United States Patent

[11] 3,552,565

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[33] Germany
[31] F 52,488; F 55,037

[54] **MAGNETIC SEPARATOR**
7 Claims, 15 Drawing Figs.

[52] U.S. Cl. **209/219,** 209/223; 336/177
[51] Int. Cl. **B03c 1/02,** H01f 17/06
[50] Field of Search 209/219, 223, 131.1, 216, 222, 221; 210/222, 223, 220; 336/222; 335/302, 304, 306

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ABSTRACT: A suspended magnet, rotary drum, magnetic pulley or like separator or cobber for the recovery of magnetic materials from comminuted nonmagnetic materials and wherein a ferromagnetic coil constitutes part of the means for energizing a ferromagnetic circuit and also constitutes part of this circuit.

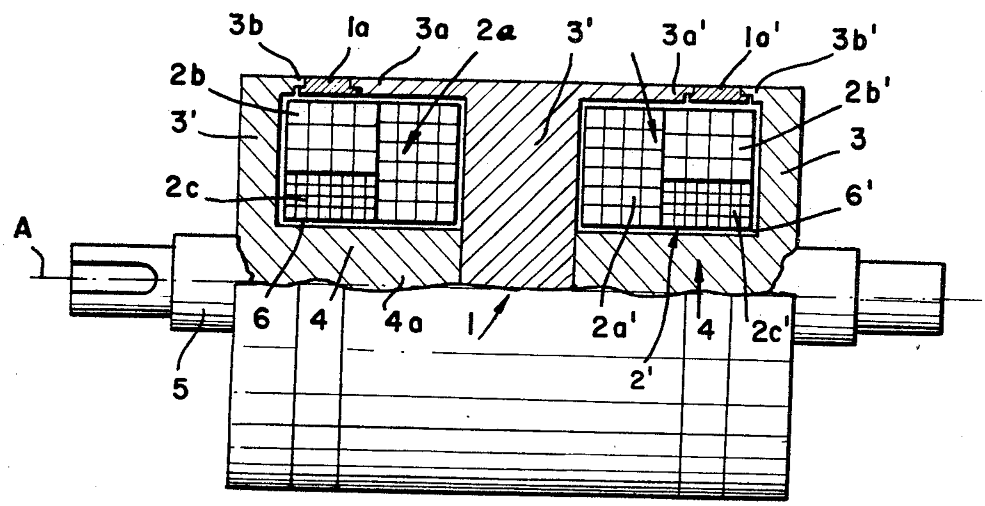


FIG.1

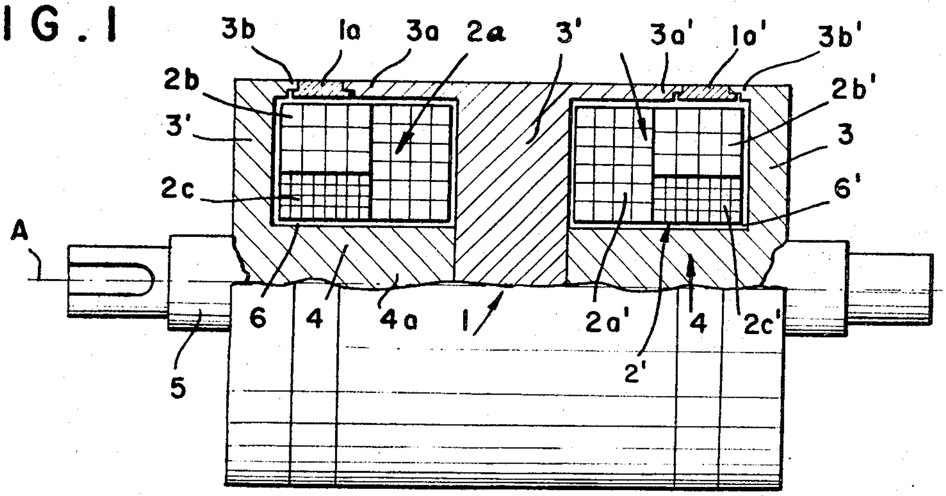
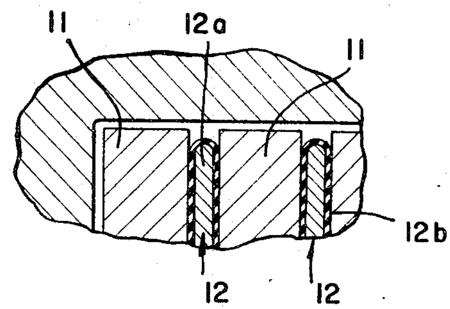


FIG.2-A



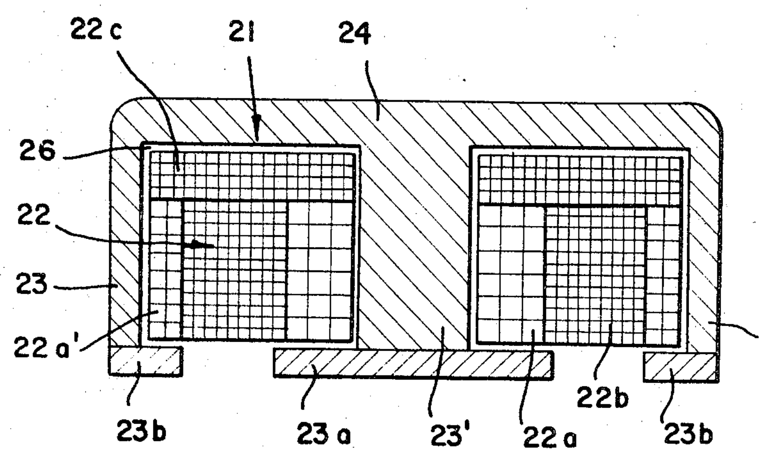


FIG.2

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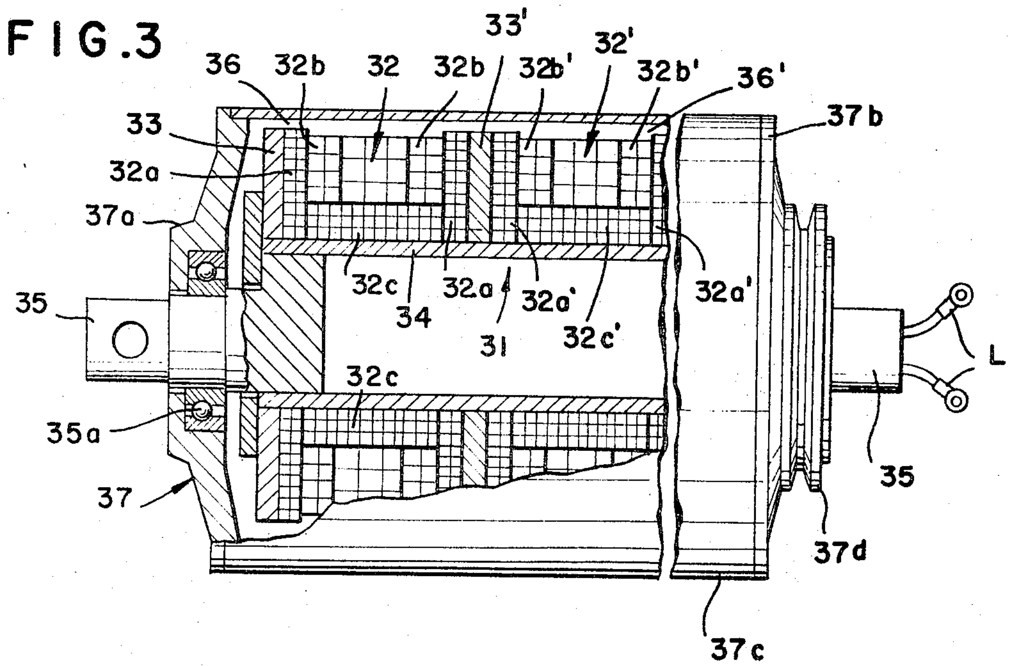
FIG.3



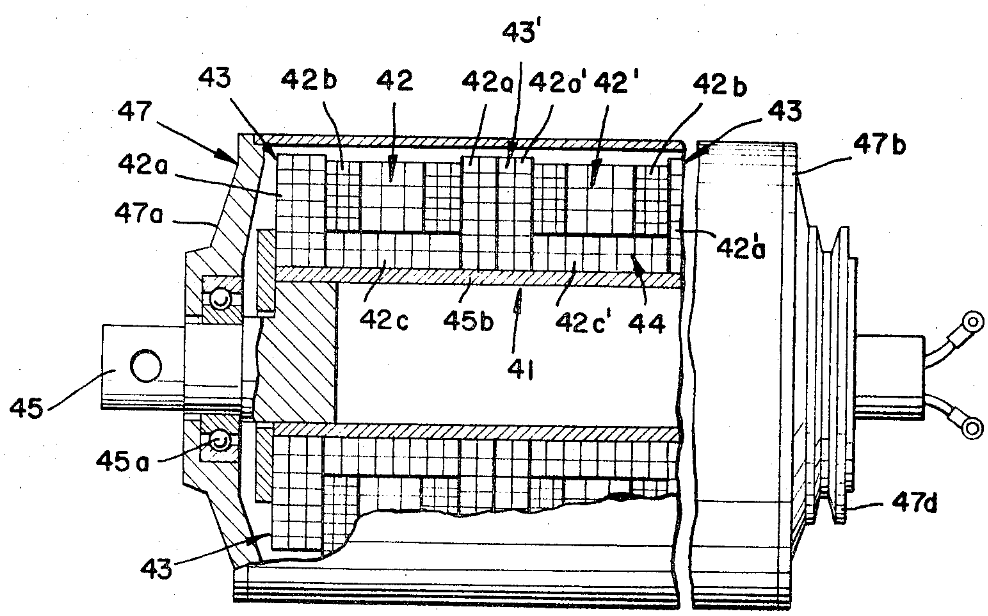


FIG.4

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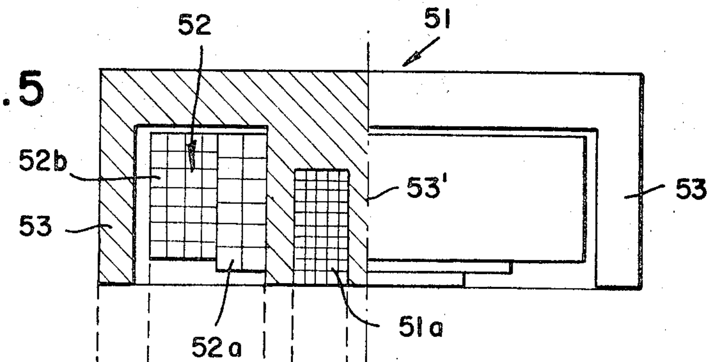
FIG.5



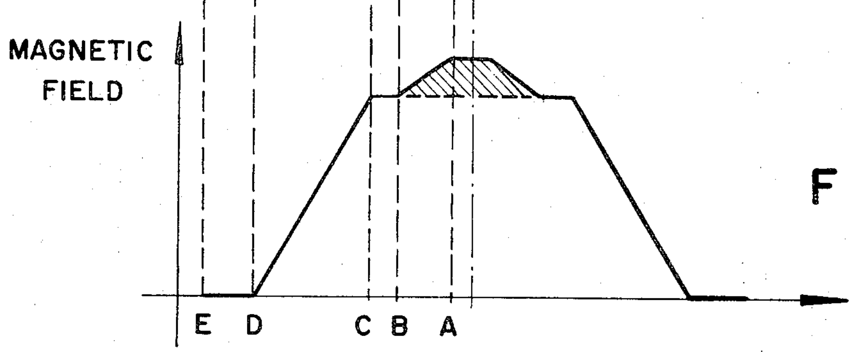


FIG.5-A

FIG.6

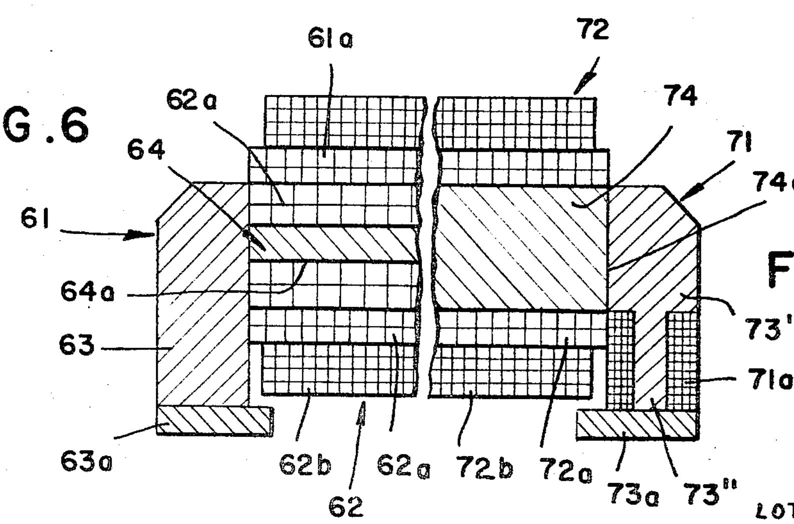


FIG.7

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FIG.8

FIG.9

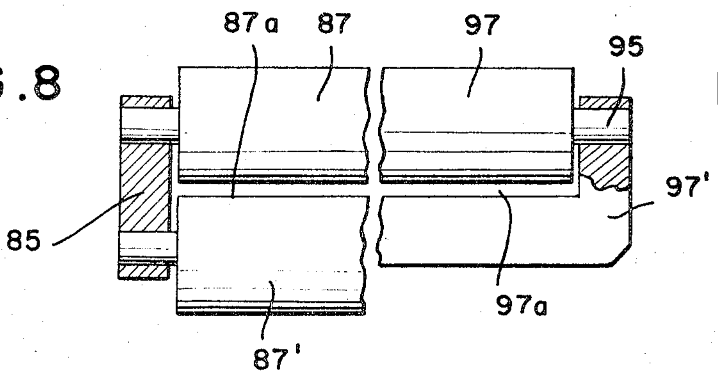

FIG.10

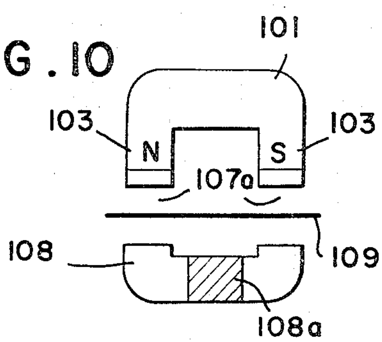

FIG.11

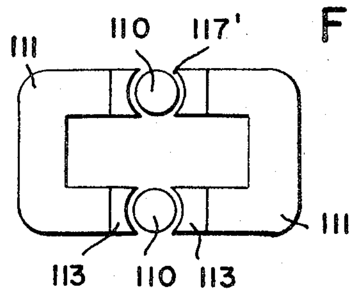

FIG.12

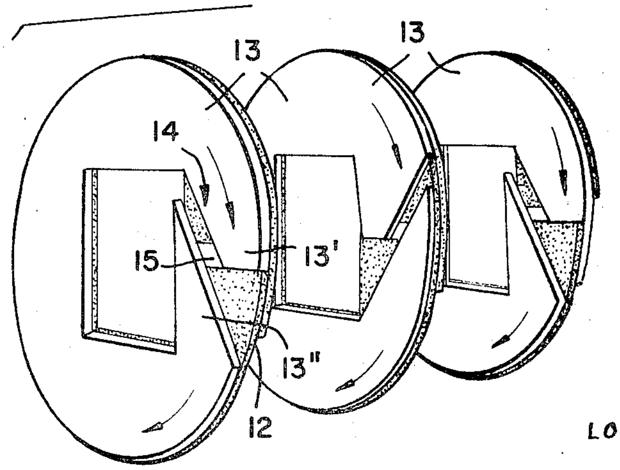

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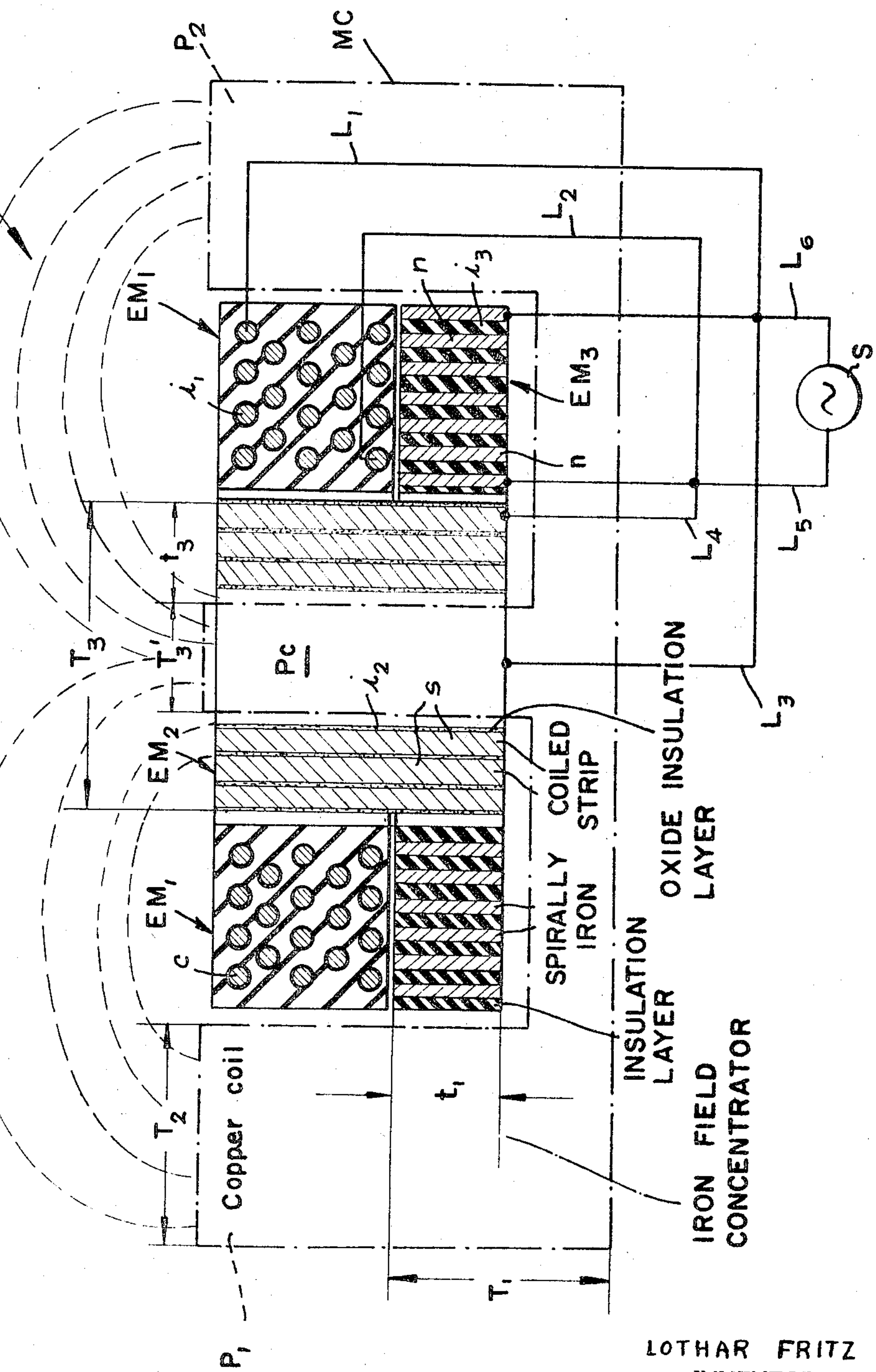
FIG. 13



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MAGNETIC SEPARATOR

My present invention relates to magnetic separators of the conveyor or drum type and, more particularly, to a magnetic separator for the removal of magnetic materials from a mass as in tramp iron removal from products displaced along a transport path or for the concentration and purification of ores and other materials by increasing the concentration of magnetic components or decreasing the concentration of magnetic substances in nonmagnetic materials.

It has already been proposed to provide magnetic pulleys and drums in the removal of tramp iron, generally considered to be iron coarser than 3 to 4 mm., from comminuted material or material to be comminuted and in concentrators or other apparatus for working up, concentrating or otherwise improving ores and the like which may contain iron or ferrous metals. Tramp iron magnetic separators may be used to protect handling and processing equipment, such as crushers and pulverizers, and to protect conveyor systems. They may include magnetic pulleys which are used to remove tramp iron from products handled on belt conveyors suspended magnets installed over a conveyor or the head pulley thereof, magnetic drums (drum separators) along which the comminuted material is fed, etc. These systems generally operate on the dry material. For the concentration and purification of ores and the like (e.g. magnetic recovery of a preponderance of a feed material containing large quantities of magnetic components or the removal of iron particles from a mass consisting predominantly of nonmagnetic materials), wet separation is more common and may make use of magnetic drum separators which attract, by virtue of a permanent magnet or electromagnet filed, magnetic components in the feed material to the rotating drum shell. Dry magnetic separators are used here as well, commonly with magnetic rollers.

The present invention is directed primarily to electromagnetic separators in which a coil generates a magnetic field which is carried in a ferromagnetic material forming the circuit and can be either a closed magnetic circuit or an open magnetic circuit. In the case of a closed magnetic circuit, one or more air gaps are provided through which the material may pass. When the system is used in a magnetic drum, it may have a U section, E section or annular configuration.

The separating force, i.e. the ability to remove iron particles from the throughgoing mass, is as high as practicable and is determined by the field strength, the geometry of the magnetic field and the air gaps (which play an important role in closed magnetic circuits). A disadvantage of the conventional magnetic separators arises from the fact that an increase in the field strength by magnetic saturation of the ferromagnetic materials cannot always be generated because of technological considerations.

The invention thus concerns electromagnetically operated magnetic separators in which a magnetic circuit is formed at least in part by ferromagnetic material, e.g. laminated ferromagnetic cores, the core cooperating with an electrically energized coil. The latter is generally wound from copper or a copper alloy of a high electrical conductivity and low heat loss, the turns of the coil being insulated from one another (as in insulated wire). The magnetic circuit can be an open circuit in which the ferromagnetic material forms a gap between, for example, magnetic poles of opposite magnetic polarity, or a closed magnetic circuit in which stray magnetic fields are used to attract the magnetically permeable material from the comminuted mass passing along the magnetic separator. In the closed system, one or more gaps can be provided through which the material passes. In the latter case, the material may be conveyed on a belt or the like through a gap between the magnetic core (having two or more poles juxtaposed with the belt) while the magnetic circuit is completed by a yoke spanning the poles, but spaced therefrom, on the other side of the belt. Typical circuit configurations may be the U shape and E shape commonly provided as well as the annular counterparts thereof.

The high separating rate and, consequently, high magnetic efficiency desired in such systems is found to be dependent, in open magnetic circuits, upon the field strength and the geometry of the magnetic field. In closed magnetic circuits, the separating efficiency is a function of the field strength in the air gaps. Besides the problem involving saturation of the core arising in conventional systems, it is found that the poles of ferromagnetic material occupy relatively little of the exposed area of the device while the larger part of the bulk of the magnetic separator is taken up with relatively large electromagnetic coils. As a practical matter it is found that increasing the size of the coil, in order to obtain high field strength in terms of ampere turns, decreases the separating area, whereas an increase in the size of the core (and thus the effective area) requires decreasing the size of the coil and, moreover, increasing the heat loss in the system. As a result, previous designs of such structures have proved to be compromises within a given volume of the magnetic separator.

It is, therefore, the principal object of the present invention to provide an improved magnetic separator, for the removal of tramp iron from a comminuted mass or for concentrating magnetic components of such mass, which will allow an increase in the separating effectiveness and "resolving power" of the separator within a given volume and will permit the magnetic separator to be of relatively simple and inexpensive construction.

This object and others which will become apparent hereinafter are attainable in a magnetic separator for the working up of magnetic materials, e.g. the removal or recovery of tramp iron from a comminuted mass containing same, for the removal of magnetic impurities from a nonmagnetic mass to be concentrated or purified, or for the recovery and concentration of magnetic particles from a mass containing such particles together with nonmagnetic particles, wherein the magnetic circuit includes a mass of ferromagnetic material concentrating the lines of force produced by an electromagnetic coil wound from insulated wire, the magnetic circuit at least in part consisting of electrically insulated ferromagnetic coils.

Viewed in another way, the invention may be considered to comprise a magnetic separator of the character described in which the energizing coil means consists at least in part of insulated ferromagnetic conductors coiled to produce a magnetic field and energized by an external source in series or in parallel with the insulated wire coil of nonferrous material and simultaneously constituting a part of the flux reinforcing magnetic core or yoke. The coil, in this case, functions to increase the effective cross section of the "magnetic circuit" while the magnetic circuit functions, in part, as the electromagnetic coil means. The ferromagnetic portion of the electromagnetic coil means is traversed by the flux generated partly by energizing the ferromagnetic coil and at least in part by the nonferromagnetic coil.

The present invention, while applicable to various configurations of magnetic separators using electromagnetic actuation, may have a relatively simple and inexpensive construction as will be apparent hereinafter. Thus the ferromagnetic coil can be wound about one pole of an open magnetic circuit device so that its turns do not bridge the poles and diminish the effective separating flux, but increase the effective cross section of the pole which the ferromagnetic coil surrounds. The ferromagnetic coil may be overlain or covered by portions of the pole, e.g. pole plates or mantels. On the other hand, the ferromagnetic coil can constitute sections of the ferromagnetic circuit without surrounding same so that, for example, a pole, yoke, core or pole plate is constituted over its entire cross section by the ferromagnetic coil.

In closed magnetic circuits, the ferromagnetic coil can be provided either in the main magnetic field generator or as all or part of the yoke juxtaposed therewith.

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. 1 is a diagrammatic elevational view of a rotary coil magnetic separation pulley or roller drum, partly broken away, embodying the present invention;

FIG. 2 is a cross-sectional view of a magnetic separator having an E-shaped magnetic circuit;

FIG. 2A is a detail view of the region IIA of FIG. 2;

FIG. 3 is an elevational view, partly broken away, of a system in which the coils are stationally but basically similar to that of FIG. 1;

FIG. 4 is a view similar to FIG. 3 of another embodiment of this invention;

FIG. 5 is a fragmentary cross-sectional view of a magnetic separator of the suspended magnet type;

FIG. 5A is a graph of the magnetic potential taken across the suspended magnet separator of FIG. 5;

FIG. 6 is a cross-sectional view of a magnetic separator with a U-shaped magnetic circuit;

FIG. 7 is a view similar to FIG. 6 of another embodiment of this invention;

FIG. 8 is a fragmentary elevational view of another magnetic separator embodying this invention;

FIG. 9 is a view similar to FIG. 8 and representing a modification thereof;

FIG. 10 is a diagrammatic elevational view of a magnetic separator according to this invention provided with an additional yoke member;

FIG. 11 is a view similar to FIG. 10 but illustrating another embodiment of the invention;

FIG. 12 is an exploded view diagrammatically illustrating the ferromagnetic coil adapted to be used in the system represented in FIG. 1, for example; and

FIG. 13 is a diagrammatic cross-sectional view explaining the present invention.

Referring first to FIG. 13, it can be seen that a basic magnetic separator structure may have a magnetic circuit MC whose poles are represented at P_1, P_c and P_2 and sustain a magnetic flux F as represented in broken lines in FIG. 13. As will be apparent in FIGS. 1—12, the magnetic material is attracted to the poles and removed from the mass in the manner fully described in Perry's Chemical Engineer's Handbook, Fourth Edition, McGraw-Hill Publishing Co., New York, and Dean and Davis, Magnetic Separation of Ores, U.S. Bur. Mines Bull., 425,1941; Taggart, "Handbook of Mineral Dressing," Wiley, New York, 1953; DeVaney, New Developments in the Magnetic Concentration of Iron Ores, Proc. Inter. Mineral Processing Congr., Institution of Mining & Metallurgy London, Paper 31, Group VI, Apr. 1960; and Forcia, Hendrickson, and Palasvirta, Magnetic Separation in Beneficiation of Mesabi Range Magnetic Taconite, Mining Eng., Dec. 1958.

The electromagnetic coil means of the present system comprises a nonferromagnetic coil EM_1 composed of helically wound turns of copper wire *c* covered with the usual electrical insulation i_1 and surrounding the pole P_c as a core. The coil EM_1 is energized by the usual electric current source S via leads L_1 and L_2, respectively. Alone, the coil EM_1 sustains a flux Φ_1 in the E-shaped core MC constituting the open magnetic circuit previously mentioned.

In accordance with the principles of the present invention, the electromagnetic coil means EM also includes coils of ferromagnetic material to increase the effective ampere turns value of the total coil system and to increase the effective cross section of the core. In this embodiment, the ferromagnetic coil comprises three or more turns of a ferrous metal band constituting a cylindrical coil EM_2 surrounding the pole P_c and surrounded by coil EM_1. The coil EM_2 can consist of magnetic steel band *s* coated upon its opposite faces with oxide layers i_2 electrically insulating the turns from one another, the coil being energized by the source S via the leads L_3 and L_4.

A further electromagnetic coil of ferromagnetic material is provided at EM_3 and surrounds both the coil EM_2 and the core pole P_c while being energized from the source S via the leads L_5 and L_6. The coil EM_3 is composed of magnetic nickel-iron alloy in the form of a spirally coiled strip *n* interleaved with a band i_3 of electrical insulation. A further coil, similar to that shown at EM_2 can surround the coil EM_1 and EM_3 to constitute part of the poles P_1 and P_2 mentioned earlier. The coil EM_3 has a thickness *t*, which contributes to the thickness t_1 of the bridge piece of the core MC connecting the poles P_1, P_c and P_2. Similarly, the electromagnetic but ferrous metal coil EM_2 has a radial thickness t_3 contributing to the overall diameter T_3 of the pole P_2 such that

$$T_3 = T_3' + 2t_3$$

The flux produced by the system thus may be described by the relationship

$$\Phi = \phi_1 + \phi_2 + \phi_3$$

wherein ** is the total flux and Φ_1, Φ_2 and Φ_3 are the flux contributions of the coils EM_1, EM_2 and EM_3, respectively.

As indicated, these principles can be used in any pole arrangement heretofore provided in magnetic separators, whether rotary or stationary and with the same, simpler or more complex outlines of the magnetic flux. Thus, instead of winding the coils about the core piece of MC, the coils can be mounted upon a shaft so that the poles P_1, P_c and P_2 are discs or flanks of the shaft and the turns surrounding the shaft. In that case, the coil EM_2 may be constituted of discs such as are shown in FIG. 12.

In FIG. 1, I show a magnetic pulley separator whose shaft **5** is integral with the yoke members **4** and carries the electromagnetic coil means **2** and **2'** on opposite sides of a central pole disc **3'**. The yokes **4** comprise central cores **4a** upon which the coil means **2** and **2'** are coaxially supported, and end flanges **3** which are integral with the cores **4a**. The ferromagnetic mass **3**, **3'**, **3a**, **4** and **4a** encloses annular chambers **6** and **6'** in which the electromagnetic coil assemblies are recieved.

These coil assemblies **2** and **2'** include a pair of nonferromagnetic coil **2b** and **2b'** surrounding the axis of rotation A of the drum and axially spaced apart in the chambers **6** and **6'**. The coils **2b** and **2b'**, only half of each being seen in FIG. **1**, may be composed of copper insulated wire as described for the nonferromagnetic coil EM_1 of FIG. **13**. A pair of ferromagnetic coils (analogous to the coil EM_2 and EM_3 previously described) may be provided in each of the chambers **6** and **6'** as represented at **2a** and **2a'** and at **2c** and **2c'**. As a result, the ferromagnetic coils contribute to the cross section of the core formed by members **3**, **3'**, **3a** and **4** while the core members constituted by the coils **2a**, **2c**, and **2a'**, **2c'**, contribute to the electromagnetic flux as previously described and the magnetic separator roller of FIG. **1** as an E-shaped magnetic path and field configuration.

The central pole **3'** has a pair of axially extending annular flanges **3a** and **3a'** overhanging the ferromagnetic coils **2a** and **2a'** but separated from inwardly turned rims **3b** and **3b'** of the flanges **3** by annular strips **1a** and **1a'** of nonmagnetic material. The coils are energized and the device operated as described in connection with FIG. **13** and in the aforementioned publications. Energization of the coil may be effected through conventional slip rings of the shaft **5**.

FIG. **2** shows the principle of FIG. **1** applied to a suspended magnet-type of separator (see Perry's Chemical Engineer's Handbook mentioned earlier) adapted to be disposed above a conveyor carrying the comminuted mass for separation of the magnetic components. In this embodiment, the magnetic circuit **21** is formed by a yoke-shaped housing **24** with a core **23'** and a pair of outer pole pieces **23**. Within the annular chamber **26** surrounding the central post or core **23'**, I provide the coil means in the form of three coaxial coils. Thus, immediately surrounding the post **23'**, a ferromagnetic coil **22a** is provided (see coil EM_2 of FIG. **13**) and is surrounded by the nonferromagnetic coil **22b** of insulated copper wire. The electromagnetic coil means also comprises an outer ferromagnetic coil **22a'** surrounding the coil **22b** and a flattened spiral coil

22c (see coil EM_3 of FIG. 13). A central pole plate 23a of ferromagnetic material overhangs the coil 22a so as to have an area essentially equal to the full cross section of the pole member constituted by the post 23' and the ferromagnetic coil 22a. Outer plates 23b overhang the outer ferromagnetic coils 22a'.

In FIGS. 3 and 4, I show embodiments of magnetic separator drums in which the outer mantel of the drum is rotatable while the magnetic coils are stationary. In these embodiments, the drum has a housing 37 or 47 which is rotatably mounted upon a shaft structure 35, 45 via bearings 35a, 45a and comprises a pair of end plates 37a, 47a and 37b, 47b in which a nonmagnetic shell 37c or 47c is held and to which the magnetic particles adhere (see the references cited) when the drum is not used. The housing 37 and 47 can be driven by V belts engaging respective pulley 37d and 47d.

In the system of FIG. 3, the magnetic circuit is constituted of a ferromagnetic sleeve 34 whose cross section is enhanced by the annular coil 32c and the coil 32c'' surrounding this sleeve 34 and composed of ferromagnetic conductors insulated from one another as previously described. The magnetic circuit also includes a pair of end plates, only one of which is shown in FIG. 3 at 33, and a central pole plate 33' between the two coil containing chambers 36 and 36' for the coil assemblies 32 and 32', respectively. The coil assembly includes a pair of of ferromagnetic coils 32a and 32a' flanking the nonferromagnetic coils 32b and 32b', respectively. The coils in this system as well may be energized, e.g. via the leads L as indicated in FIG. 13, and create E section magnetic configurations through which the shell 37c sweeps to carry the magnetic particles therealong.

The system of FIG. 4 is generally simple except that the entire pole cross section is constituted here by the insulated turns of ferromagnetic conductors. Thus a nonmagnetic sleeve 45b is here shown to carry the core 44 of a magnetic circuit 4', the core 44 being constituted solely by the ferromagnetic coils 42c and 42c' while the pole pieces 43, 43' are constituted by the ferromagnetic coils 42a and 42a' which are of the construction previously described and enclosed the nonferromagnetic coils 42b of the electromagnetic means 42, 42'. This system operates and may be energized as described for the system of FIG. 3.

In FIG. 5, I show another suspended magnet cobbing system in which the magnetic circuit 51 has a central pole 53' and a pair of outer poles 53, the central pole 53' forming a post surrounded by the electromagnetic coil means 52. The coil means 52 includes a ferromagnetic coil 52a analogous to the coil EM_2 previously mentioned and a nonferromagnetic coil 52b surrounding same. The central pole may consist at least in part of a further coil 51a of ferromagnetic wire, the turns of which are electrically insulated from one another.

The field strength or magnetic potential generated across this system is illustrated in FIG. 5A in which the magnetic field strength is plotted along the ordinate while the locations along the magnetic separator are plotted along the abscissa. From FIG. 5A, it can be seen that there is negligible field strength or magnetic potential in the region E—D from the pole 53 to the coil 52b while the magnetic potential increases linearly in the region D—C, remains constant in the region C—B and increases again in the region B—A when the additional coil 51a of ferromagnetic wire is energized in parallel with the coils 52a and 52b. Similar ferromagnetic coils may be added in the system of FIGS. 3 and 4 to flank the nonferromagnetic coils thereof.

Two other suspended magnet separators having U-shaped magnetic circuits are shown in FIGS. 6 and 7, only half of the section being seen in each case. The yoke 64, 74 constituting the magnetic circuit 61, 71 is provided with a pair of poles, only those at 63 and 73' being seen. The yoke 64 is constituted with a core 64a of reduced diameter and a coil 61a of insulated ferromagnetic wire, the core 64a being flush with yoke 64 and, in turn, constituting the core for an outer ferromagnetic coil 62a and a nonferromagnetic coil 62b of the electromagnetic coil means 62. A pole piece 63a overhangs, in part, the electromagnetic coil means 62. In the system of FIG. 7, the core 74a is composed entirely of solid (previously laminated) ferromagnetic material and is surrounded by a ferromagnetic coil 72a and the nonferromagnetic coil 72b of the coil assembly 72. Here an additional flux contribution is made by the ferromagnetic coil 71a surrounding the leg 73'' of the pole piece 73' which has a pole piece 73a overhanging the coil 71a. The latter forms part of the flux traversed pole member.

FIGS. 8 and 9 represent additional embodiments of the present invention in which a pair of roller drums 87 and 87' are spaced apart via a gap 87a and are connected by a ferromagnetic (iron) bridge 85. The magnetic separator drum 87 and 87' can be the drums represented at FIGS. 1, 3 and 4. In this case, each drum acts as a flux concentrating yoke, reinforcing the action of the other. In the system of FIG. 9, only a single drum 97 is provided although a bridge piece 97' connects its shaft ends 95 while forming the gap 97a and constituting a reinforcing yoke of magnetically permeable material. The drums of FIGS. 3 and 4 can be used in the system of FIG. 9.

I have further found that the system of FIG. 10 is especially effective in the removal of magnetic particles from a comminuted mass displaced through the system on the conveyor belt 109. In this system, an open magnetic circuit 101 is constituted with pole members 103 being spaced from the conveyor belt 109 via the gaps 107a. The magnetic circuit 101 may be the U section device shown in FIG. 5 or in FIG. 7. On the opposite side of the band 109, I provide an additional yoke member 108 which can be constituted in whole or in part of ferromagnetic coil although only the region 108a is represented here as constituting a ferromagnetic coil. In fact, the constructions of FIGS. 6 and 7 may be used as the additional yoke members 108 with suitable polarity reversal with respect to the juxtaposed poles of the magnetic circuit 101.

FIG. 11 represents an embodiment in which two U-shaped open magnetic circuits 111 are in opposition and cooperate with drums 110 of ferromagnetic material between the poles 113 via gaps 117'. Simple iron drums 110 may be used while the members 111 may be the U section magnetic circuit of FIGS. 6 and 7.

As previously indicated, when the coils are coaxial with the drum, I prefer to make the ferromagnetic coils from discs as shown at 13. The ferromagnetic discs are provided with inclined slots 14 which retain the annular layers 12 of electrically insulating material but are open at 15 (along radial slots) to permit the tongues 13' and 13'' to contact one another and thus electrically connect the discs in the manner of a continuous helicoidal coil with a constant current flow sense represented by the arrows. Each ferromagnetic disc 13 thus constitutes a single turn of the coil. The discs may be assembled into a drum adapted to be used as the drum 110 in the system of FIG. 11 or may simply form the coils 2a, 32a, etc. of the drums of FIGS. 1, 3 and 4. Another coil construction is represented in FIG. 2A in which the turns of the ferromagnetic coil 22c are shown to consist of ferromagnetic band 11 with intervening insulating layers 12. In this case, the layers 12 each comprises a nonferromagnetic conductive core 12a flanked by insulating strips 12b separating the turns of the band 11 from one another and the foil 12a from these bands. This system has been found to provide substantially higher flux density since it combines the high current carrying capacity of a copper, silver or aluminum foil 12a with the magnetic properties of less conductive ferromagnetic coil 11 with which the foil is interleaved.

The improvement described and illustrated is believed to admit of many modifications within the ability of persons skilled in the art, all such modifications being considered within the spirit and scope of the invention except as limited by the appended claims.

I claim:

1. A magnetic separator for the removal of magnetically permeable substances from a mass containing same in com-

bination with nonmagnetic substances, comprising a magnetically permeable body having a pair of magnetic pole faces closed within said body in a magnetic circuit and open across a gap between said faces along the periphery of said body; and electromagnetic coil means in said body for establishing a magnetic field through said circuit, said coil means being constituted at least in part of a ferromagnetic coil having a plurality of electrically insulated turns of a ferromagnetic conductor lying in said circuit away from said pole faces and forming part of said magnetic circuit without obstructing the magnetic field in the space externally of said body between said pole faces.

2. The magnetic separator defined in claim 1 wherein said magnetic circuit includes at least one magnetic pole member, said ferromagnetic coil surrounding said pole member and inducing the magnetic field therein while increasing the flux traversing cross section of said pole member.

3. The separator defined in claim 1 wherein said magnetic circuit comprises a yoke having a pair of pole members and a bridge member magnetically connecting said pole members, said ferromagnetic coil surrounding said bridge member for inducing a magnetic flux therethrough upon electrical energization of said ferromagnetic coil while increasing the flux traversing cross section of said bridge member.

4. The separator defined in claim 1 wherein said ferromagnetic conductor forms a magnetically permeable bridge between said pole faces.

5. The separator defined in claim 1 wherein the turns of said ferromagnetic coil are interleaved with turns of a nonferromagnetic coil electrically energized in parallel with said ferromagnetic coil, said coils being provided with insulation means between the turns of said ferromagnetic and nonferromagnetic coils whereby the turns of said ferromagnetic coils are electrically insulated from one another.

6. The separator defined in claim 1 wherein said turns are provided with an oxide layer electrically insulating them from one another.

7. The separator defined in claim 1 wherein each of said turns is formed as a respective ferromagnetic disc and said ferromagnetic coil is a stack of such discs.