magnetic separator came out one after another in the 1960s and 1970s, making the technology reach a relatively high level.

Compared with the above magnetic separation technique, a medium–intensity magnetic separator remains at a primary level, with poor adaptability and high cost. The appearance, in the mid 1980s, of Nd–Fe–B permanent magnetic material, two to three times cheaper than Sm–Co permanent magnet material, laid a reliable technical foundation for the development of a medium–intensity

magnetic separator, making its development and application possible economically and technically.

As expected, with the appearance of a permanent magnetic material with even higher magnetic energy product, development of magnetic separation technology will certainly advance in the course of permanent magnet–electromagnetic permanent magnet types.

Drum medium–intensity magnetic separators with Nd–Fe–B permanent magnetic materials were developed in Germany and USA in 1989. The separators have been used to concentrate some weakly magnetic minerals and to remove feebly magnetic impurities from some materials, and good results have been obtained. The peak magnetic field intensity on the drum surface of the separators was 0.67 T and 0.70 T, respectively,

China has abundance of feebly magnetic minerals. However, there is not a kind of medium–intensity magnetic separator suitable especially for weakly magnetic materials. In the past few decades a relatively large amount of coarse material which was not subjected to pre–concentration directly entered a ball mill due to the lack of suitable separation equipment for coarse material, resulting in energy losses.

On the other hand, for ores from some mines a high–grade concentrate can be obtained at coarse size fractions. However, the ore must be ground finely because of nonexistence of efficient separation equipment for coarse material. Such an approach increases the energy consumption and reduces the percentage of a lump concentrate because the coarse feed had to be milled by the existing grinding equipment suitable for coarse material.

In order to solve the above problem, we have developed, over a period of several years, a drum medium–intensity magnetic separator. Good technological results have been obtained in separation of ilmenite and of coarse manganese ore.

## DESIGN OF A DRUM MEDIUM-INTENSITY MAGNETIC SEPARATOR

### Design of a Magnetic Circuit

At present, various high-intensity magnetic separators, Jones high-intensity magnetic separators or induced-roll high-intensity magnetic separators use a closed magnetic circuit. In order to increase the magnetic field strength, the separation gap should be small. The key to the design of the drum permanent medium-intensity magnetic separator lies in its magnet. If it has a traditional open circuit it cannot generate a high field strength, even when Nd-Fe-B permanent magnetic material is used.

Through several years of thorough research, a higher magnetic field strength has been achieved with an extrusion type open magnetic circuit of a high-intensity magnetic field. In this magnetic circuit, three co-polar magnets sit opposite one another, concentrating their magnetic lines in the same direction. The peak field strength on the surface of the magnet can be up to 1.4 T, and the peak field strength of the drum surface can be as high as 0.8 T. A test curve of the magnetic field strength of a 600x1200 mm dry permanent medium-intensity magnetic separator is shown in Fig. 1 while a test curve of the magnetic field strength of a 1000x2400 mm wet permanent medium-intensity magnetic separator is given in Fig. 2.

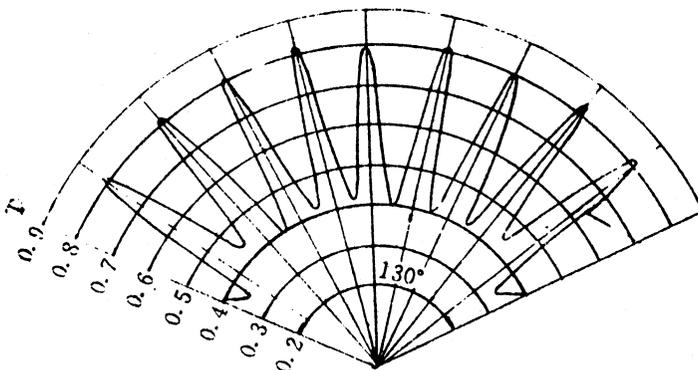


Fig. 1 A test curve of the magnetic field strength on the drum surface of a dia. 600x1200 mm dry permanent medium-intensity magnetic separator

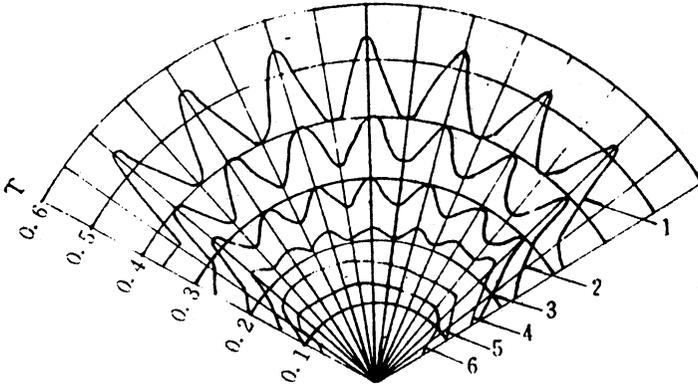


Fig. 2 A test curve of the magnetic field strength of a 1000x2400 mm wet permanent medium-intensity magnetic separator.  
 1—drum surface, distance from the drum surface:2—10 mm, 3—20 mm, 4—30 mm, 5—40 mm, 6—50 mm.

### Assembly of the Magnet

Design of a permanent magnet should depend on its manufacturing technical feasibility. The key is how to press together co-polar permanent magnetic materials with a high magnetic energy product. Mechanical fixing is a successful way of solving this key problem providing a reliable and practical technique for manufacture of magnetic separators.

## THE PRINCIPLE OF SEPARATION

### The Collection Force

Schematic diagram of the separation process is shown in Fig. 3. Material is fed onto the drum surface from a hopper. Magnetic material is attracted to the surface of the fan-shaped magnetic field area, it rolls with the drum many times, and becomes a concentrate outside the magnetic field. Non-magnetic material is

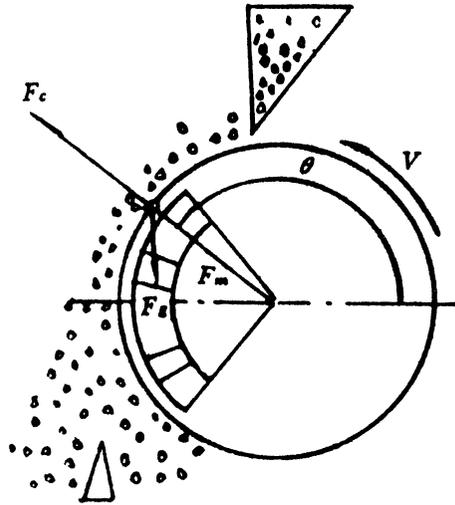


Fig. 3 The principle of separation

thrown away from the drum by the action of centrifugal force to form the tailings fraction.

As is shown in Fig. 3, three forces are applied to the material to be separated:

- magnetic force:  $F_m = \chi H \frac{dH}{dx}$
- centrifugal force:  $F_c = \frac{m v^2}{R}$
- force of gravity:  $F_g = mg$

Components of a material begin to separate from each other along their own trajectories of motion at a separation point, by the influence of various forces. At this separation point, the collection force applied to the magnetic material is:

$$\mu \chi H \frac{dH}{dx} \geq \mu m \frac{m v^2}{R} + mg \sin \theta - \mu mg \cos \theta \tag{1}$$

where  $\chi$  is the magnetic susceptibility,  $v$  is the linear velocity of the drum,  $\theta$  is the separation angle.  $m$  is the mass of the material particle,  $H$  is the magnetic field

strength,  $R$  is the diameter of the drum,  $\mu$  is the coefficient of friction and  $g$  is the acceleration of gravity.

It can be seen from eq. (1) that if an adjustment of the rotational speed of the drum makes the separation point just at  $\theta = 135^\circ$ , or if the rotational speed is constant and the position of the splitter is adjusted, then the magnetic material will deviate towards a side of the drum by the influence of the magnetic force resisting the centrifugal force. Therefore, the separator has a smaller separating magnetic field than other separators.

In this respect, much work has been done in the separation trials. Material which could be separated at 1.2 T with other magnetic separators, can be separated at only 0.8 T with this separator, with good results.

#### Calculation of the Capacity

The capacity of a drum magnetic separator can be calculated by:

$$Q = Lvrf\rho \quad (2)$$

where  $Q$  is the capacity,  $L$  is the length of the drum,  $v$  is the linear drum velocity,  $r$  is the diameter of a particle,  $f$  is the looseness of the feed and  $\rho$  is the mean density of the material.

It can be seen from eq. (2) that the coarser the material, the higher the the capacity of the separator. Naturally, the looseness of the material varies with its particle size distribution. In addition, an increase in the drum diameter increases the capacity of the separator.

#### DESIGN OF THE FEEDING SYSTEM

Since the separator has a longer body of the drum and wider feed size range, even feed distribution is of great importance. According to the mechanical design and to the separation principle of the top feeding type permanent magnetic separator, a

single-deck feeding should be, in principle, adopted to achieve good separation results. Based on previous experience, a two-stage hopper feed system should be designed. The first feeding hopper, with openness three times as large as the largest size of the feed material, is not equipped with vibrators and a sluice board.

The second-stage hopper, suspended from its frame with a spring, is an open-type hopper, which is equipped with a vibration motor. The feed rate of the second-stage feeding hopper can be controlled as a result of adjustable amplitude and inclination of the motor. Therefore, it can feed both evenly in a very wide area and prevent blinding resulting from coarse particles and such impurities as a fibre.

### **THE SEPARATION TESTS**

An industrial separation test was carried out using the  $-30 + 0.5$  mm Dounan manganese ore, as is shown in Fig. 4. The separator was praised by its users for such advantages as good separation results, no water consumption, less maintenance and low energy consumption. Its application will certainly simplify the process flowsheet achieving good economic results.

A spiral concentrate from the Pan Zhi Hua beneficiation flowsheet (i.e. feed to a high-intensity magnetic separator) was divided into two size fractions, namely  $-0.4 + 0.1$  mm and  $-0.1 + 0.04$  mm, and then treated by the separator, as is shown in Fig. 5.

Removal of iron from  $-1$  mm corundum grinding material of the Gui Yang No. 7 abrasive wheel plant was carried out in several size fractions with the separators. Comparative test results obtained with an electromagnetic separator and the permanent magnetic separator are shown Table 1.

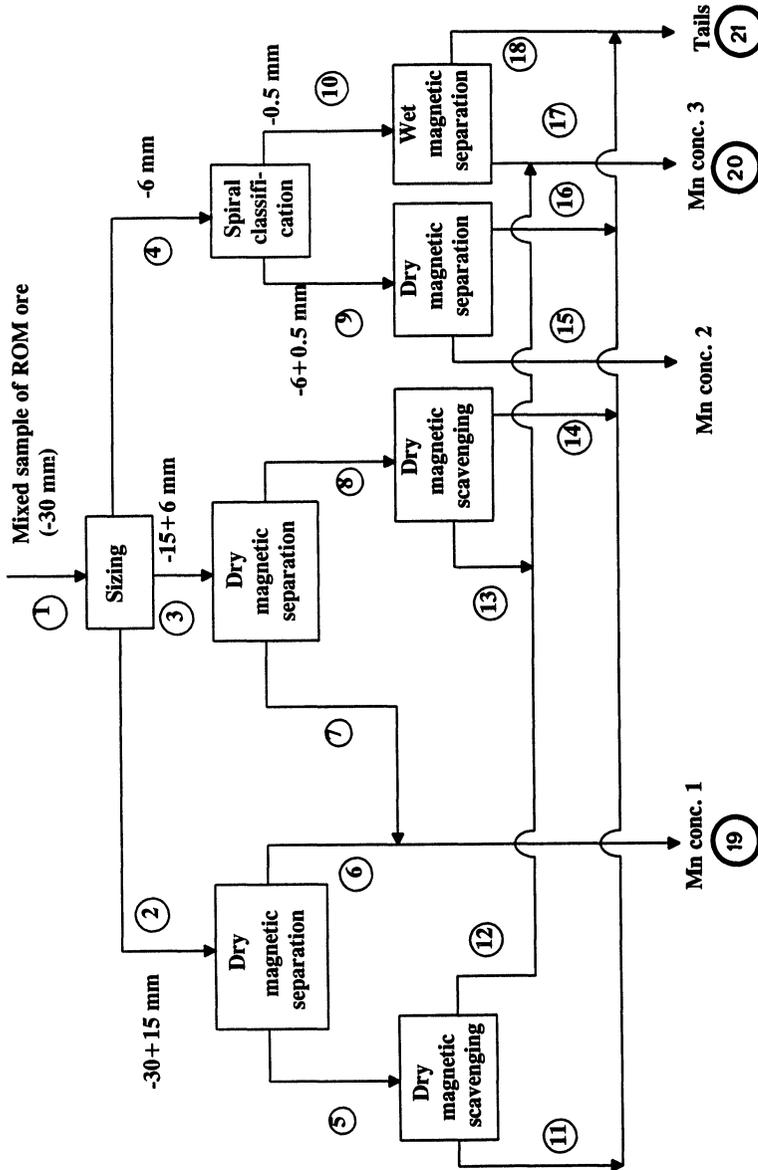


Fig. 4 A flowsheet for medium-intensity magnetic separation of -30+0.5 mm mixed mineral from the Dounan manganese mine. Legend: yield, grade, recovery (%).

- (1) 100.0, 22.40, 100.0; (2) 36.12, 24.43, 39.38; (3) 29.61, 23.40, 30.93; (4) 34.27, 19.41, 39.69; (5) 24.99, 18.29, 20.42; (6) 11.13, 38.25, 18.96; (7) 6.09, 43.29, 11.76; (8) 23.52, 18.26, 19.17; (9) 26.27, 20.52, 24.06; (10) 8.00, 15.78, 5.63; (11) 15.12, 11.41, 7.77; (12) 9.87, 28.85, 12.56; (13) 11.27, 27.83, 13.99; (14) 12.25, 9.47, 5.18; (15) 12.66, 31.39, 17.71; (16) 13.61, 10.55, 6.35; (17) 2.84, 28.13, 3.57; (18) 5.16, 8.97, 2.06; (19) 17.22, 40.03, 30.72; (20) 23.98, 28.29, 30.21; (21) 46.14, 10.15, 21.36.

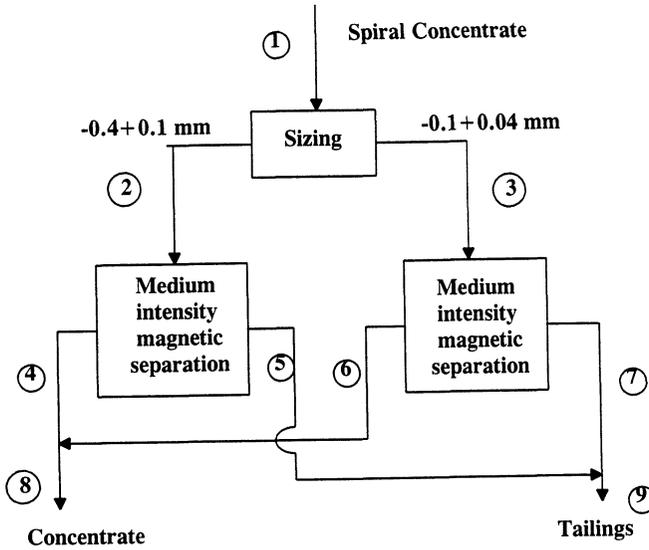


Fig. 5

A flowsheet for the dry medium-intensity permanent magnetic separation of coarse titanium concentrate from the spiral separation stage of the Pan Zhi Hua ilmenite mine. Legend: yield, grade, recovery (%).

## CONCLUSIONS

The appearance of Nd-Fe-B permanent magnetic material will facilitate development of magnetic separators towards permanent magnetic types. With appearance of permanent magnetic material will even higher magnetic energy product, magnetic separators will certainly advance in the course of permanent magnet-electromagnet-permanent magnet.

A medium-intensity permanent magnetic separator shown in Fig.7 has a magnetic induction of up to 0.8 T on the drum surface as a result of the application of the extrusion-type open permanent magnetic circuit and Nd-Fe-B magnetic material. The results obtained in the separation trials of the Dounan manganese ore show that the separation size can be up to 30 mm.

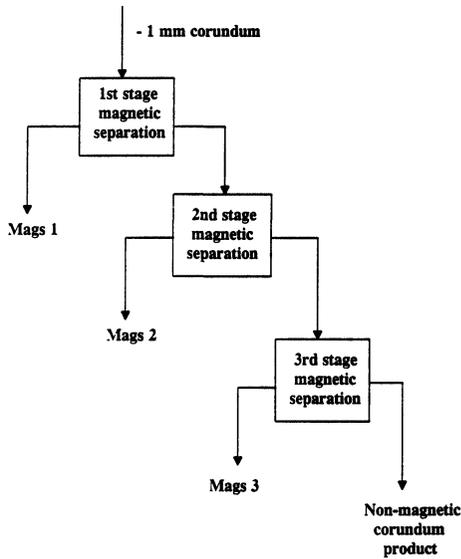


Fig. 6 A flowsheet for iron removal from corundum in the Gui Yang No. 7 abrasive wheel plant

Table 1 Comparison of separation results with electromagnetic and permanent magnetic separators

|  | content of good corundum in one-stage magnetic material | content of good corundum in two-stage magnetic material | content of good corundum in three-stage magnetic material | content of magnetic material in three-stage corundum production |
|--|---|---|---|---|
| drum electro magnetic separator                    | 10—15%  | ≥50%  | ≥60%  | ≤0.015  |
| drum permanent medium intensity magnetic separator | ≤1%   | ≤3%   | ≤15%  | ≤0.013%   |

Mechanical fixation is a successful way to fix Nd-Fe-B permanent magnetic material. An even feed distribution can be achieved by a two-stage feeding system.

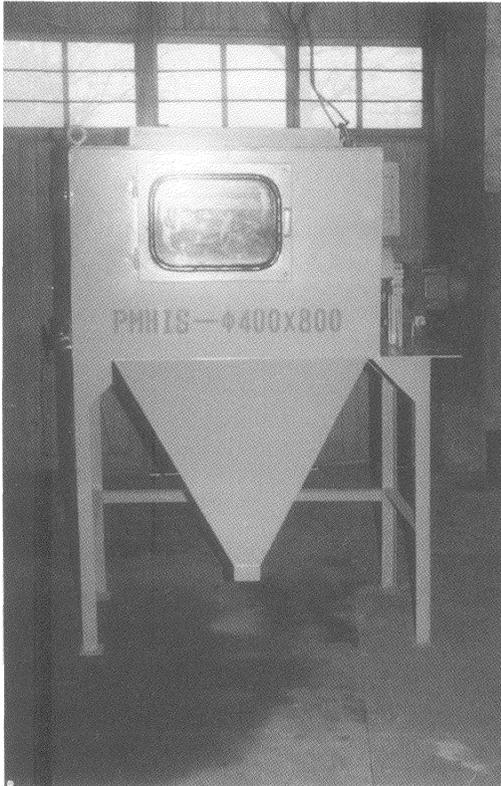
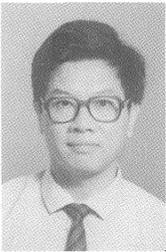


Fig. 7 The medium-magnetic permanent drum magnetic separator

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