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RING-SHAPED MAGNETIC POTENTIAL BARRIERS FOR SEPARATION OF WEAKLY MAGNETIC PARTICLES

J. Gerhold and J. Schmidt

ATF - Anstalt für Tieftemperaturforschung, F.R.G.

Résumé-Les séparateurs magnétiques nommés "Open Gradient Magnetic Separator" paraissent avantageux pour la séparation sèche ou humide de particules de susceptibilité faible. Les systèmes à symétrie axiale sont particulièrement intéressants car ils permettent de combiner forces centrifuges et forces magnétiques. On forme ainsi une barrière de potentiel radiale infranchissable par les particules magnétiques. Cette barrière peut être réalisée à l'aide d'aimants de type "Helmholtz". L'élaboration de tels aimants pour les séparateurs centrifuges est décrite.

Abstract-Weakly magnetic materials may be separated within Open Gradient Magnetic Separators using dry or wet processes. Axial-symmetric arrangements are of special interest when utilizing centrifugal forces in addition to magnetic forces. Thereby gradient fields are needed which generate mainly radially inwards directed forces. Such forces form a kind of magnetic potential barrier which cannot be transversed by magnetic particles. The necessary field distributions can be attained by means of properly shaped coils which are arranged similar to the known Helmholtz configuration. The layout of such superconducting coils for applications in centrifugal separators is discussed.

In order to gain high magnetic forces or energies within Open Gradient Magnetic Separators, it is advisable to use superconducting magnets. Axial-symmetric arrangements are of special interest, since centrifugal and magnetic forces may be used acting against each other.

Generally the magnetic forces acting on a weakly magnetic particle may be derived from the equilibrium of energy within a given system. One can define a mechanical potential of the magnetic forces by /1/.

$$U = V \cdot \chi \cdot \Phi \quad (1)$$

where Φ means the specific potential of the field $\mu_0 H$ which is independent of the properties of the particles, i.e. the volume V and the susceptibility χ respectively:

$$\Phi = - \frac{\mu_0}{2} H^2 \quad (2)$$

One configuration often used is a cylindrical multipole. Fig.1 shows the radial profile of the specific potential. It demonstrates that the specific magnetic forces F_s (which are the derivation of the potential, i.e. the slope of the curve) increase very rapidly near the winding. On the other hand, they vanish quite quickly as the distance increases. So if one needs a certain force, one is restricted to a relatively small area which is narrowed even further by the need for thermal insulation. In addition, particles may stick to the outer wall unless special conditions are met. This is the main disadvantage of all

Fig. 1 - Specific potential profile
for a SC Quadrupol
($r_0 = 1\text{m}$; $B_0 = 4\text{T}$)

outside. Naturally, a potential barrier of this ideal shape can only be obtained approximately. Fig. 3 shows as an example the potential barrier of a Helmholtz coil. The magnetic field of this arrangement produces a rather slurred barrier which results in comparatively low

Fig. 2 - Ideal potential barrier

radial forces. If one concentrates only on the plane of symmetry, there are no axial forces. Even if one leaves this plane, there is a certain range within which the axial forces are much lower than the radial ones. Fig. 3 shows a cross-section through the coils arrangement with the contour lines of constant potential. The resulting magnetic forces are perpendicular to these contour lines. Within the area indicated by narrow lines, the deviation of the forces from the ideal radial direction is less than 30°.

The Helmholtz arrangement is certainly not the best for separation. Simply by varying the distance between the two coils, the barrier can be made much steeper resulting in specific forces of up to several 10^7N m^{-3} , see fig. 4. This is sufficient for separation of haematite or of siderite for instance. Moreover, the shape of the cross-section of the single coils influences the value of the peak force.

similar configurations which use alternatively energized coils.

For a simple separation process using centrifugal forces we would prefer something like the ideal magnetic potential barrier shown in fig. 2. The forces are constant within a certain range Δr and they are zero at any other spot. Magnetic particles which are enclosed within this "pot" cannot escape, whereas non-magnetic particles are not influenced and therefore may move to the

Fig. 3 - Potential barrier and
contour lines of a
Helmholtz coil

Fig.4 - Potential barrier for various coil distances d . (NbTi@ 4,2K cross section 14810 mm^2)

Fig.5 - Specific energies versus minimum magnetic forces

Fig.5 gives calculated specific energies versus the minimum forces for the arrangements shown in fig.4. These energies grow considerably with the peak forces. A high separation work may therefore be possible.

All these data were calculated by means of a special computer program [2] which gives the values of the specific potential at any point and which takes into account the critical parameters of the superconductor to be used.

In order to prove these results and to measure the characteristics of one possible separation process, we are building a model separator (see fig.6). Its essential parts are the two coils forming the magnetic field and a horizontal separation disc rotating between them. The disc is divided into an inner part and an outer ring, leaving a small gap between them. Furthermore, the surface of the outer ring is a few millimeters below that of the inner part. So the two parts form a kind of jumping platform. The mixture of magnetic and non-magnetic particles is fed onto the centre disc. Both kinds of particles will drift slowly towards the edge. Here they are thrown off due to the centrifugal force, and if the speed of rotation is high enough, the non-magnetic particles will reach the outer ring. The magnetic particles are

drawn back to the centre since the magnetic forces are directed inwards. So if the centrifugal forces are not too large, the magnetic particles are trapped within the "pot" formed by the magnetic forces (see fig.3). This means that they are hindered from reaching the outer side of the gap, and thus fall onto the collector disc below.

Fig.7 shows the trajectories of the different particles. The two limiting conditions for correct separation are:

1. Non-magnetic particles must be able to reach the outer ring in spite of the gravity which pulls them down.
2. Magnetic particles must fall onto the collector.

Fig. 6 - Model separator of ATF

Fig. 7 - Particle trajectories

The first condition can be transformed into a minimum value of the rotating velocity which is only influenced by the geometry of the jumping platform and by the diameter of the arrangement. This minimum of rotating velocity naturally implies a minimum value of the centrifugal force. Therefore, the second condition can be used for computation of the minimum magnetic forces which must act against them

At this state of fundamental study, an optimization can be attempted. One desirable property is that the target points of magnetic and non-magnetic particles are as far apart from each other as possible. This guards against slurring effects due to a spread in susceptibility or perturbations such as collisions of particles.

The optimization with respect to this property shows, that it is more advisable to aim at high specific energies than at high forces, naturally considering the requirements mentioned above.

As a consequence, this determines the operation of the superconductor. Our calculations showed, that for a process with no perturbations at all, it is best to operate the superconductor at its point of maximal $B \cdot J$ (where B and J are the flux density and the critical current density respectively).

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