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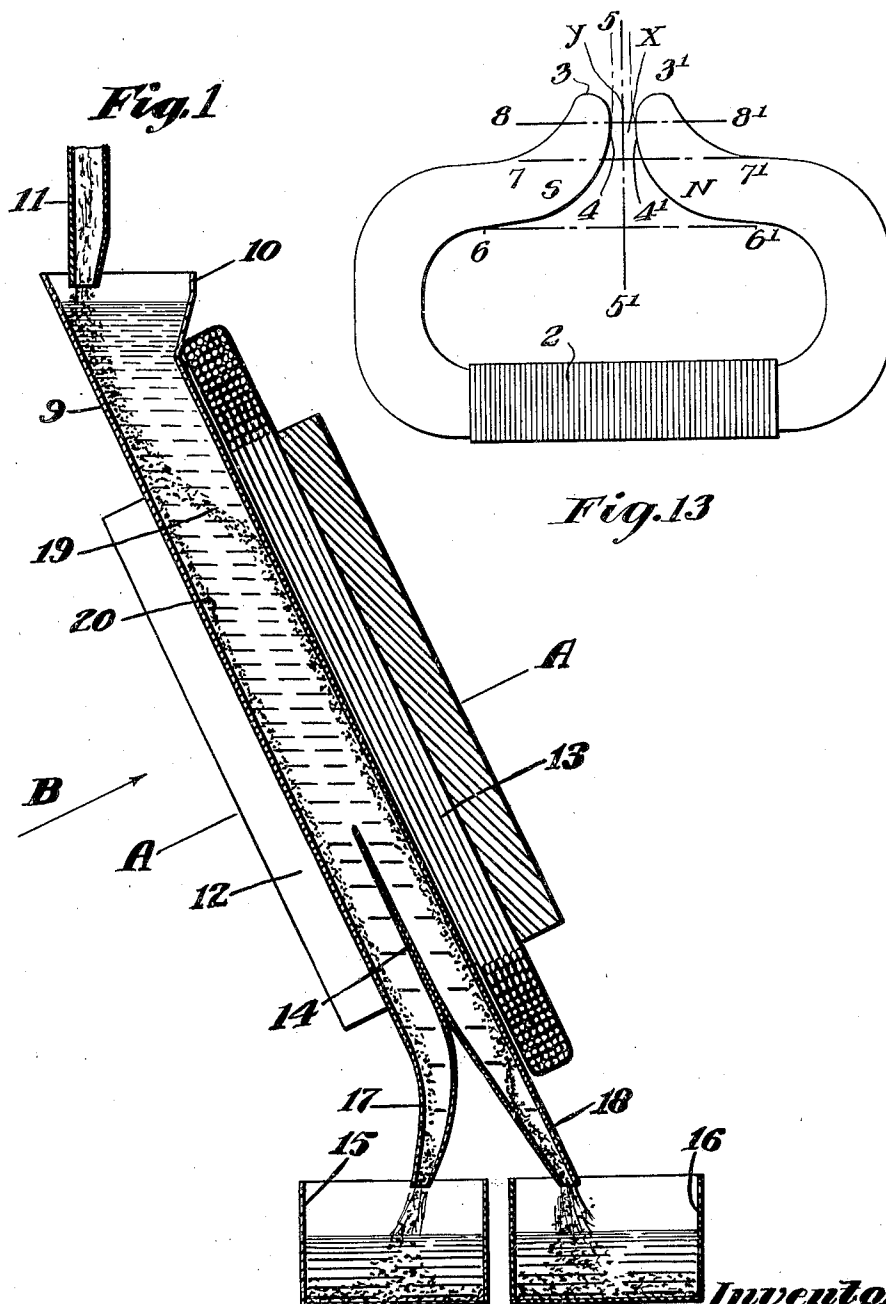
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2,056,426

MAGNETIC SEPARATION METHOD AND MEANS

Original Filed May 31, 1932

5 Sheets-Sheet 1



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Oct. 6, 1936.

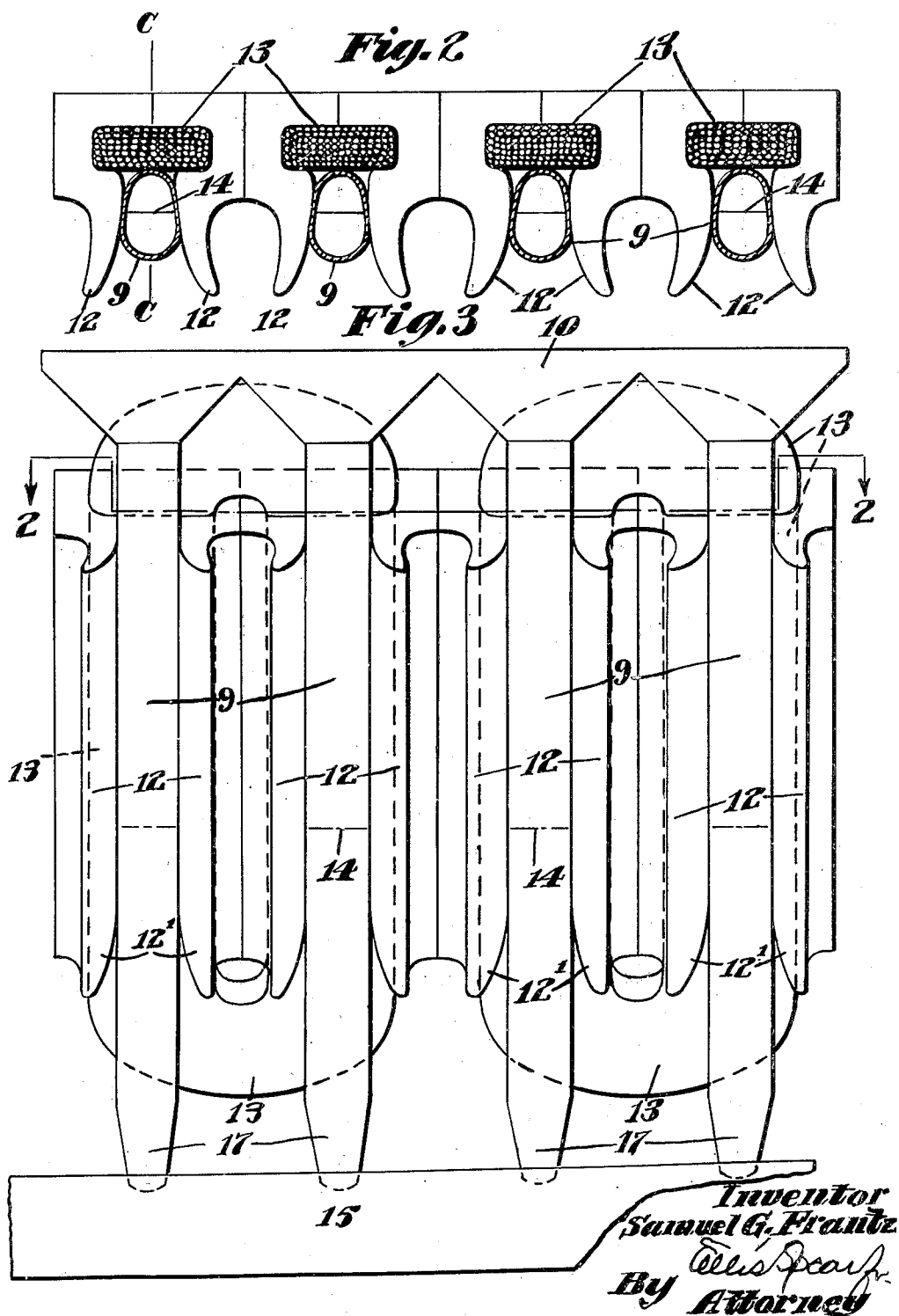
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MAGNETIC SEPARATION METHOD AND MEANS

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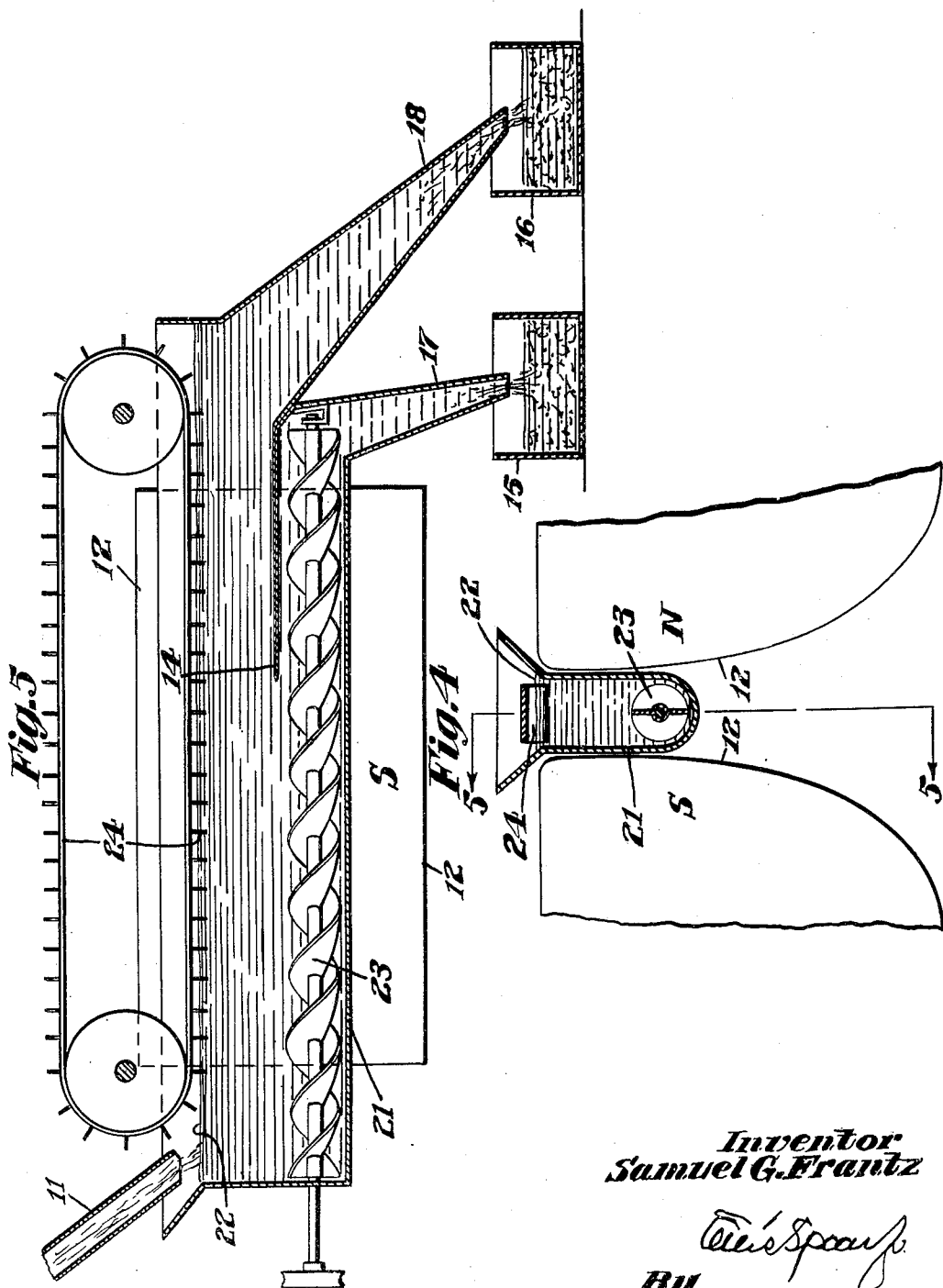
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MAGNETIC SEPARATION METHOD AND MEANS

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5 Sheets-Sheet 3



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MAGNETIC SEPARATION METHOD AND MEANS

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Fig. 6

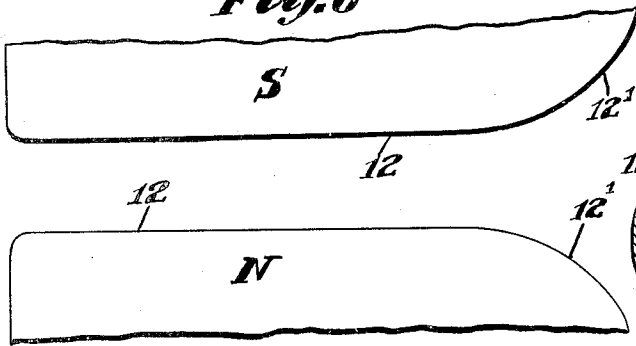


Fig. 7

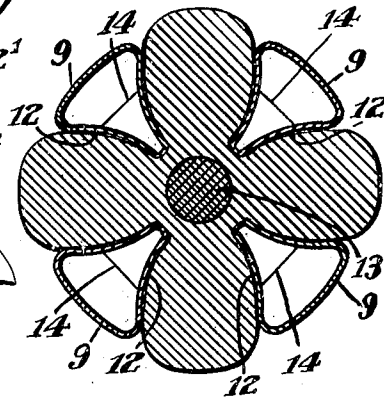


Fig. 8

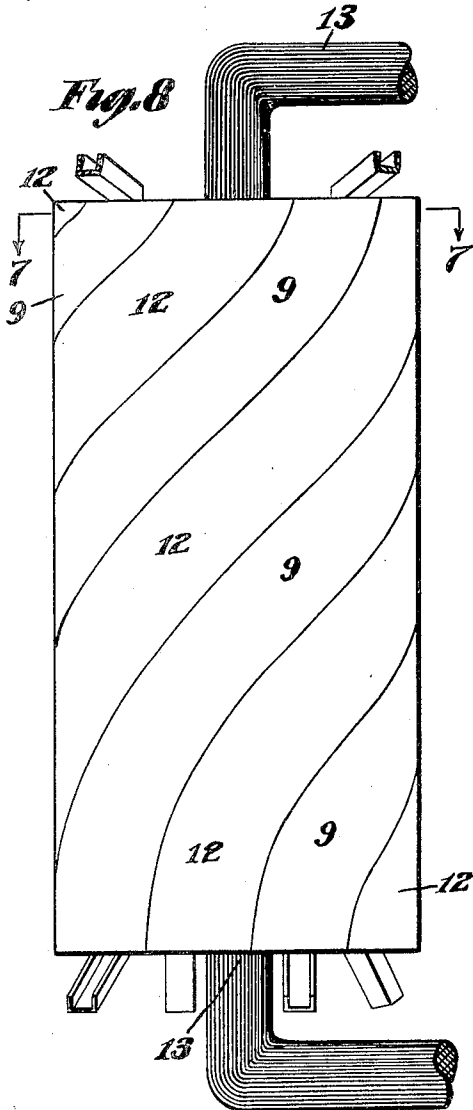
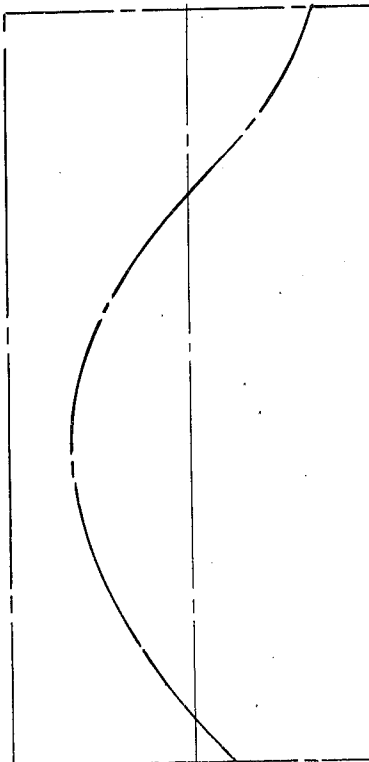


Fig. 8^a



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MAGNETIC SEPARATION METHOD AND MEANS

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Fig. 9

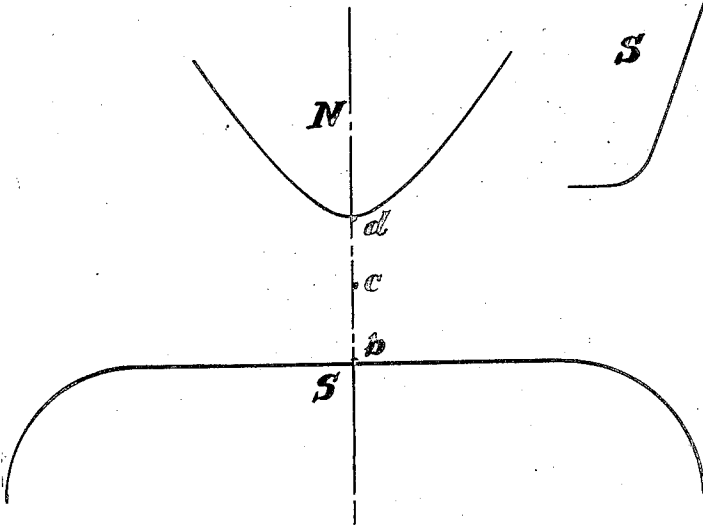


Fig. 10

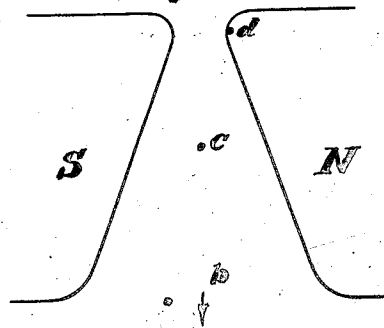


Fig. 11
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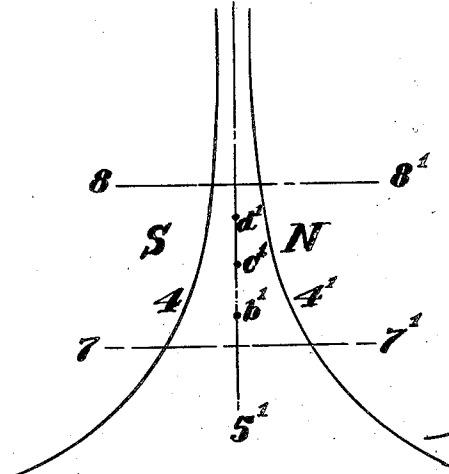
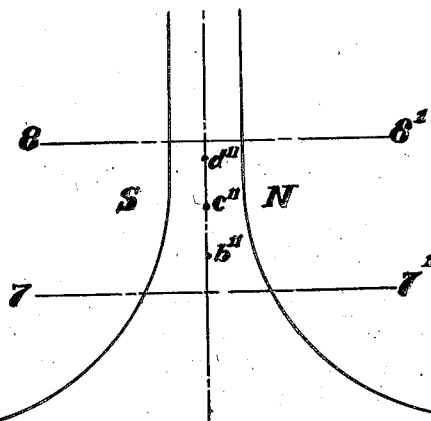


Fig. 12



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UNITED STATES PATENT OFFICE

2,056,426

MAGNETIC SEPARATION METHOD
AND MEANS

Samuel Gibson Frantz, Princeton, N. J.

Application May 31, 1932, Serial No. 614,380
Renewed February 5, 1936

19 Claims. (Cl. 209—232)

The purpose of my invention is to provide a magnetic separator to separate mixtures of various minerals into their component constituents on the basis of their magnetic susceptibilities. In particular my invention provides a more economical and more precise method of separating certain kinds of mixtures than do the devices heretofore used. The various other advantages will be apparent from the specification which follows.

In general in magnetic separators heretofore used, magnetic forces have been exerted on the magnetic particles in the grain mixture by means of localized concentrations of magnetic flux; typical of such arrangements are the field between a pointed and a flat pole piece, and the field near a magnetized serrated or laminated rotor or other attractor. It seems to be inherent in these previous designs that the operating space, that is the space in the magnetic field where magnetic forces are effective to cause separation of magnetic from non-magnetic particles, is very much restricted in volume. Thus for example, in a rotor type machine as shown by Johnson and others, the operating space is a small volume immediately surrounding a line parallel to the rotor axis and passing through the point where the grain stream leaves the rotor. Also, in the old Edison machine the grain is dropped through a columnar space in which the operating spaces are small spaces adjacent to the pole pieces of the magnets, and the rest of the columnar space is not usefully employed for separation.

It is obvious that since every particle must be passed through the operating space, for a given rate of feed for the grain the time during which a particle is in the operating space will be very small if the operating space is small. It follows that if the volume which is effective as operating space is greatly increased, either the tonnage capacity or the sensitiveness of the machine will be correspondingly increased; for if the same tonnage were fed through the larger operating space the time during which magnetic forces act on a given particle would be greater.

My invention relates to separating machines in which the operating space is a large volume as compared with the localized and restricted operating spaces of the previously used separators, and particularly to machines in which the magnetic field in the operating space is of a special configuration.

In separators embodying my invention the length of the operating space, measured parallel to the flow of the grain is in general great in

comparison with other separators, so that the length of the action of the magnetic force on the grain is relatively long, both in space and in time, and especially if the operating space is filled with water. Thus it is that in my invention the magnetic force on a particle instead of being of such short duration as to be considered an impulse, is in general of such long duration that the direction of motion assumed by a particle is substantially the direction of the resultant of the magnetic and gravitational forces on the particle.

Also, as will be shown the magnetic force may be made substantially a constant for any particle, that is, independent of the position of the particle in the operating space, so that the direction of motion assumed by particles in that space will be practically independent of the initial positions and velocities of the particles on their entrance to the space, which are irrelevant to the purpose of the separation, but will be almost solely a function of the mass susceptibility of the particle.

In all previous magnetic separators, so far as I am aware, the question of whether a given particle will be discharged with the more magnetic or the less magnetic fraction is determined only partly by its mass susceptibility, and quite largely also by the fortuitous circumstance of the position and velocity of the particle at its entrance into the operating space. This is so because in those separators the effective magnetic force to cause separation is not the same for various paths through the operating space, but is different for different paths and may vary several hundred percent between different possible paths of a particle.

An example may serve to make clear the importance of this. Suppose a magnetic separator of any type previously used is fed with a mixture of equal parts of grains A and B, B having a mass susceptibility of 10^{-3} and A a mass susceptibility twice as great, or 2×10^{-3} ; and suppose the current in the winding to be adjusted so that half of the total feed is delivered in each of the fractions discharged by the separator, X and Y. If a perfect separation had been made all the A grains would go into fraction X, and all the B grains into Y. Previously used separators however will not approach a perfect separation between grains whose susceptibilities are so close together, and it will be found that X is composed of say 65% A and 35% B, and Y of 65% B and 35% A. The reason is that although the mean magnetic force for all paths is just sufficient to remove particles of mass susceptibility greater than 1.5×10^{-3} , and to reject those at lower mass

susceptibility, on some paths the effective force is perhaps three times as strong, and all particles having such paths will be delivered to fraction X regardless of whether they are A or B. Similarly certain other paths followed by some of the particles are through regions in which the effective force due to the field is perhaps only half as great as the mean, and insufficient to remove either A or B, which are both indiscriminately passed to fraction Y.

Thus it is seen that to make a good separation between two components whose mass susceptibilities are close together it is important that the effective magnetic force on a particle for different paths shall be substantially a constant. Previously used separators have not been able, nor so far as I am aware tried so to control the configuration of the magnetic field that its effect on a particle is independent of its initial path. This control is one of the objects of the present invention.

Other advantages will be apparent from the specification which follows.

In the drawings:

Fig. 1 is a longitudinal cross section of a separator embodying my invention, taken on the line C—C of Fig. 2.

Fig. 2 is a cross section on the line A—A of Fig. 1.

Fig. 3 is a side view of the separator shown in Fig. 1 as seen from the direction of the arrow B.

Figs. 4 and 5 are schematic views showing a modification of the separator shown in Figs. 1 to 3 inclusive.

Fig. 6 is a detail view of the pole faces shown in either Figs. 1 to 3 or Figs. 4 and 5, as seen from the direction of B of Fig. 1 or as seen from above in Figs. 4 and 5.

Figs. 7, 8 and 8^a show a further modification.

Figs. 9 to 12 inclusive are diagrams to illustrate the motions of particles in various kinds of magnetic fields.

Fig. 13 is a schematic representation in cross section of the magnetic circuit of a separator.

In Figs. 1 to 3 inclusive, I have indicated at 9 inclined tubes into which the mixture to be separated is introduced from the hopper 10 by feed pipe 11. Each tube 9 is placed between pole pieces 12 whose surfaces adjacent the tube 9 are shaped so as to provide within the tube a magnetic field of suitable configuration which will be discussed later. The windings 13 energized from some suitable source of electricity serve to supply magneto-motive force across the gaps between the pole pieces 12. Near the lower termination of the pole pieces 13 there is placed within each tube a divider 14 which serves to keep apart the products of the separation and to allow them to be conveyed into separate receptacles 15 and 16 through the discharge tubes 17 and 18 respectively.

The device may either be operated flooded with water as shown, or it may be operated dry; in the latter case the grain being dried sufficiently so that the particles do not adhere to one another. The operation of the device wet will now be described. The grain mixture, fed through 11 into hopper 10 descends through the tubes 9. Upon arriving adjacent to the upper extremity of the pole pieces the particles find themselves in a magnetic field which tends to urge the more magnetic constituents in the direction upwards and towards the right in Fig. 1. The dots 19 indicate the drift of these more magnetic particles to the right in the tube as they at the same time

sink downwards under the influence of gravity. The less magnetic particles 20 continue to slide down the lower or outer part of the tube 9 undisturbed by the magnetic field. In some cases it may be desirable to promote turbulence in the water of the upper part of tube 9, in order that all the particles may be freed from each other to prevent entrainment of non-magnetic particles with the stream 19 or of magnetic particles with the stream 20. This turbulence may be achieved by the use of water jets, mechanical stirrers or the like. In many cases, however, such devices are wholly unnecessary.

The more magnetic particles move downward and pass above the divider 14 before they pass out of the magnetic field which terminates near the lower ends of the pole pieces 12. They are then discharged through the pipe 18 into a suitable receptacle 16. The less magnetic particles pass below the divider 14 and are discharged through the pipe 17 into 15.

A modification of the type of separator shown in Fig. 1 is illustrated in Figs. 4 and 5. In Fig. 4 the space between the pole faces 12 contains a horizontal trough 21. This trough is filled with water up to the level 22. The grain is fed through a pipe 11 and falls to the bottom of the trough. In the bottom of the trough 21 is a screw conveyor 23 suitably driven to propel the grain to the right in Fig. 5. When the grain reaches the operating space between the pole faces 12 the more magnetic constituents are lifted by the magnetic force and rise to the surface of the water. A conveyor 24 is provided which moves these more magnetic grains to the divider along the surface of the water. The divider 14 serves to keep the two constituents separated as they emerge from the operating space.

A detail of practical importance in either form is the configuration of the pole faces 12 near the discharge end. Instead of being cut off squarely, as they may be at the feed end, they should be cut away according to a curve somewhat resembling that shown in Fig. 6 at 12'. The purpose of this curvature is to prevent the clogging of the machine by an unduly great convergence of magnetic field tending to hold magnetic particles at the ends of the pole faces nearest the discharge.

It will be understood that although the embodiments of the device shown in Figs. 1 to 6 are shown as operated wet, it is also possible to operate these devices dry. In the case of Fig. 4 the conveyors 23 and 24 may then be omitted and a closed tube substituted for the trough 21, and the motion of the particles through the device assured by a shaking motion of the tube possibly supplemented by an inclination of the device in direction of the flow of grain.

Fig. 7 shows another arrangement embodying my invention. In Fig. 7 the pole faces are designated at 12. Between these faces there are any number of operating spaces 9 which may be tubes as in Fig. 2. Immediately surrounding the axis, which is vertical, is the winding 13 serving to energize the device. The operating spaces 9 as well as the pole faces 12 are preferably of helical form, so that particles descending through 9 will at the same time undergo a rotary motion about the axis. Splitters 14 placed in the spaces 9 near the bottom of the device serve to separate the magnetic from the non-magnetic particles. The magnetic particles are drawn in by magnetic forces towards the axis; the less magnetic particles are kept toward the outside in their

descent by the centrifugal force resulting from their rotary motion. Suitable means are provided for feeding each space 9 at the top near the periphery and for discharging the separation products at the bottom. The winding 13 may be closed externally through another similar device set beside the first one, if desired.

It is well known that the force exerted by a magnetic field on a particle magnetized by induction is proportional to the gradient of the quantity H^2 where H is the field intensity, susceptibility being considered constant; and so far as I am aware in all previously used magnetic separators the force exerted on a particle increases rapidly as the particle travels in the field under the influence of magnetic forces. In these cases, therefore, a magnetic particle is always in unstable equilibrium under the influence of magnetic and gravitational forces as regards all possible paths of motion. This kind of field is hereinafter referred to as a katadynamic field.

For reasons both of economy and of accuracy in separation and in particular in the type of separator represented by my invention it is much more desirable that a particle of a given kind while in the separating zone of a magnetic separator should be subjected to magnetic forces which either are substantially constant regardless of the particular position of the particle in the zone, or decrease as the particle moves under the influence of the magnetic force, so that if each particle is also acted on by some constant force such as gravity, it will be in either neutral or stable equilibrium as regards motion along the line of the gradient of H^2 . I shall now disclose how this may be achieved. Specifically one aspect of my invention is the provision in a magnetic separator of a magnetic field such that throughout the separating space the magnitude of the gradient of the square of the field strength is either substantially a constant, or decreases as the value of H^2 increases. These kinds of field are hereinafter referred to, respectively, as isodynamic and anadynamic.

By the term "operating space" is meant that space, zone or volume in a magnetic separator in which magnetic forces are applied to the particles to give physical separation on the basis of the magnetic susceptibilities of the particles.

By the term "cylindrical force field" is meant a magnetic field in which surfaces representing equal magnitudes of H^2 are cylindrical surfaces (not necessarily of revolution). By the term "direction of the axis of a cylindrical force field" is meant the direction of the elements of these cylinders.

In other words, in a cylindrical force field corresponding points in different cross sections taken perpendicular to the axis have the same values of H .

By the term "isodynamic magnetic field" is meant a magnetic field in which the gradient of the square of the field intensity is substantially constant in magnitude throughout the volume considered.

By the term "anadynamic magnetic field" is meant a magnetic field in which the gradient of the square of the field intensity decreases in magnitude in the direction in which the square of the magnetic field intensity increases.

By the term "katadynamic magnetic field" is meant a magnetic field in which the gradient of the square of the field intensity increases in magnitude in the direction in which the square of the magnetic field intensity increases.

By the term "isodynamic magnetic separator" is meant a magnetic separator in which throughout a considerable part of the operating space the magnetic field is substantially isodynamic.

By the term "anadynamic magnetic separator" is meant a magnetic separator in which throughout a considerable part of the operating space the magnetic field is anadynamic.

By the term "katadynamic magnetic separator" is meant a magnetic separator in which throughout a considerable part of the operating space the magnetic field is katadynamic.

The above definitions of "isodynamic", "anadynamic" and "katadynamic" may be more briefly expressed by means of mathematical formulae.

Magnetic field intensity = H .

If the direction in which H^2 increases most rapidly is parallel to the y axis, and H^2 increases with increasing values of y , the force on a particle is proportional to

$$\frac{d}{dy}(H^2)$$

which is the gradient of H^2 . The derivative of this gradient with respect to y is

$$\frac{d^2}{dy^2}(H^2)$$

and at any point

$$\frac{d^2}{dy^2}(H^2) = -a^2$$

a being a function of position.

For an isodynamic field, a is zero.

For an anadynamic field, a is finite and real.

For a katadynamic field, a is imaginary.

In accordance with these definitions, it will be seen that the previously used magnetic separators, as pointed out above, are katadynamic.

I have illustrated in Figs. 9 to 12 inclusive the difference in the behavior of particles in the three kinds of fields above defined.

Fig. 9 represents a particle in a katadynamic magnetic field such as is found in all previous magnetic separators of which I am aware. Assume a magnetic particle to be placed at c and the magneto motive force adjusted so that the magnetic force on the particle is just equal and opposite to its weight. If now the particle be moved ever so little above the point c , the magnetic force will exceed the weight of the particle and the particle will be drawn upward with ever-increasing acceleration until it strikes the upper pole piece at d . If the particle be moved downward ever so little from c , the magnetic force will become insufficient to sustain it and the particle will drop downward by gravity until it strikes the lower pole piece at b . Hence the motion of a particle of given susceptibility upward or downward is determined by the initial position and velocity which it may happen to have in the operating space.

Fig. 10 also shows a katadynamic field arrangement with differently shaped pole pieces. The remarks above as to Fig. 9 apply equally to Fig. 10.

Fig. 11 represents a particle in an isodynamic magnetic field. Assume a particle of a certain definite susceptibility to be placed at point c' , and the magneto motive force of the magnet adjusted so that the magnetic force on the particle is just equal and opposite to its weight.

If now the particle be moved up to point d' , the magnetic force upon it will still be just equal and opposite to its weight, and the same would be true if the particle were moved down to point b' .

Fig. 12 illustrates the behavior of a magnetic particle in an anadynamic field. Assume a particle of a certain definite susceptibility be placed at point c'' and the magnetomotive force adjusted so that the magnetic force is just equal and opposite to the gravitational force. If now the particle be displaced upward and released it will return to point c'' , above which the gravitational force exceeds the magnetic force for this particle, and below which the magnetic force upward exceeds the gravitational force. Therefore c'' is the position of equilibrium for this and similar particles on the line of symmetry.

If a particle of greater susceptibility than the first be placed at c'' and released, it will move upward to some such position as d'' at which it would be in stable equilibrium as regards vertical forces, and to which it would return if displaced either up or down from d'' . A particle of less susceptibility would likewise find a position of stable equilibrium at some such point as b'' . In general all particles of the same susceptibility will tend to be in equilibrium as regards vertical forces at the same height, and if a mixture of particles of different susceptibilities be introduced into the field the particles will tend to arrange themselves in horizontal layers at heights corresponding to their susceptibilities.

In Fig. 13 which is a schematic representation in cross section of the magnetic circuit of a separator embodying my invention, 1 is the core about which is wrapped the winding 2 supplied with electric current from a suitable source. 3 and 3' are the pole pieces forming the termination of core 1. Their opposing surfaces 4 and 4' are shaped to a special form which is discussed below. 5-5' represent the plane of symmetry of the device, 6-6' is a horizontal plane to which surfaces 4 and 4' are asymptotic as they are also to 5-5'. 7-7' and 8-8' are planes parallel to 6-6' which limit approximately the operating space of the device.

The mathematical expression of the shape of surfaces 4 and 4' to give between these planes 7-7' and 8-8' the best configuration of magnetic field is approximately $x^2 + \delta^2 y = \text{a constant}$. If δ is zero, the field will be isodynamic. If δ is finite and real, the field will be anadynamic. δ is preferably small compared to unity. In other words, if the exponent of x in the equation is equal to 2, the field is isodynamic; and if greater than 2, the field is anadynamic. If the exponent is less than 2, that is if δ is imaginary the field is katadynamic. An analysis of the reasons for this is given below.

There is a certain magnetomotive force $2F$ available to drive the magnetic flux across the gap between 4 and 4'. In the region between 7 and 7' and 8 and 8', where the surfaces 4 and 4' do not depart greatly from parallelism with 5-5', the distance travelled by the flux across the gap is substantially equal to the horizontal distance between 4 and 4'; this distance will be designated by $2x$. The distance above the plane 6-6' at which the gap is equal to $2x$ will be designated by y . Then the magnetic field intensity H at any height y is equal to

$$\frac{F}{x}$$

This involves the assumption, sufficiently accurate for practical purposes, that the pole face is an equipotential surface.

Throughout this region the field gradient is substantially upward perpendicular to plane 6-6',

that is, parallel to the y axis. The field gradient therefore is equal to

$$\frac{dH}{dy}$$

and the gradient of the square of the field, to which the force on a particle is proportional is

$$\frac{dH^2}{dy}$$

Since

$$H = \frac{F}{x}$$

and in the isodynamic case $x^2 y = c$, a constant, we may write

$$H^2 = \frac{F^2 y}{c}$$

Differentiating, we have

$$\frac{dH^2}{dy} = \frac{F^2}{c}$$

which is a constant, and therefore the force on a particle is a constant regardless of its position, within the space in which the assumptions are true.

If

$$x^{2+\delta^2} y = c,$$

$$\frac{1}{x^2} = \left(\frac{y}{c}\right)^{\frac{2}{2+\delta^2}}$$

$$H^2 = F^2 \left(\frac{y}{c}\right)^{\frac{2}{2+\delta^2}}$$

$$\frac{dH^2}{dy} = \frac{2F^2}{2+\delta^2} \frac{y^{\frac{2}{2+\delta^2}-1}}{c^{\frac{2}{2+\delta^2}}} = \frac{F^2}{c^{\frac{2}{2+\delta^2}}} y^{\frac{-\delta^2}{2+\delta^2}}$$

Now if δ^2 is a small positive quantity it is obvious that the force will decrease as y increases and the field will be anadynamic.

If δ^2 is negative, that is if δ is imaginary the field will be katadynamic. The most useful fields are obtained when δ is either zero or a small real quantity.

In ordinary language, it may be said that in the operating space of a katadynamic separator, a magnetic particle free to move in the direction of increasing field intensity cannot be kept in equilibrium by a constant force. On the other hand, in isodynamic and anadynamic separators, such a particle in the operating space could be maintained respectively in neutral or stable equilibrium, as regards motion in the direction of the gradient of H^2 , by a constant force.

Since, as is well known, the energy density of a magnetic field equals

$$\frac{\mu H^2}{8\pi}$$

the energy gradient is a vector having the same direction as the gradient of H^2 , and a magnitude

$$\frac{\mu}{8\pi}$$

times as great. The expressions "direction of energy gradient" and "direction of gradient of H^2 " are therefore synonymous, and correspond to the direction in which a particle of given positive susceptibility is urged by a magnetic field.

The word "cylindrical" is used herein in its broad mathematical sense of referring to surfaces generated by a straight line moving parallel to a given line and passing through a given curve. The term "cylindrical field" refers to a field whose

equipotentials are cylindrical surfaces. It is obvious that neither such a field nor its energy gradient can have any component in the direction of the elements of the cylindrical surfaces.

5 What I therefore claim and desire to secure by Letters Patent is:—

1. In a magnetic separator, pole pieces having cylindrical pole faces contoured substantially to the form of equipotential surfaces of a cylindrical isodynamic field, a gap between said faces, and means for feeding a grain stream through said gap and substantially parallel to the elements of said faces, whereby particles in said stream are urged in the direction of the energy gradient of said field and substantially perpendicular to said stream.

2. In a magnetic separator, pole pieces having cylindrical pole faces contoured substantially to the form of the curves $x^2y=a$ constant.

20 3. In a magnetic separator, pole pieces having cylindrical pole faces contoured substantially to the form of the curves

$$x^{2+\delta}y=a \text{ constant}$$

25 where δ is not less than zero.

4. In a magnetic separator, a feed channel, and pole pieces so contoured as to produce in said channel an isodynamic field, said channel being between and substantially parallel to the faces of said pole pieces and perpendicular to the direction of the energy gradient of said field, whereby magnetic particles in said channel are urged in the direction of said energy gradient and substantially perpendicular to said channel.

30 5. In a magnetic separator, a feed channel, and pole pieces so contoured as to produce in said channel an anadynamic field, said channel being between and substantially parallel to the faces of said pole pieces and perpendicular to the direction of the energy gradient of said field, whereby magnetic particles in said channel are urged in the direction of said energy gradient and substantially perpendicular to said channel.

40 6. In a magnetic separator, cylindrical pole pieces on either side of an elongated operating space, said pole pieces being so contoured as to produce within said operating space a field in which the gradient of H^2 is substantially constant in magnitude and feed means for feeding a grain stream through said operating space in the direction of its length, whereby magnetic particles in said stream are urged in a direction substantially perpendicular to said stream.

50 7. In a magnetic separator, pole pieces so shaped as to give in the operating space between them a force on a magnetic particle which remains substantially constant as the particle moves in the direction of said force in said space and means for feeding particles through said space in a direction substantially perpendicular to said force and parallel to the faces of said pole pieces.

8. Magnetic separator, comprising a feed tube inclined from the vertical, means for feeding grain and water into the upper end of said tube, two elongated convex cylindrical pole pieces on opposite sides of said tube and parallel with said tube effective to urge magnetic particles toward one side of said tube, and constricted discharge means at the bottom of said tube.

70 9. Magnetic separator as claimed in claim 8, in which the pole pieces are contoured substantially to the form of equipotential surfaces of a cylindrical isodynamic field.

10. Magnetic separator comprising two elongated horizontal cylindrical pole pieces, a horizontal trough disposed between said pole pieces, means for feeding grain into one end of said trough, conveying means for conveying the grain towards the other end of said trough, said pole pieces being contoured substantially to the form of equipotential surfaces of a cylindrical isodynamic field, the direction of the energy gradient of said field being substantially perpendicular to the direction of flow of grain through said trough.

11. Magnetic separator comprising a helical channel disposed around a vertical axis, feed means for feeding a grain stream therinto, and pole pieces having continuous pole faces respectively above and below said channel, the gap between said pole faces decreasing with decreasing radius from the axis, whereby to exert inward radial forces on magnetic particles in said channel.

12. Magnetic separator as claimed in claim 11, in which the pole faces are contoured substantially to the form of equipotential surfaces of an isodynamic field.

13. Magnetic separator as claimed in claim 11, in which the gap between said pole faces decreases less rapidly with decreasing radius than the gap given by the formula $x^2(R-r)=a$ constant, where x is the gap, r the radius from the axis and R a constant, whereby to give an anadynamic field.

14. Magnetic separator as claimed in claim 11, in which the gap x between the pole faces is given substantially by the formula $x^2(R-r)=a$ constant, where r is the radius from the axis, and R is a constant, whereby to produce substantially an isodynamic field.

15. In the process of magnetic separation, that step which consists in passing the grain through an operating space in which the gradient of H^2 is substantially constant in magnitude in a direction substantially perpendicular to the direction of said gradient.

16. In the process of magnetic separation, that step which consists in passing the grain through an operating space between pole faces conforming substantially to equipotential surfaces of an isodynamic field in a direction substantially parallel to said faces.

17. In the process of magnetic separation, that step which consists in passing the grain through an operating space in which the field is isodynamic in a direction substantially perpendicular to the energy gradient of said field.

18. In the process of magnetic separation, that step which consists in passing the grain through an operating space in which the field is anadynamic in a direction substantially perpendicular to the energy gradient of said field.

19. In a magnetic separator, cylindrical pole pieces on either side of an elongated operating space, said pole pieces being so contoured as to produce within said operating space a field in which the gradient at H^2 is substantially constant in magnitude, and feed means for feeding a grain stream through said operating space in the direction of its length, whereby magnetic particles in said stream are urged in a direction substantially perpendicular to said stream, said pole pieces at their discharge ends being so flared as to produce a gradually decreasing field in the space between them, whereby the discharge of magnetic particles is facilitated.

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