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Maxwell et al.

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[54] **HIGH GRADIENT TYPE MAGNETIC SEPARATOR WITH CONTINUOUSLY MOVING MATRIX**

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[52] **U.S. Cl.** **209/213;** 209/218; 209/219; 209/232

[51] **Int. Cl.**[2] **B03C 1/02**

[58] **Field of Search** 209/214, 219, 223, 224, 209/225, 226, 218, 230, 231, 232, 39; 210/222, 223

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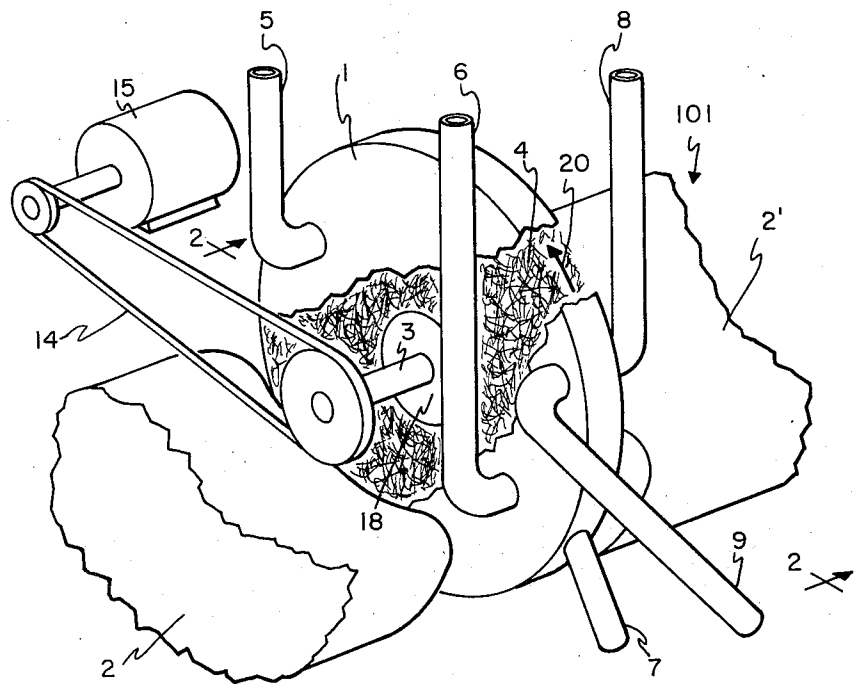
Primary Examiner—Robert Halper

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[57] **ABSTRACT**

Apparatus wherein a matrix is moved into and out of the influence of a magnetic field as a continuously moving element. Magnetic and non-magnetic particles to-be-separated are introduced in a liquid, in the form of a slurry, or are carried by some other fluid medium. The medium, together with the particles to-be-separated, is passed through the matrix in such a way that the average relative velocity with respect to the matrix is parallel, anti-parallel and adjustable in magnitude during the time the matrix is under the influence of the magnetic field. This unique feature allows the magnitude of the competing forces (non-magnetic) to be varied in such a way as to give effective control over the character and degree of the separation effected. The non-magnetic particles are generally removed when the medium is under the influence of the field and the magnetic particles are generally removed after the matrix has left that influence.

10 Claims, 8 Drawing Figures



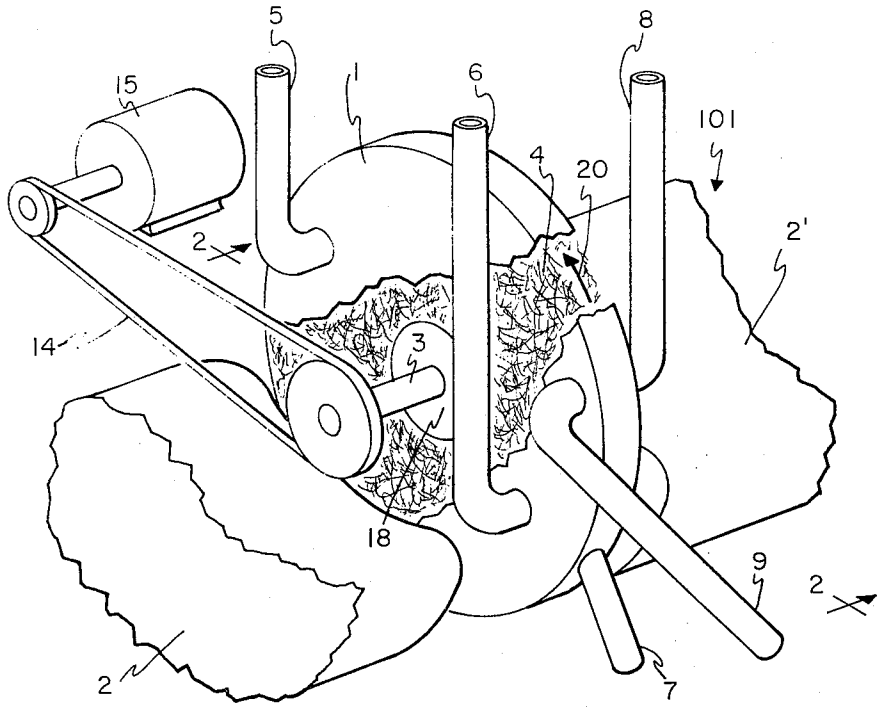


FIG. 1

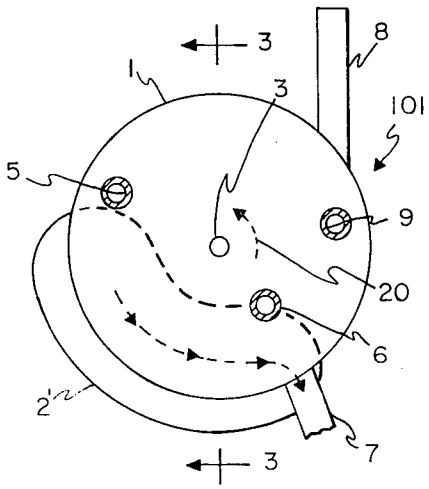


FIG. 2

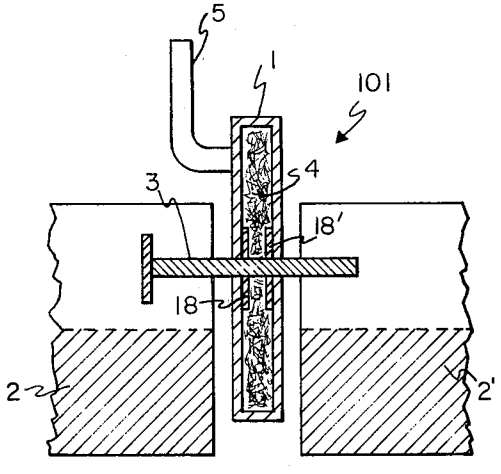


FIG. 3

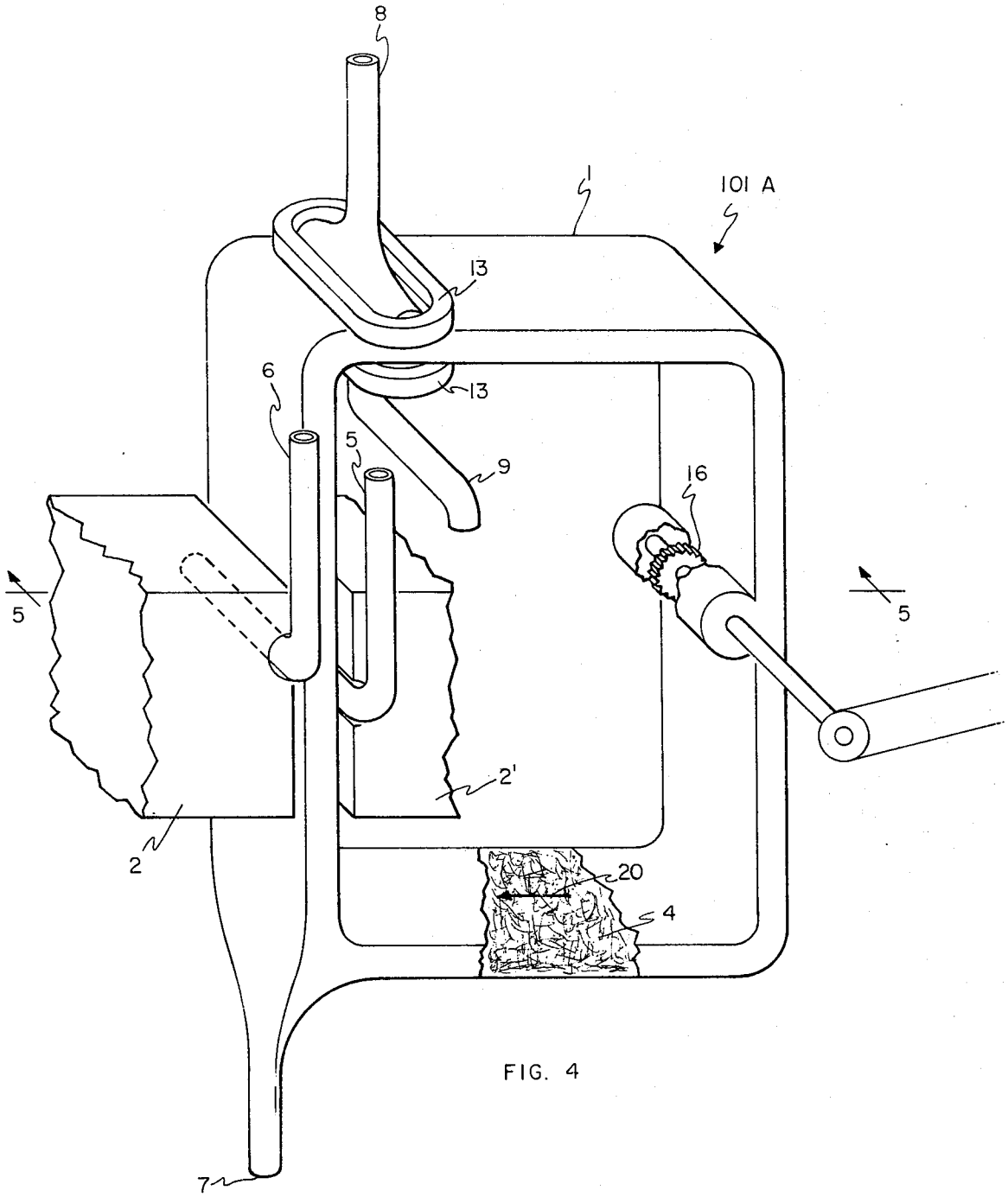


FIG. 4

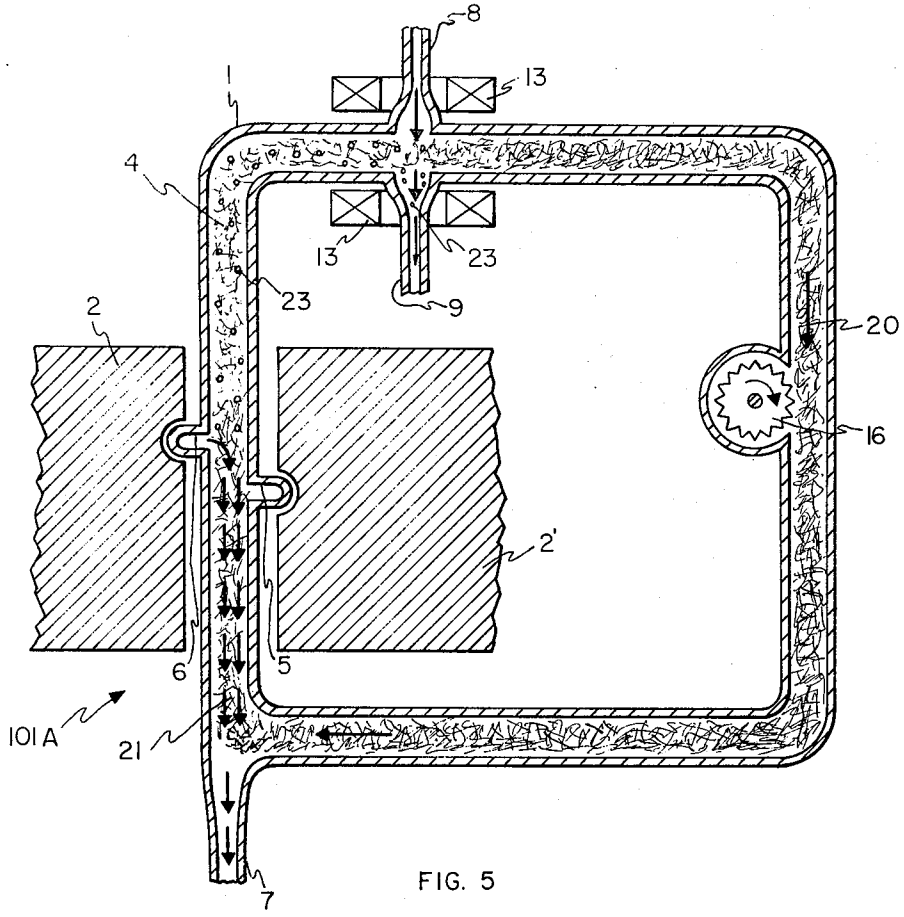


FIG. 5

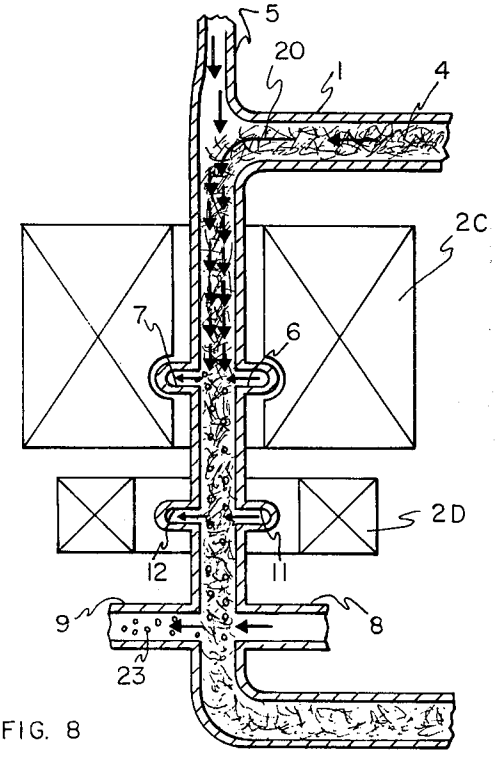


FIG. 8

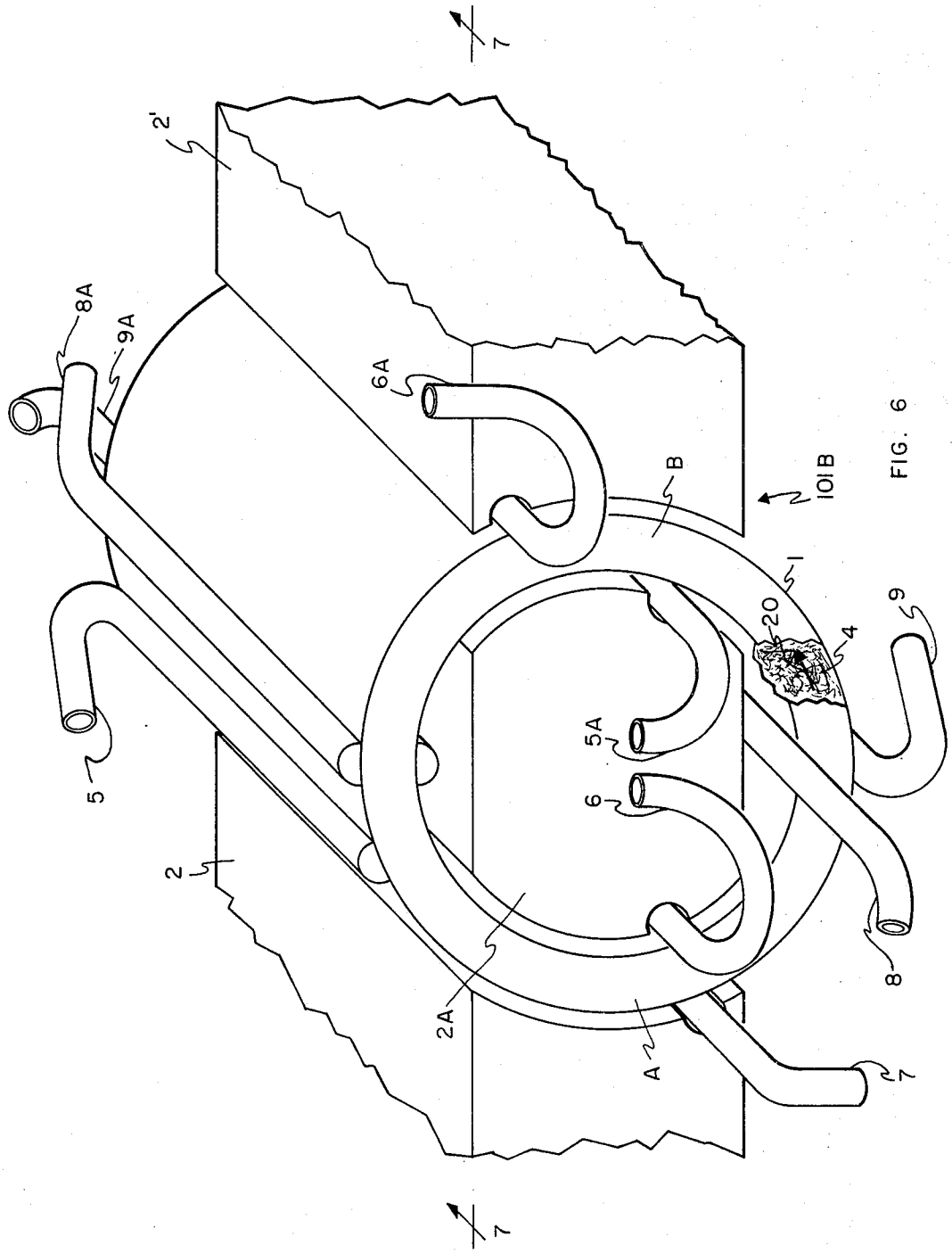


FIG. 6

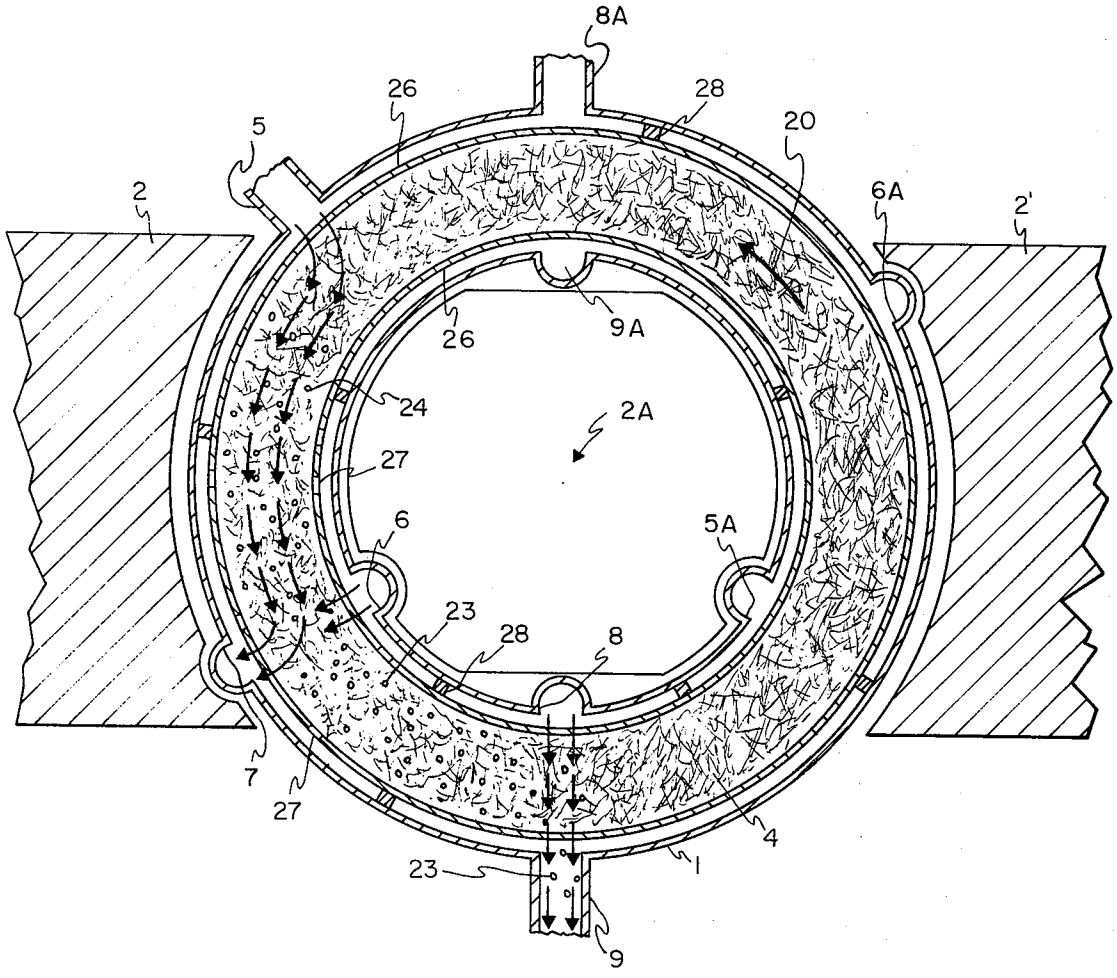


FIG. 7

HIGH GRADIENT TYPE MAGNETIC SEPARATOR WITH CONTINUOUSLY MOVING MATRIX

This invention was developed in the course of work done under a contract with the National Science Foundation.

The present invention relates to high gradient type magnetic separators and, more particularly, to magnetic separators wherein a matrix is moved continuously into and out of the influence of a magnetic field.

Patents of interest include: U.S. Pat. No. 2,329,893 (Girard); No. 2,430,157 (Byrd, Jr.); No. 2,786,047 (Jones et al.); No. 2,331,769 (Frantz); No. 2,954,122 (Colburn); No. 3,150,291 (Laquer); No. 3,177,408 (Mills et al.); No. 3,239,725 (Wiederhold); No. 3,279,602 (Koffenstette et al.); No. 3,394,330 (Schindler); No. 3,567,026 (Kolm); No. 3,627,678 (Marston); No. 3,676,337 (Kolm).

In the 1971–72 annual report of the Francis Bitter National Laboratory of the Massachusetts Institute of Technology, at pages 148–157, there are discussed in some detail uses to which separators of the type described in the Kolm patents above, with its corrosion-resistant wool matrix, can be put. At pages 150–151 of the report, there is discussed a moving matrix separator (called "carousel separator") recently developed by Magnetic Engineering Associates, Inc., of Cambridge, Massachusetts. The moving matrix separator is particularly useful in those situations wherein substantial amounts of magnetic particles (i.e., mags) in a slurry or the like containing both magnetic particles and non-magnetic particles (i.e., tailings) are to be removed. The large amount of trapped particles tends to fill the matrix quite quickly in the absence of some measure to alleviate the condition. The moving-matrix machine contemplates a condition wherein the mags and tailings are separated in the machine and are removed therefrom on a continuous basis. In the carousel separator, the slurry is introduced to travel between inlet and outlet within the magnetic field region in a direction which provides an average velocity of slurry which is generally orthogonal to the matrix velocity; whereas it is an object of the present invention to provide a moving matrix separator wherein the average velocity of the slurry relative to the moving matrix is parallel or anti-parallel and may be varied in magnitude during the time the matrix is under the influence of the field. This feature permits a great degree of control over the forces in the magnetic separator which compete with magnetic forces and thereby determine the degree and character of the separation. In a high gradient type magnetic separator such as the one described here, the competing forces are largely determined by the relative velocities of the particles, slurry and matrix. In the separator described here in the relative velocity between the matrix and the slurry is controllable independent of the average through-put velocity of the slurry in the separator. This allows, for example, for the large trapping efficiency at zero relative velocity, between matrix and slurry to be affected at finite through-put rates. Conversely, a large matrix-slurry relative velocity may be set to produce a high grade product without increasing the average through-put rate.

The foregoing and still further objects are evident in the description that follows and are particularly pointed out in the appended claims.

By way of summary, the objects of the invention are attained in a magnetic separator that includes means

for introducing a slurry containing particles of differing magnetic and physical properties to a magnetic matrix adapted to move continuously so that portions thereof are at all times moving into and out of regions in the separator through which fluids are passed to carry in particles to-be-separated and to carry out certain particles. Further included is means for creating a magnetic field in all or some regions of the separator wherein the matrix is moving. For example, the magnetic field may be made high in the region where the least strongly magnetic particles are removed from the matrix, less strong where the less strongly magnetic particles are removed and, finally, very weak where the strongest magnetic particles are removed from the matrix. In general, a fluid medium containing particles of differing magnetic and physical properties is passed through the matrix such that the average slurry velocity with respect to the matrix is parallel, anti-parallel or zero during the time the slurry is within the high magnetic field region. The removal of the slurry and least magnetic particles is accomplished by allowing the slurry to flow out of the matrix in the presence of the high magnetic field. The matrix, which has trapped the more strongly magnetic particles, passes into a region of the separator away from the main slurry flow into a region of lower magnetic field where it may be washed by a fluid flow which enters and leaves carrying with it particles of intermediate magnetic strengths. The washing fluid may be introduced in such a way as to make its velocity perpendicular or parallel to the direction of the matrix movement. The final washing of the most magnetic particles from the matrix is generally accomplished by a fluid stream directed perpendicular to the matrix motion in a region of substantially zero magnetic field.

The invention is hereinafter discussed with reference to the accompanying drawing in which:

FIG. 1 is an isometric partial view, partly cutaway, showing a separator embodying the inventive concepts described herein;

FIG. 2 is a view, on a slightly reduced scale, taken upon the line 2—2 in FIG. 1, looking in the direction of the arrows;

FIG. 3 is a view, taken upon the line 3—3 in FIG. 2, looking in the direction of the arrows;

FIG. 4 is an isometric partial view, partly cutaway, of a modification of the separator of FIG. 1;

FIG. 5 is a section view taken upon the line 5—5 in FIG. 4, looking the direction of the arrows;

FIG. 6 is an isometric partial view, partly cutaway, of a further modification of the separator of FIG. 1;

FIG. 7 is a section view, slightly enlarged, taken upon the line 7—7 in FIG. 6, looking in the direction of the arrows; and

FIG. 8 is a side section view of still another modification of the separator of FIG. 1.

In order to simplify the explanation herein, the major portion thereof is devoted to a separator wherein the matrix is a magnetic wool material as is described in the Kolm patents. Before going into a detailed discussion of the apparatus there follow some brief preliminary remarks, taken in the main from said report, which it is believed will establish proper context for the present system.

One of the examples of use mentioned in the two Kolm patents is that of removing impurities from kaolin. In such a process a slurry containing the kaolin and impurities in a slurry are passed through a corrosion-

resistant, magnetic wool matrix which retains the kaolin while passing the impurities. It should be noted, however, that most of the slurry is water, and the kaolin and the impurities are present in very small concentration. There are other uses for such separators (e.g., ore benficiation and others, as noted in said report) wherein the concentration of magnetic components in the slurry is quite considerable and constitute as much as 50 percent or more of the solid material in the slurry. It is quite necessary, therefore, to have some means for rapidly removing the trapped magnetic particles from the matrix. Also, the composition of the separator products is of great concern. The variables available for use toward solution of the various problems encountered in removal systems are magnetic field intensity, flow rate or, more precisely, relative motion between the slurry and the matrix, and the geometry and magnetic properties of the matrix. The present invention provides a great deal of flexibility in connection with its capacity to modify said relative motion, as is noted in some detail hereinafter.

Referring now to FIG. **1**, a magnetic separator embodying the present concepts is shown at **101**. The separator includes a housing **1** containing a matrix **4** and kidney-shaped pole-pieces **2, 2'** which produce a magnetic field over a portion of the housing and matrix. The slurry to-be-processed is introduced through a pipe **5** and travels, as indicated in FIG. **2**, through the matrix **4** and out at the pipe labeled **7**. It may be seen that during this passage of the slurry through the matrix the flow is generally in the direction of the rotation of the matrix. This rotation (direction is indicated by the arrow shown at **20**) is produced by a motor **15** and chain and sprocket assembly **14** which transmits a rotating force through a shaft **3** to the disc-shaped matrix **4** by means of the flanges **18** and **18'**. The pipe labeled **6** provides means for introducing a washing fluid stream into the matrix while that portion of the matrix is in the influence of the magnetic field. This stream acts in such a way as to wash the non-magnetic or less strongly magnetic particles into the pipe **7**. Additional washing fluid is introduced at a pipe **8** to wash the magnetic components from the matrix out through a pipe **9**. The magnetic components are trapped on the matrix in the region where the magnetic field is active and carried around to the point in the housing where the pipes **8** and **9** are attached. The cleaned portion of the matrix then rotates around to the point at which the pipe **5** is attached to the housing **1** and where new slurry to-be-processed is introduced. The rotation of the matrix permits relative velocities between the matrix and the slurry to be varied in magnitude from zero, if the average slurry velocity and average linear velocity of the matrix are the same, to some reasonable value when the matrix is made to move more rapidly.

In FIG. **4** elements which perform the same function as like elements in FIGS. **1—3** are given identical numbers even though the separator **101A** of FIG. **4** is a modification in some respects from that shown in the earlier figures; this numbering scheme holds true for the other later-discussed figures as well. The separator **101A** is of the endless belt type. Again, the housing is shown at **1**. The slurry is introduced through the pipe **5**, it travels down (as is best shown in FIG. **5** and as indicated by arrows **21**), and it leaves the housing and separator through the pipe **7**. The matrix at **4** in this example is made to travel generally opposite to the direction of the slurry flow which moves in the direction of the arrows **21**. This permits extremely large relative velocities between the matrix and the slurry to be realized. Washing fluid is introduced through the pipe **6** and travels generally downward leaving the housing through the pipe **7**. The trapped magnetic components designated **23** are carried by the moving matrix up to the point at which the pipes **8** and **9** are attached to the housing. The combined action of the wash fluid introduced through the pipe **8** and a weak alternating magnetic field produced by a pair of coils **13** (to vibrate the matrix) remove the magnetically trapped particles **23** from the matrix. These particles exit through the pipe **9**. The means for moving the matrix, which in this example is in the form of an endless belt, is shown at **16**. It is a toothed wheel which engages the belt to transmit force to it. The toothed wheel **16** is driven by a chain and sprocket arrangement like that shown in FIG. **1**.

FIGS. **6** and **7** a further modification of the separators in FIGS. **1–3** is shown. This separator, which is designed **101B**, is in the form of a hollow cylinder. Both the housing **1** and the matrix **4** are in the form of hollow cylinders. The applied magnetic field is produced by the pole pieces **2** and **2'** and a further pole piece **2A**. These pole pieces are part of a magnetic circuit by which a strong magnetic field may be efficiently produced in the matrix in the regions labeled A and B between these poles. The field will be relatively small outside these regions. Both of the regions A and B of strong magnetic field may be utilized simultaneously as individual separators. The pipes **5, 6, 7, 8** and **9** are utilized in the same way as in the example shown in FIGS. **1–3** since the matrix is made to turn in a parallel direction to the slurry flow at the region A. Thus, a slurry can be introduced through the pipe **5**; tailings **24** in the slurry and most of the fluid leave the separator through the pipe **7** and are aided in this by cleaning water introduced as a high-pressure stream through the pipe **6**. The mags **23** remain attached to the matrix **4** and are removed through the pipe **9** under the influence of further, high-pressure water introduced through the pipe **8**. At the region B pipes **5A, 6A, 9, 8A** and **9A** are utilized to perform the same function as do the pipes **5, 6,** 7, 8 and **9** in FIGS. **4** and **5** since, at the region B, the direction of the slurry flow is generally anti-parallel to the motion of the matrix **1**. The direction of the motion of the matrix in this example is again shown by the arrow **20**.

FIG. **8** shows a modification of the endless belt type separator illustrated in FIGS. **4** and **5**. In this embodiment, the slurry flow and the belt velocity are generally parallel. The slurry is introduced through the pipe **5** and exits through the pipe **7**, being washed by a fluid introduced through the pipe **6** in the region of large magnetic field. The magnetic field in this case is produced by a pair of coils **2C** and **2D**. These coils produce a field which is generally parallel to the direction of the flow of the slurry. In a region of lower but not negligible magnetic field a further washing of magnetic components from the matrix is accomplished by washing fluid introduced through a pipe **11**. The components washed from the matrix **4** exit through a pipe **12**. Finally, the most magnetic components are washed from the matrix at the point where wash fluid is introduced through the pipe **8**. These components exit through the pipe **9**.

The essential feature of the separators shown in the figures described above is control of the relative veloc-

ity between the matrix and the slurry carrying the components to be separated. It is known that this relative velocity greatly affects both the degree of separation between the components, known as the grade of the products, and the actual amount of the component of interest in a given product, i.e., the recovery. In general, the grade of the magnetic components increases as the relative velocity between the matrix and the slurry increases, while the recovery decreases. A decrease in the relative velocity produces an increase in recovery. Depending on the particular use of the separator, an increase in either the grade or the recovery may be desirable. This may be accomplished in the case of the separators described by controlling the rotation of the matrix or by controlling the slurry flow rate.

A special advantage of the type separator herein described is its lower magnetic field requirements. It is known that the recovery (but generally not the grade) of the magnetic components increases as the strength of the applied magnetic field increases so that in other types of magnetic separators, in which the relative matrix-slurry velocity is always non-zero, the recovery is limited by the field. Since the type separator described here permits the recovery to be increased by decreasing the relative matrix-slurry velocity, its magnetic field requirements can be significantly lower. This, in turn, can mean lower power requirements and cost savings in practice.

The geometry of the separators described here possess another useful feature. Magnetic fields produced by magnetized iron poles are generally strongest when the poles are placed close together. In addition, the power requirements of iron electromagnets are, in practice, lower for narrow pole spacing. The present separator operates in such a way that the slurry flow is always parallel to the faces of the poles. This permits a reasonable path length for the slurry in the magnetic field. A slurry flow generally perpendicular to the pole faces would, by contrast, provided too short a path length. A further advantage of the narrow width geometry of the separator described here is that washing the magnetic components may be accomplished efficiently. The short path of the wash fluid through the matrix in the narrow direction minimizes the impedance to the wash stream and maximizes the washing effect.

The magnetic separators described here may be operated with a variety of fluid media, including, for instance, water or air or both, in combination, and the term "slurry" comprehends both. As an example, a water slurry of magnetic and less magnetic particles might be introduced to the separator. Clean water would be used to wash the trapped components on the matrix in the magnetic field region while a jet of air would be used to remove the magnetic components and any remaining water outside the field region. The resulting magnetic product would be to some degree "dewatered". Dewatering is often desirable in practical processes.

The matrices to be used in the type separator described here depend in form somewhat on the particular geometry of the separator, that is, disc, endless belt, or hollow cylinder. The material of which the matrix is fabricated may be, for example, stainless steel wool. This material would be packed in the form required by the particular separator with the necessary reinforcing framework to permit it to hold its shape. Various types of reinforcing frameworks for stainless steel wool matrices may be used, including hollow wire forms into which the wool is packed or frames over which the wool may be laid, e.g., the perforated framework, labeled **26** in FIG. **7**, which has holes **27** to allow the slurry to pass through the matrix **4**. In the case of endless-belt or hollow-cylinder-type separators, a segmented matrix of interconnected frames may be used. It is important that the construction of the matrix frame, whatever its form, be such as to allow relatively unimpeded flow of the slurry (except for the magnetic components) parallel to the direction of motion of the matrix (i.e., in the circumferential direction) so that the average slurry velocity may be controlled by hydrostatic means independent of the matrix motion. The general requirements for the matrix material itself are that it be a finely stranded ferromagnetic material which is able to withstand the compressive forces of an applied magnetic field without deforming significantly. Significant deformations would be such as to leave large voids in the matrix volume permitting slurry to pass by the matrix instead of through it. Measures must be taken to avoid short-circuiting of the matrix by the slurry by provision of appropriate seals (see, for example, seals **28** in FIG. **7**); also rotating seals at the various shafts are needed.

Further modifications of the invention herein described will occur to persons skilled in the art and all such modifications are deemed to be within the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. Apparatus for separating magnetic particles of greater and lesser magnetic moment from a mixture thereof carried in a fluid vehicle comprising;

a shaped fibrous matrix of magnetically permeable material;

magnetic field means operatively disposed to effect a magnetic field region and through which field region said matrix moves to effect induced magnetization in a portion thereof as said matrix moves therepast; inlet means for said mixture operatively disposed for flowing said mixture through said matrix;

outlet means disposed adjacent to said magnetic region for removal of particles of lesser magnetic moment from said magnetized matrix;

said particles of greater magnetic moment being held and conducted within said magnetically induced matrix past said magnetic field;

means operatively disposed for subsequently conducting a cleansing fluid to and from said matrix for removing said latter magnetic particles therefrom beyond said magnetic region, and means for effecting continuous rotation of said matrix in a direction parallel or antiparallel to the direction of flow of said mixture so as to permit between said mixture and said matrix a relative average velocity variable in magnitude in parallel and antiparallel directions during a major part of the time the mixture is in the magnetic field region.

2. Apparatus as set forth in claim **1**, said means for effecting continuous rotation being a variable speed motor.

3. Apparatus as set forth in claim **1**, including additional means for conducting a cleansing fluid to and from said matrix for removal of said former magnetic particles within the region of said magnetic field.

4. Apparatus as set forth in claim 1, said means for effecting continuous rotation being a variable speed motor including additional means for conducting a cleansing fluid to and from said matrix for removal of said former magnetic particles within the region of said magnetic field.

5. Apparatus as set forth in claim 1, said matrix being in the form of a disc.

6. Apparatus as set forth in claim 1, said matrix being in the form of a cylinder.

7. Apparatus as set forth in claim 1, said matrix being in the form of an endless belt.

8. Apparatus as set forth in claim 1, said means for conducting a cleansing fluid comprising conduit means adjacent said matrix and magnet means adjacent said matrix and encompassing said conduit means thereat for effecting a vibratory magnetic field to loosen particles in said matrix.

9. Apparatus as set forth in claim 8, said means for conducting a cleansing fluid comprising at least one channel extending the width of said cylinder.

10. Apparatus as set forth in claim 8, said means for conducting a cleansing fluid comprising at least one channel extending the width of said belt.

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