United States Patent [19]

Kolm

[11] **3,838,773**

[45] **Oct. 1, 1974**

[54] **VIBRATING-MATRIX MAGNETIC SEPARATORS**

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[73] Assignee: **Massachusetts Institute of Technology,** Cambridge, Mass.

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[21] Appl. No.: **342,178**

[52] **U.S. Cl.** ..... **209/10,** 209/223 R, 210/223, 210/388

[51] **Int. Cl.** **B01d 35/06**

[58] **Field of Search** 210/42, 222, 223, 388; 209/214, 223, 225–227, 232, 216, 10; 55/3, 100; 241/79.1, 24

[56] **References Cited**

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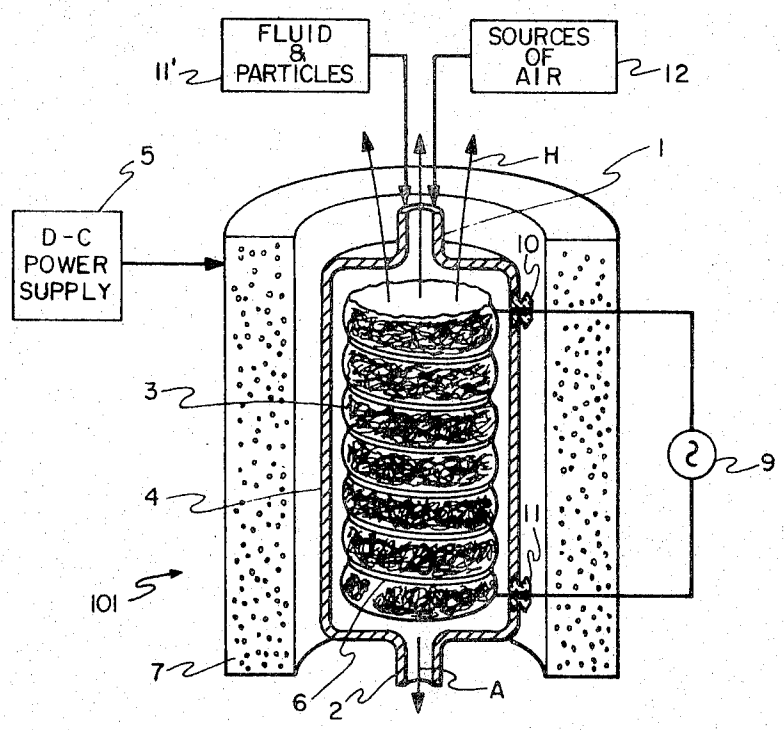
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Primary Examiner—Roy Lake
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[57] **ABSTRACT**

A magnetic separator for separating particles in a fluid stream from one another on the basis of the magnetic dipole moment of the individual particles. The separator has a filamentary-type matrix which is magnetized, along with the particles, by a d-c magnetic background field. There is embedded in the matrix an electrical conductor which vibrates, when energized by a source of alternating current during separator operation because of electromagnetic interaction between the current and the field, thereby to effect vibration also of the matrix in which the conductor is embedded. An alternate mechanism for effecting vibration of the filaments of the matrix is that of applying an alternating magnetic field having a component transversely directed to the background field.

18 Claims, 7 Drawing Figures



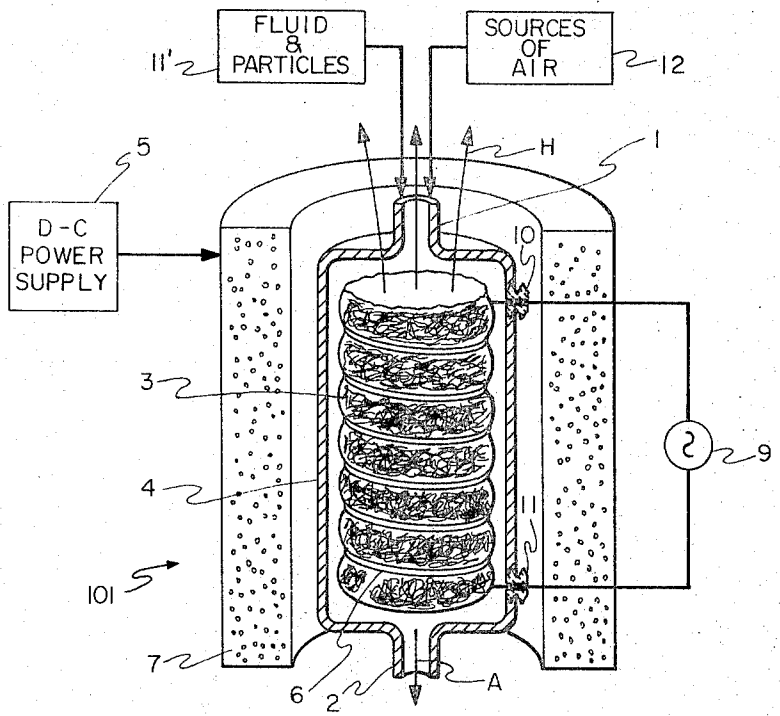

FLUID & PARTICLES
SOURCES OF AIR
11'
12
H
1
5
D-C POWER SUPPLY
10
3
4
9
11
101
7
6
2
A

FIG. 1

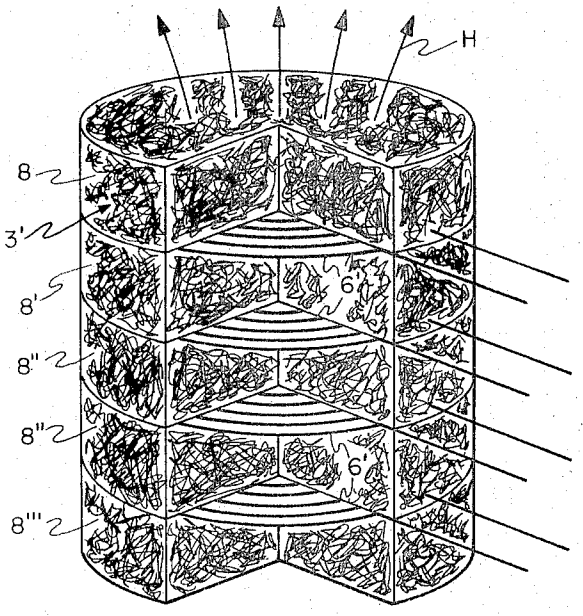

H
8
3'
8'
6'
8"
8"
6'
8'''

FIG. 2

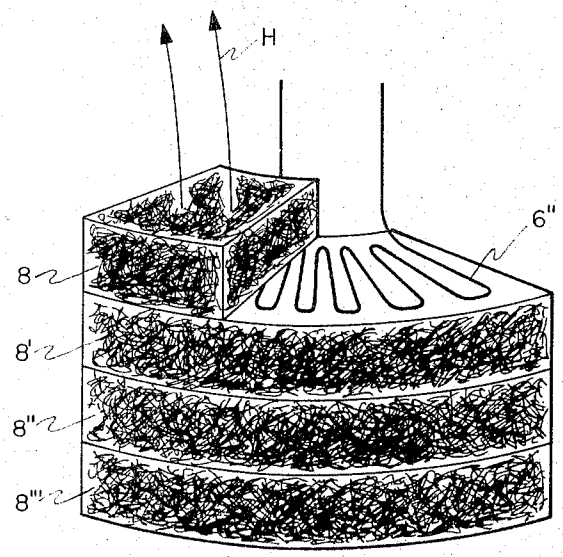


FIG. 3

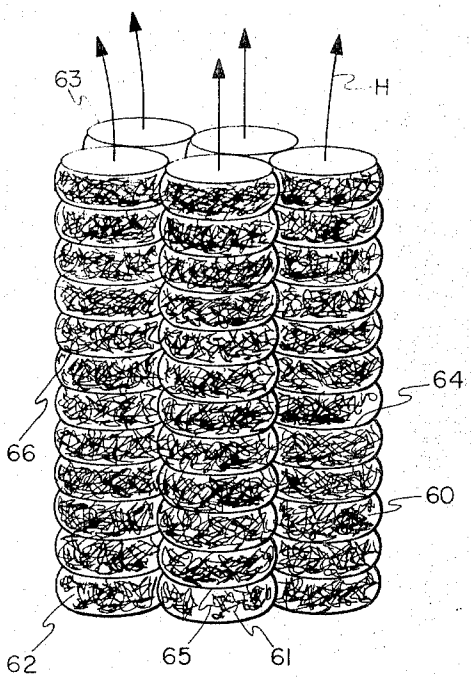


FIG. 4

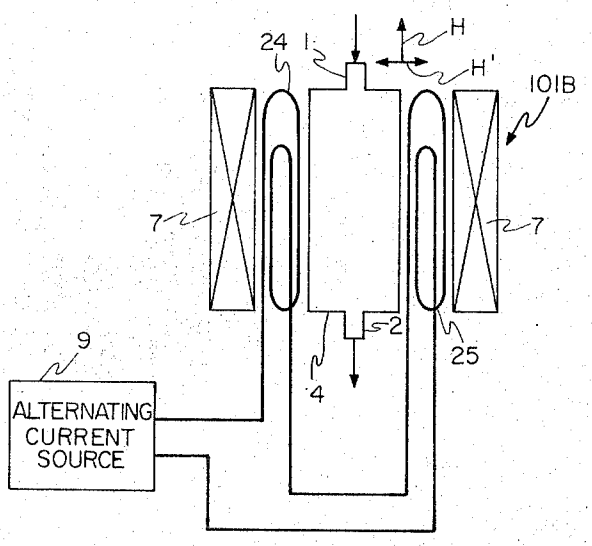


FIG. 7

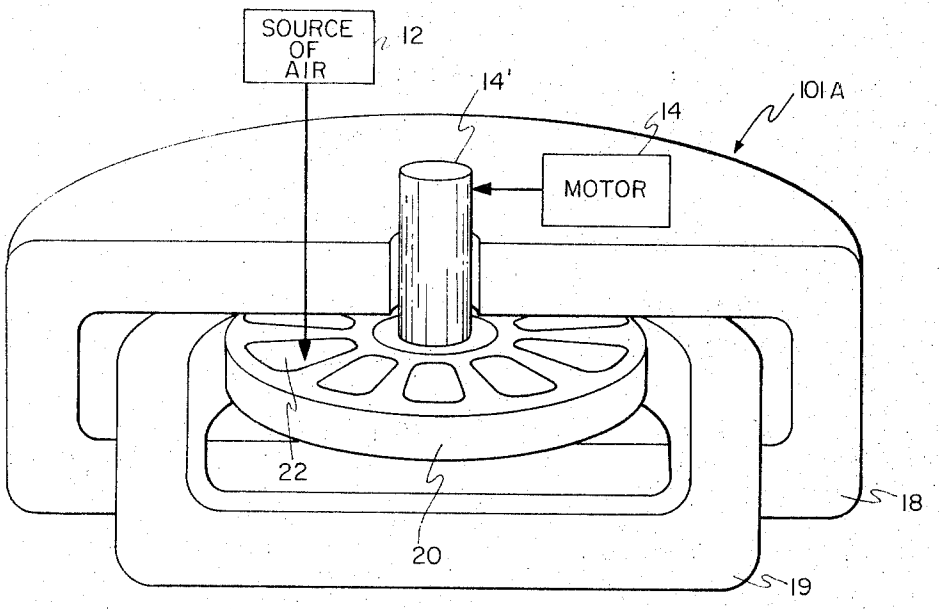

SOURCE OF AIR
12
14'
14
101A
MOTOR
22
20
18
19

FIG. 5

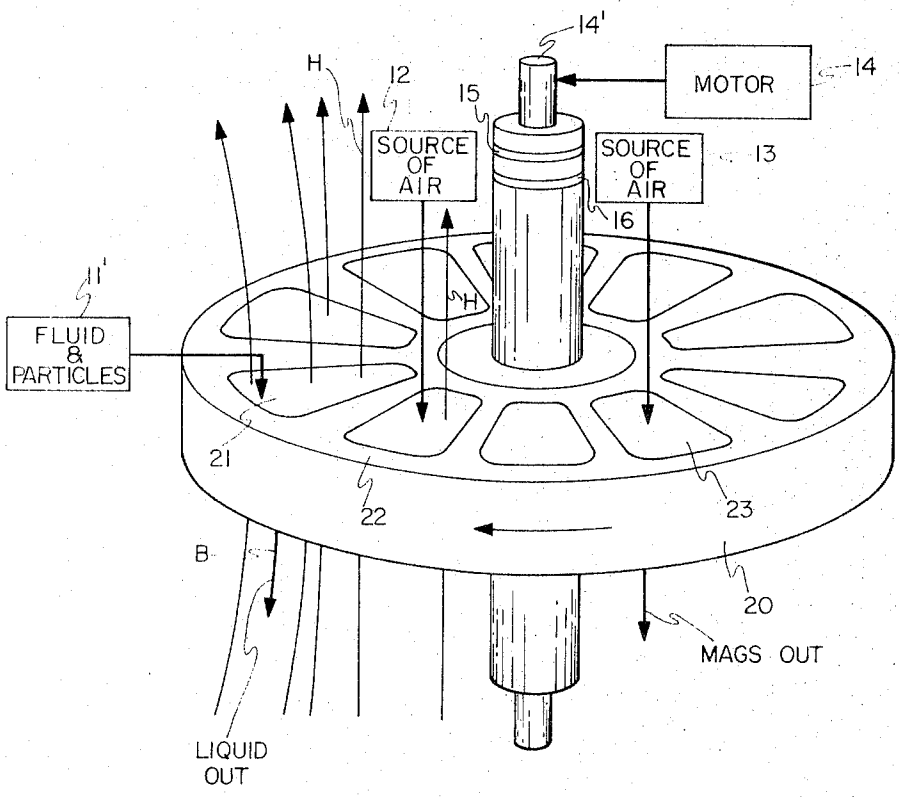

14'
H
12
15
MOTOR
14
SOURCE OF AIR
SOURCE OF AIR
13
16
11'
FLUID & PARTICLES
H
21
22
23
B
20
MAGS OUT
LIQUID OUT

FIG. 6

VIBRATING-MATRIX MAGNETIC SEPARATORS

This invention was made in the course of work performed under a contract with the Air Force Office of Scientific Research.

The present invention relates to a magnetic separator having a filamentary-type matrix wherein provision is made to effect continuous vibration of the matrix during the separation process.

Attention is called to U.S. Pat. Nos. 3,567,026 (Kolm); 3,627,628 (Marston); and 3,676,337 (Kolm), as well as the further patents and other references cited in connection with said letters patent. See also a description of a moving-matrix separator developed by Magnetic Engineering Associates, Inc., and described in the Francis Bitter National Magnet Laboratory Report (July 1971-July 1972) pages 150 et seq.

In the discussion that follows the separator discussed in greatest detail is one having a stainless steel wool matrix, like that discussed in the Kolm patents. The separator there discussed is particularly useful in processes wherein the material to be removed from a slurry or other fluid carrier is a small percentage of the total slurry volume. More precisely, it is most useful in those situations wherein a slurry or other fluid carrier containing a small percentage of particles is passed through the separator since, even in a typical situation in which the wool matrix working volume fills say five percent of the total volume wherein separation or filtration occurs, nevertheless, the volume of wool appears quite dense and there is a tendency toward mechanical, as distinguished from magnetic, separation and clogging. The density of the steel wool or other filamentary-type matrix cannot be arbitrarily reduced below some minimum amount because the magnetizing background field effects packing of the matrix filaments which is in some relationship to the intensity of that field. It has been found for present purposes that the amount of purely mechanical separation in such systems can be greatly reduced by effecting continuous vibration of the matrix.

Accordingly, an object of the present invention is to provide novel vibration schemes for the filamentary-type matrix of a magnetic separator, whereby continuous vibration of the matrix filaments can be effected during the separation or filtration process.

A further object is to provide vibration schemes that are particularly useful for the type separators disclosed in the Kolm patents.

The clogging problem can be ameliorated by a moving matrix separator of the type discussed in the Bitter National Magnet Laboratory Report, but such apparatus is essentially a low pressure system and some mechanical filtration does occur. It is, therefore, a still further object to provide novel vibration schemes for either static or moving matrix designs.

Most important separation processes involve particles in a slurry, some of the particles being separated magnetically (i.e., mags) and retained in the matrix and the remainder of the particles (i.e., tailings) being removed from the matrix with the liquid part of the slurry, the mags being removed later. It is often quite vital that the mags be dried. Another object of the invention is, therefore, to show a novel way by which to dry the particles that are separated magnetically from the slurry.

These and still further objects are discussed in the description that follows and are particularly delineated in the appended claims.

The objects of the invention are attained by a magnetic separator or filter adapted to separate particles in a fluid stream into at least two groups on the basis of the magnetic susceptibility (i.e., on the basis of induced magnetic dipole moment) of the individual particles in the fluid. The separator includes a ferromagnetic filamentary matrix that contains a plurality of paths therethrough along which the carrier and particles can travel and means for establishing a continuous or d-c (i.e., unidirectional) magnetic background field in the volume occupied by the matrix to magnetize the matrix and the particles. Vibration means is provided to effect vibration of the magnetized matrix filaments during the separation process to prevent purely mechanical attachment of particles to said filaments. In one form the vibration means includes an electric current conductor which is embedded in the matrix and electrically insulated therefrom, said conductor being adapted to connect to a source of alternating current and, when energized, to effect vibration of the fibers during the separation process by mechanical interaction between the conductor means and the matrix. The vibration is generated by interaction between the continuous background field and the alternating current in the conductor, the vibrating force occurring wherever the electric conductors of the conductor means are not parallel to the direction of the background field. In another form of the invention, vibration of the matrix is effected by applying an alternating magnetic field to the matrix, the alternating field being oriented in a transverse direction to the background field; more specifically, the alternating field has a component thereof so oriented.

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

FIG. **1** is an isometric section view, partially in schematic and block diagram form, of a system embodying one scheme for effecting vibration of the filaments of a filamentary matrix of a magnetic separator;

FIG. **2** is an isometric section view of a matrix, like the matrix in FIG. **1**, but showing a modification of the vibration scheme;

FIG. **3** shows a further modification;

FIG. **4** shows a matrix made up of a plurality of matrices like the matrix of FIG. **1**;

FIG. **5** is an isometric section view of a modification of the system of FIG. **1** and shows a separator with a rotatable matrix;

FIG. **6** is an isometric view of the rotor portion of the separator of FIG. **5**; and

FIG. **7** is a schematic representation, partially in block diagram form, of a modification of the separator of FIG. **1**.

By way of brief introduction to the description that follows, the inventive concept contemplated by the present specification is concerned with effecting vibration of the filaments of a filamentary magnetic matrix of a magnetic separator during the time that particles having an induced magnetic dipole moment are being attached to and retained by the filaments to effect separation. Such vibration of the matrix is effected while the matrix is magnetized so as to dislodge from the filaments those particles which are held purely or mostly by mechanical force and to discourage purely mechanical attachment. Two mechanisms for effecting such vi-

bration are hereinafter described: in the first-described system an insulated coil is embedded in the matrix and vibration is effected by mechanical interaction between the coil and the matrix; and in the second system an alternating magnetic field oriented orthogonal to the steady-state background field which magnetizes the matrix, interacts electromagnetically with the filaments in a periodic fashion to effect such vibration.

Referring now to FIG. 1, a magnetic separator embodying the present inventive concepts is shown generally at **101.** A carrier fluid stream, which may be air but is usually water or another liquid from a source **11'** is introduced to the separator **101** at inlet **1,** of a non-magnetic container **4,** and removed at outlet **2** as indicated by the arrow labeled A. The slurry or other fluid stream contains particles of differing magnetic susceptibility, size, shape, etc., and the particles are separated from one another on the basis, mostly, of the induced magnetic dipole moment of each, as later discussed. The separator includes a ferromagnetic filamentary matrix **3** of stainless steel wool or like material, that contains a plurality of paths therethrough along which the carrier fluid can travel. A d-c (i.e., continuous) background field, represented herein by the arrows designated H, in the volume occupied by the matrix **3** is provided by a solenoidal magnet winding **7** which is energized by a d-c power supply **5.** The solenoid magnet may be provided with an external iron flux return path, which is not shown, to enhance the field intensity in the region occupied by the matrix. The background field H acts to magnetize the matrix **3** and the particles therein, as explained in detail in the Kolm patents and as now explained in lesser detail.

The particles to be separated can be magnetic (i.e., ferromagnetic) and/or paramagnetic; that is, ferromagnetic particles can be separated as a group from paramagnetic particles or from each other, and paramagnetic particles can also be separated from one another. The term "magnetic susceptibility" refers to the ability of a material to accept magnetization. The term "induced magnetic dipole moment" is used to describe the degree of magnetization of a particle; it is the product of magnetic field intensity, and magnetic susceptibility, and the volume of the particle being magnetized. Thus, to separate a particle magnetically from a slurry, the magnetic forces of induced magnetic dipole moment and magnetic field gradient (see the Kolm patents for a detailed explanation) must overcome the tendency of the slurry to remove or prevent attachment of the particle to the matrix. Thus, two particles of differing magnetic susceptibility, but of identical mass, size (i.e., volume) and shape, can be segregated from one another. Alternatively, particles of identical susceptibility but different size could be segregated from each other and classified into size fractions. Essentially, however, it is the induced magnetic dipole moment which distinguishes one particle from another, and, for ease of explanation, that will be the only distinguishing feature discussed hereinafter—it being kept in mind, however, that the other named characteristics enter the filtration process. Also, as noted, magnetic particles can be separated from one another in the separator **101** just as such particles can be separated from paramagnetic particles, and that paramagnetic particles can be separated from one another. In addition, mention is made herein of separating particles into two groups; but it will be appreciated that by this is meant at least two groups since, particularly in the moving matrix machine later noted, it is possible to segregate particles into more than two groups. The term "mags" is an accepted term in the art to designate particles (magnetic or paramagnetic) retained in a matrix magnetically while the other particles of lesser induced magnetic dipole moment (called "tailings" herein) pass through and out of the matrix with the carrier fluid. Both terms are used herein in their usual way.

It has been found, for present purposes, particularly when a large part of the fluid carrier medium is occupied by particles that there is a great tendency toward mechanical retention of the particles by a filamentary-type matrix. This is particularly true when the carrier is air, for example, or the particles are an ore such as taconite or coal which is passed through the separator in substantial volume. In this circumstance in the system of FIG. 1 in the absence of the now to be described feature, the particles in the carrier very quickly pile up at the inlet end of the matrix **3,** and these particles include materials which in this particular system have essentially no magnetic dipole moment. To prevent purely mechanical filtration, there is embedded in the matrix **3** an insulated electric current conductor coil **6** that is connected to a source of alternating current **9** (30–1,000 Hz). When the conductor coil **6** in FIG. **1** is energized, there is electromagnetic interaction between the continuous background field H and the alternating current in the coil **6,** a vibrating force upon the coil occurring wherever the conductors of the coil **6** are not parallel to the direction of the background field. It turns out that the electromagnetic force and the mechanical spring effect of the coil combine to impart a somewhat complex vibratory movement to the coil **6.** The vibratory movement is transmitted to the matrix **3** in which it is embedded by purely mechanical interaction. The coil **6** must be distributed throughout the matrix **3** to vibrate all parts thereof and it must have portions non-parallel to the field, as above noted. This can be done by placing a helical coil, as shown in FIG. **1,** whose axis is parallel to the flux lines H within the center region of the magnet coil **7.**

The system of FIG. **1** is used for a modified batch-type operation. Thus a carrier fluid and particles are introduced at **1,** the carrier fluid and tailings passing into, through and out of the matrix **3,** leaving at the outlet **2;** the mags are retained by the matrix **3.** Later the background field H is turned off and the matrix is purged by flushing (washing) or blowing out the mags. If the carrier is a liquid such as water, for example, it may be necessary to dry the mags prior to removal. In such a situation the field H is maintained, the vibratory action is continued, the excess or retained water is removed by blowing a stream of air from a source of air **12** through the matrix and out the outlet **2,** as shown, until the mags are dried adequately. At this juncture the magnetic field is turned off and the mags are removed under the influence of the air stream. A small amount of vibration produced by the vibration winding itself without the background field facilities this air purging operation.

The matrix in FIG. **4** comprises filamentary matrices **60, 61, 62** and **63** around each of which there is wound a helical conductive and insulated coil as shown at **64, 65, 66,** respectively, the electrically conductive coil around the matrix **63** not being shown in FIG. **4.** The matrices **60, 61 . . .** can be placed within a single non-

magnetic housing, like the housing **4**, which in some circumstances will preferably be also electrically non-conductive.

The current source **9** in FIG. **1** is connected to the coil **6** by leads which pass through the non-magnetic housing **4** through bushings **10** and **11**. The insulated coil **6** is a multi-fiber cable or ribbon of woven, braided or stranded (e.g., twisted or transposed "Litz" wire) configuration. Individual fibers are sufficiently thin and of sufficiently tempered material to withstand prolonged vibration without fatigue failure. Useful materials for this purpose include phosphor bronze, beryllium bronze, nichrone, stainless steel, chrome copper, silver bearing copper, for example. The coil is insulated with one or several layers of an elastic and chemically resistant material such as, by way of illustration, Buna N or Nitrile, Neoprene, Butyl rubber, GR-S synthetic rubber, natural rubber, silicone rubber, polyacrylic rubber, vyram, polysulfide rubber, chlorosulfonated polyethylene, fluorinated butyl acrylate, fluorocarbon rubber, or teflon. The insulation is reinforced for abrasion resistance with braided glass fiber, nylon, rayon or the like.

The configuration shown in FIG. **2** can also be used. Here the matrix designated **3'** is made up of a plurality of pancakelike matrix elements **8, 8'** . . . and between each matrix element there is disposed an insulated electric wire formed into the spiral coils labeled **6'** whose planes are oriented essentially perpendicular to the direction of the background field H. The spiral coils **6'** are sandwiched between layers of matrix material so that substantially all parts of the matrix material are subjected to said mechanical interaction.

In FIG. **3** an electrical conductor **6''**, which meanders back and forth between layers, again labeled **8, 8'** . . . , of matrix material, provides the needed vibrating forces. Again the direction of the conductor is essentially perpendicular to the direction of the background field H and a conductor, like the conductor **6''**, is sandwiched between the further layers **8', 8''** . . . so that substantially all positions of the matrix are subjected to mechanical interaction.

The separator shown at **101A** in FIGS. **5** and **6**, is called a "carousel" separator by the manufacturer. It is described in detail in said Francis Bitter National Magnet Laboratory Report and it is not believed that a further detailed explanation need be made here. Essentially, the separator comprises a case **18** that houses a field coil **19** adapted to magnetize a matrix material contained in the compartments **21, 22, 23** . . . in the rotor shown at **20**. In this simplified explanation, a slurry is introduced to the compartment **21**, the liquid and tailings pass into, through and out of the matrix in the compartment as indicated by the arrow labeled B. The compartment **22**, which is still within the region of the field H (and is being vibrated) is purged by an air stream from the source, again designated **12**, while at the same time the mags in the compartment **23**, at a position outside the region of the field H, are blown from the matrix by an air stream from a source of air **13**. The whole of the matrix in the rotor compartment contains an insulated electrical conductor like the conductor of the coil **6**, or the spiral coil **6'**, or the meandering conductor **6''**, or some other configuration and which is energized during system operation. Alternating current to the rotor to energize the vibration conductor is delivered through slip rings **15** and **16**. It will be appreciated that the orientation of the conductors is important, as before explained, and that vibration will occur only in the region of the field H. Rotation of the rotor **20** is accomplished through suitable mechanical coupling from an electric drive motor **14** through drive shaft **14'**. The slip rings **15** and **16** can be replaced by commutators (four or more in number) thereby to energize the conductors embedded in the matrix selectively only at such time as such conductors are within the region of influence of the field H.

The separator shown at **101B** in FIG. **7** contains a number of elements that perform the same function as is performed in the system of FIG. **1** and the same numerals are applied. It is of course understood that there is a matrix within the housing **4**, that the housing **4** is non-magnetic and, in this embodiment preferably also electrically non-conducting. Means is provided in the embodiment of FIG. **7** for establishing an alternating field H' within the volume occupied by the matrix and in a direction approximately perpendicular to the direction of the background field, as shown. Applying the transverse alternating field H' is equivalent to oscillating the background field through a small angle either side of the vertical direction of orientation shown, said angle being determined by the ratio of the intensity of the background field to that of the oscillating (i.e., alternating) transverse field. The matrix filament will try to follow the oscillatory movements of the field and will thereby be vibrated, as before. The transverse field can be provided by a pair of windings **24** and **25** which can be pancake type windings contoured to the shape of the housing **4** and suitably insulated from the winding **7**. The windings **24** and **25** are energized by the source of alternating current **9**, as before.

Separators with filamentary-type matrices require about 7,500 gauss background field H to saturate the filaments, and fields of that intensity and above are required to remove paramagnetic colloidal materials on an industrial scale; ferromagnetic particles and larger paramagnetic particles can be removed with lower fields. The transverse field necessary for effective shaking is about one percent of the background field H. As used herein "filamentary-type matrix" denotes a matrix of magnetic wool, braided fibres, woven fibres, metal lath and the like, and these latter terms are deemed interchangeable.

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 in the appended claims.

What is claimed is:

1. A magnetic separator adapted to separate particles in a carrier fluid stream into at least two groups on the basis of the induced magnetic dipole moment of the individual particles in the fluid, that comprises: a ferromagnetic filamentary matrix that contains a plurality of paths therethrough along which the carrier and particles can travel, means for establishing a continuous magnetic background field in the volume occupied by the matrix to magnetize the matrix and the particles, and electric current conductor means embedded in the matrix and electrically insulated therefrom, said conductor means being adapted to connect to a source of alternating current and when energized to effect vibration of the fibers during the separation process by mechanical interaction between the conductor means and

the matrix, said vibration being generated by interaction between the continuous background field and the alternating current in said conductor means, the vibrating force occurring wherever the electric conductors of the conductor means are not parallel to the direction of the background field.

2. A separator as claimed in claim **1** in which the conductor means is an insulated electric wire which is formed into one or several helical coils with their axes essentially parallel to the direction of the background field, distributed throughout the matrix material so that substantially all positions of the matrix are subjected to said mechanical interaction.

3. A separator as claimed in claim **2** which further includes a source of alternating current of 30 to 1,000 Hz frequency connected to energize the conductor means during the separation process.

4. A separator as claimed in claim **3** in which the matrix is a stainless steel wool matrix, at least some of the particles being retained by the steel wool in an operable system.

5. A separator as claimed in claim **3** in which the source of alternating current is controllable in current amplitude and frequency, thereby to provide some control over the degree of mechanical and magnetic retention of particles.

6. A separator as claimed in claim **1** which includes an inlet to admit the fluid containing the particles to the matrix, and an outlet to discharge the fluid and those particles which are not retained magnetically, said inlet and outlet serving also to purge the matrix of the magnetically retained particles after the background field has been turned off.

7. A separator as claimed in claim **1** in which the matrix is operable to move continuously so that portions thereof pass from a region in which said portions are exposed to the background magnetic field to a region in which there is no magnetic field, and back again, a plurality of fixed inlets and outlets being provided to introduce the carrier fluid and particles to the matrix, to remove residual tailings from said portions of the matrix while those portions are in the magnetic field region, and to purge the matrix of magnetic particles when said portions of the matrix are outside the magnetic field region, all operations being conducted in a continuous cycle while the matrix is in motion, means being provided to connect said conductors selectively to a source of alternating current during all or parts of the separation cycle.

8. A separator as claimed in claim **1** in which the conductor means is an insulated electric wire which is formed into one or several spiral coils with their planes essentially perpendicular to the direction of the background field, sandwiched between layers of matrix material so that substantially all positions of the matrix are subjected to said mechanical interaction.

9. A separator as claimed in claim **1** in which the conductor means is an insulated electric wire which meanders back and forth between layers of matrix material, the direction of said wire being essentially perpendicular to the direction of the background field, distributed throughout the matrix material so that substantially all positions of the matrix are subjected to said mechanical interaction.

10. A separator as claimed in claim **1** in which the conductor means is a multi-filament cable or ribbon of woven, braided or stranded configuration, individual filaments being sufficiently thin and of sufficiently tempered material to withstand prolonged vibration without fatigue failure, and insulated with an elastic and chemically resistant material, reenforced for abrasion resistance.

11. A separator as claimed in claim **1** in which the fluid is water, in which the particles separated are mags and tailings, the mags being retained within the matrix by said magnetic force and the water and tailings passing into, through, and out of the matrix, means being provided to blow a stream of gas through the matrix while the matrix is subjected to the background field and to mechanical vibration simultaneously to remove excess water from the fluid, said last-named means acting also to purge the matrix of the mags when the magnetic field has been turned off but the mechanical vibration is still in effect.

12. A magnetic separator adapted to separate particles in a fluid carrier stream into at least two groups on the basis of the induced magnetic dipole moment of the individual particles in the fluid, that comprises: a ferromagnetic filamentary matrix that contains a plurality of paths therethrough along which the carrier and particles can travel, means for establishing a magnetic background field in the volume occupied by the matrix to magnetize the matrix and the particles, and means for establishing an alternating magnetic field in said volume and in a direction approximately perpendicular to the direction of said background field, thereby to apply a vibrating force to the magnetized filaments of the matrix.

13. A separator as claimed in claim **11** which further includes a source of alternating current of 30 to 1,000 Hz frequency connected to energize the conductor means during the separation process.

14. A separator as claimed in claim **12** in which the matrix is a stainless steel wool matrix, at least some of the particles being retained by the steel wool in an operable system.

15. A separator as claimed in claim **13** in which the source of alternating transverse field is controllable in current amplitude and frequency, thereby to provide some control over the degree of mechanical and magnetic retention of particles.

16. A separator as claimed in claim **12** which includes an inlet to admit the fluid containing the particles to the matrix, and an outlet to discharge the fluid and those particles which are not retained magnetically, said inlet and outlet serving also to purge the matrix by washing or blowing out the magnetically retained particles after the background field has been turned off.

17. A separator as claimed in claim **12** in which the matrix is operable to move continuously so that portions thereof pass from a region in which said portions are exposed to the background magnetic field to a region in which there is no magnetic field, and back again, a plurality of fixed inlets and outlets being provided to introduce the fluid carrier and particles to the matrix, to remove residual tailings from said portions of the matrix while those portions are in the magnetic field region, and to purge the matrix of magnetic particles when said portions of the matrix are outside the magnetic region, all operations being conducted on a continuous cycle while the matrix is in motion, means being provided to apply the alternating magnetic field at one or more portions of the matrix.

18. A magnetic separator adapted to separate particles in a fluid carrier into groups on the basis of the magnetic characteristics of the individual particles, that comprises, a ferromagnetic filamentary matrix that contains a plurality of paths therethrough along which the carrier and particles can travel, means for establishing a magnetic background field in the volume occupied by the matrix to magnetize the filaments that make up said matrix and the particles therein so that some of the particles are attracted to and become attached to the filaments by virtue of magnetic forces, and vibration means operable to effect vibration of said filaments to discourage purely mechanical attachment thereto while magnetic separation is occurring, said separator serving not only to remove particles from a fluid on the basis of their magnetic characteristics, but also to dry magnetic particles or mags retained in the matrix by magnetic forces in a system in which the carrier is a liquid by blowing a stream of air or other gas through the matrix while said matrix is subjected to a background magnetic field and to mechanical vibration simultaneously, until a desired degree of moisture reduction has been achieved, whereupon the background field is turned off or the matrix is moved to a region of zero field and the dried mags are removed from the matrix, said separator including means for introducing a gas stream to a portion of the matrix in said volume during the time at which the portion of the matrix is magnetized and being subjected to vibration but after a major part of the liquid has been removed from the portion of the matrix, thereby to effect drying of the mags.

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