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COMPLETE SPECIFICATION

Improvement in Magnetic Induced Roll Ore Separator

I, JAMES HALL CARPENTER, a Citizen of the United States of America, of P.O. Box 3272, Jacksonville, Florida, United States of America, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

My invention relates to improved magnetic induced roll ore separators.

An important object of my invention is to increase the sensitivity of magnetic induced roll separators.

Another object of my invention is to increase the flexibility of application of an induced roll separator.

A further object of my invention is to decrease the size, weight, and, consequently, the cost of induced roll separators without a proportionate reduction in capacity.

A great variety of minerals demonstrate magnetic attractabilities which range between that of magnetite, for example, which has an attractability about 40 per cent. of that of iron, through that of pyrrhotite with an attractability about 0.6 per cent. of that of iron, to those of materials such as willemite, 0.2 per cent. of that of iron, and witherite, 0.02 per cent. of that of iron, witherite being a diamagnetic material. Because of the differences in magnetic attractabilities of minerals, various machines have been developed to separate the more magnetic from the less magnetic ~~attractabilities of minerals, vari~~ particular importance in weakly magnetic ores are belt-type and induced roll type machines. Of these types, the induced roll machine has the advantage of greater tons per hour capacity and lower cost, while the belt machine has been more sensitive and selective. The belt machine is limited in application, however, to those minerals which are sufficiently magnetic to be lifted from a moving belt by magnetic force. There are many minerals which have not been heretofore separable by either of these machine types, being too weakly magnetic to be lifted in the belt machine, and not differing enough in attractability from other minerals in the same ore to be separated by induced roll machines. It has been uneconomic, furthermore, in certain circumstances, to remove small quantities of valuable minerals mixed with others since induced roll machines with sufficient tons per hour capacity would not accomplish the separation and the investment in and operating costs of sufficient belt machines to handle the desired capacity would be greater than the value of the mineral extracted. This has been the situation, for example, in a rutile concentrate comprising about one per cent. ilmenite.

An important object of my invention, accordingly, is to improve the selectivity and sensitivity of induced roll separators whereby such separators may replace belt-type separators in certain applications and whereby such induced roll separators are capable of performing separations at high capacity and with relatively high concentration of desired very slightly magnetic minerals which have not heretofore been separable by magnetic separation in commercial quantities.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings, in which:

Fig. 1 is a side view of a three stage

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minerals in mined ores, and of

magnetic induced roll separator in accord with my invention;

Fig. 2 is a back view of the three stage separator of Fig. 1;

Fig. 3 is a perspective expolded view of a feed trough and separator unit, partially cut away, showing details of a machine in accord with my invention;

Fig. 4 is a detail, partially sectional, side view of a portion of a magnetic roll in accord with my invention;

Fig. 5 is a diagrammatic illustration of details of the arrangement of major parts of a separator in accord with my invention; and

Fig. 6 is a diagrammatic portrayal of the roll and pole faces with a magnetic flux plot as they may exist in accord with my invention.

The three stage machine of Fig. 1 comprises three unit magnetic induced roll ore separators designated 1, 2 and 3, respectively, each of which may be identical to the other except for the adjusted arrangement of the ore feeding systems. Each unit comprises a cylindrical roll 4, preferably of iron or steel of very high permeability, and a generally square magnetic core. The core is made up of a back pole piece 5, of generally rectangular shape, a generally rectangular upper core member 6, a pair of cylindrical coil core members 7 bolted between piece 5 and member 6, and a front pole piece 8 bolted to upper core member 6 in a manner to permit slight adjustments in its position. The core is bolted to a suitable non-magnetic frame 9, which may be of aluminum, and the frames of the units 1, 2 and 3 are bolted together by bolts 10 to form the three stage separator machine. Coils 11 are excited by direct current to establish magnetic flux in the core and through the roll 4, and the amount of current supplied may be sufficient to saturate the core throughout at least most of its length. The flux will flow through the core members 7, within the coils, and through members 6 and 8, across the air gap 12 separating the front pole face 13 from the roll 4, through the roll and the back air gap 14 to the pole face 15 of the back pole piece 5, and thence to the core member 7.

The core is bolted to the frame by bolts 16, 17, 18, and it will be seen that bolt 18 passes through an elongated aperture 19 in front pole piece 8, which permits adjustment of the pole piece toward and away from the roll 4 to regulate the air gap 12. The bolt 20 passes through a second elongated aperture 21 in pole piece 8 and holds pole piece 8 to core member 6. By loosening bolts 18 and 20, adjustments of the air gap 12 are accomplished by turning a set screw bolt 22 threaded into pole piece 8 and bearing against the bolt 20 within aperture 21. When the adjustment is properly completed, bolts 20 and 18 are again tightened to retain the members firmly in the desired positions.

The rolls 4 as seen in Fig. 1 will be driven to rotate in a clockwise direction toward pole face 13, and comminuted ore, or a mineral mixture, of which portions are to be separated in accord with the relative magnetic attractabilities of the portions, is directed in a sheetlike stream onto the upper surface of the roll from a feed box 23, as indicated by a short arrow in the drawing. The feed box is preferably formed of aluminum and comprises a hollow rectangular receptacle open at the top, to receive ore through a tube or pipe 24, and having a slot 25 along a lower edge which is adjustably partially closed by a flow regulating plate 26 carrying a rack 27 engaging a manually rotatable adjusting pinion 28. The ore stream is applied to the roll as a sheet, extending across the roll nearly from end to end thereof, which escapes under the lower edge of plate 26 and falls over an upstanding shoulder 29 of the bottom of the feed box. The shoulder 29 serves to keep the stream far enough away from the magnetic core piece 5 to prevent the attraction thereof from interfering with the flow.

The particles of ore falling on the rotating roll surface rotate with the surface into the strong magnetic field between the roll surface and pole face 13, and the more magnetic particles tend to cling to the surface, while the less magnetic particles are thrown from the surface by centrifugal force. The less magnetic particles thus describe an arc in approximately the direction indicated by the arrow 30, while the more magnetic particles tend to remain for a greater time on the roll surface and are thrown off generally in the direction of arrow 31. A splitter bar 32 is selectively positioned to separate the two streams from the roll and to direct the streams into respective upper feed trough sections 33 and 34.

The arrangement of the upper feed trough sections may be understood by reference to the trough to receive the charge for unit 1, wherein sections 35 and 36 are divided by a solid wall 37. The sections are provided with outlet openings 38 and 39, respectively, which for unit 1, permit the ore from both sections to drop into a lower feed trough 40. Tube 24 communicates between this lower trough and the feed box 23. Bushings 41 and 42 are screwed into the openings 38 and 39, respectively, to prevent accumulation of ore in screw threads formed in these openings.

It has been assumed in arranging the inter-unit feed for the machine of Fig. 1 that it is desired to separate the raw ore in the top unit into an intermediate product and an intermediate tailings, and to pass the intermediate product through unit 2 and the intermediate tailings into unit 3 for further separations. This feed arrangement is often desirable because no magnetic separation can be completely effective for reasons well known in the art. The products of unit 2 may then comprise a final product, of high concentration, and a tailings which may or may not comprise a sufficient percentage of the desired magnetic product to justify its return to the feed trough for unit 1. The products of unit 3 are the final tailings and a magnetic product of relatively low concentration which should be returned to unit 1.

To accomplish this feeding program, the the more magnetic stream from unit 1, as divided by splitter bar 32, falls into the upper feed trough section 34 for unit 2, and thence falls through opening 43 into the lower feed trough 44 of the unit. The contents of the lower feed trough in turn are passed through tube 45 into feed box 46 and on to the roll. The splitter bar for unit 2 is adjusted by a manual knob 47 to divide the output into sections 48 and 49 of the upper feed trough of unit 3. A tube 50 is screwed into the bottom opening of section 48 and the final more magnetic product is collected from this tube. Another similar tube 51 is screwed into the section 49 of the unit 3 upper feed trough, and this tube leads off tailing which may be discharded or returned to the feed trough for unit 1 as desired.

The original tailings from unit 1 may comprise an appreciable amount of the desired final more-magnetic product, and a tubing 52 is screwed into the bottom opening of trough section 33 to lead off this mixture. A hose or tube 53, preferably of neoprene or other synthetic rubber-like material, is connected to tube 52 and leads downwardly to engage a tube 54 extending through the lower feed trough 55 for unit 3, and through an aperture in the core structure to empty into feed box 56. The less magnetic portion of the mixture furnished to feed box 56 falls, at the bottom of the unit 3, from an outlet 57 and comprises the final tailings of the machine, while the more magnetic particles fall from an outlet 58. These more magnetic particles may be returned to the feed trough 40 of unit 1, or, if desired, and depending upon the percentage of desired product therein, it may be supplied to the feed trough 44 of unit 2. In this arrangement, it will be noted that the lower feed trough 55 is not utilized to carry ore particles but that it is bypassed by tubes 50, 51 and 54.

The machine as shown in Fig. 1 further includes includes knobs 59 associated with each pinion, such as pinion 28, by means of which the rate of flow from each feed box on to its adjacent roll may be conveniently individually adjusted by hand. Heavy anti-friction bearings 60 for the rolls 4 may be supported by suitable blocks or plates 61 bolted to the back pole piece of the magnetic core structure. Each block 61 is preferably adjustable in position whereby the back air gap may be accurately set. An ear 62 may extend from each of the blocks 61 to support the adjacent respective feed box of each unit. As shown in Fig. 1, each roll may be provided with a felt wiper blade 63 to bear against the roll surface immediately below each back air gap. Such wipers will clear the roll surface of any particles adhering thereto which might jam in the back air gap or otherwise interfere with normal operation. The base 64 of the machine, below unit 3, may be selected as suitable to the location of the machine. The upper and lower feed troughs, such as troughs 36 and 40, and associated parts, the bushings 41 and 42, feed tubes 24, 50, 51, 52 and 54, feed boxes 23, 46 and 56, and the parts associated therewith, including the adjusting racks and pinions, the splitter bars 32, and the frame members 9 and 64 may all be of aluminum, and insofar as possible, non-magnetic materials are preferred for all parts of the machine except for the cores, core bolts and rolls. However, magnetic steel may be necessary to provide sufficient strength in bearing blocks 61, and positioning of the blocks away from the path of ore particles will minimize disturbances from this source.

Fig. 2 shows further details of the ore feeding arrangements of the machine. Since both sections of the upper feed trough of unit 1 feed the lower feed trough 40, internally smooth bushings 41 and 42 are applied in each of the two outlet or bottom openings of each of the sections. The lower feed trough 40 is provided with an aperture aligned with each respective outlet opening of the upper feed trough, but, since all of the ore in the unit 1 upper feed trough is to be fed to the roll of unit 1, these openings are covered by small plates 65 and 66 bolted to the trough. Referring now to Figs. 1 and 2, the more magnetic particles falling from roll 4 of unit 1 are collected in an upper feed trough section 34, for unit 2, which is open through bushings 43 into the lower trough 44. The less magnetic portion of the ore, however, is collected in the other section 33, and tubes 52 are inserted

through the apertures in the wall of lower trough 44 and are screwed into the openings into this other section 33. The material flowing from bushings 43 into trough 44 is prevented from leaking therefrom by plates 67 and by flanges 68 formed on tubes 52. The arrangement is such that tubes 52 are screwed into the openings in the upper trough until the flanges 68 seat firmly against lower trough 44. Hoses 53 are forced on to tubes 53 and connect with tubes 54 to supply the unit 3 feed box 56 as best seen in Fig. 1. Tubes 50 and 51 extend through openings in the lower feed trough 55 unit 3 and the flanges 69 on these tubes seal the openings in trough 55 which the tubes extend, the upper ends of the tubes being screwed into the upper feed trough openings.

The plates 65, 66 and 67, and tube flanges 68 and 69 are identified in both Figs. 1 and 2 and may be seen in the side view in the former. Several other parts of the machine described in connection with Fig. 1 have been similarly identified in Fig. 2 and the earlier description will be found applicable thereto.

Fig. 2 shows a drive arrangement for the three rolls comprising belt driven pulleys 70 and belts 71. A separate pulley is desirably keyed to the shaft extending from each roll, and either belt drive as shown, or chain or gear drive, may be employed.

The detail arrangements of a unit of the machine, such as unit 1 of the machine Fig. 1, are shown in Fig. 3, partially in section. As seen therein, the upper feed trough is divided into two sections 35, 36 by a dividing wall 37. When it is desired that the charge of ore particles supplied to section 35 of the upper trough shall fall into the lower feed trough 40, aluminum bushings 41 are screwed into the openings in the bottom diagonal wall of section 35, and plates 66 are bolted, by bolts 72, to cover those openings of the lower trough which are aligned with bushings 41. The openings 39 of trough section 36, which is internally threaded, may also receive an externally threaded, but internally smooth, bushing 42, and the opening 73 in the lower feed trough which is aligned with opening 39, may be covered by a plate 65. As heretofore explained, the bushing 42 and plate 65 may be omitted and a flanged tube may be screwed into opening 39 to extend through opening 73 if it is desired to lead the material from section 36 into any receptacle other than the lower trough 40. As also explained above, a tube flange in this case will abut the lower trough 40 snugly about the opening 73 to prevent leakage of any materials in the trough around the tube. Feed tubes 24 are provided with upper flanges 74 and extend through openings in a lower wall of the lower trough 40, the flanges being bolted by bolts 75 to the trough and serving to prevent leakage around the tubes.

The feed tubes 24 pass through apertures 76 in the upper core member 6 of the magnetic core structure and deliver the ore from the lower feed trough 40 to the feed box 23 of the unit, as theretofore explained in connection with unit 1 of Fig. 1. The apertures 76 in the upper portion of the core structure thus permit gravity feed of the ore into a feed box which is disposed in the central open space within the core structure and which is arranged to supply the ore between the inner ends, or pole faces, of the pole pieces to the uppermost portion of the roll surface. In other words, the apertures make possible a compact core construction which bridges above the roll. Such construction not only reduces the overall size of machine, but makes possible a shorter magnetic circuit and, importantly, disposes the pole pieces at right angles to one another to extend upwardly from the core at substantially 45 degrees to the horizontal, and to the vertical. The importance of this arrangement of the pole pieces is further considered herein in connection with Fig. 6.

Fig. 3 further discloses in detail the manner in which the core members of coils 11 are held to upper core member 6, by means of bolts 77 disposed in counterbored openings in member 6 and threaded into the core members of the coils, it being understood that the lower core member comprising back pole piece 5 is preferably similarly attached to the coil cores. The arrangement of the feed box 23, held in place to bearing blocks by bolts engaging in openings such as opening 78, has been described as comprising a front flow regulating plate 26 movable by means of rack 27 and co-operating pinion 28 to control the rate of flow of comminuted ore particles over shoulder 29. It will be seen that the particles flowing from the feed box fall through the space separating the inner ends of pole pieces 5 and 8 on to the top of the roll 4. Roll 4 rotates toward the pole face 13 of front pole piece 8 and throws the less magnetic constituents of the ore to the right of splitter bar 32, while the more magnetic constituents fall behind or to the left of the bar as seen in the drawing.

The construction of the roll 4 is shown in detail in Fig. 4. The roll is usually preferably of solid ferro-magnetic material, such as magnetic steel of high permeability, although laminated roll construction, if sufficiently resistant to bending, may, under some circumstances, be preferred or acceptable. A solid rotor pro-

vides less reluctance than a rotor of laminated construction and is used for that reason, even though the solid roll is more subject to heating during operation in the high intensity field and may require greater power to rotate. An important advantage in the use of a solid roll is its greater resistance to bending, and this is of particular importance because I have found that, for the most successful operation of machines in accord with my invention, the air gaps between the roll surface and the respective pole faces are as short and as constant as possible. Bending of the roll not only limits the minimum gap to which the machine may be adjusted, but also causes the gap to be less midway between the ends of the roll than near the ends thereof. It has also proved desirable in my invention to utilize a roll of small diameter and a smaller diameter is permitted with the solid roll.

The roll surface as seen in Fig. 4 is spirally grooved from end to end, the groove being, for example, between two thirty-seconds and three thirty-seconds of an inch in width and about one thirty-second of an inch in depth, and leaving lands 79 between adjacent turns of the spiral groove of approximately the same width as the groove. The groove is filled with a band 80 of non-magnetic material such as copper or bronze, and this material may be forced into the groove and soldered therein by suitably fluxing and dipping the roll into a bath of molten solder. Thereafter the surface of the roll is preferably ground smooth. It will be understood that mention herein of the roll surface is intended to designate the lateral active cylindrical surface laying entirely, or substantially entirely, between the ends of the pole faces 13 and 15. Thus in specifying portions of the roll surface area, or the like, the area of the end surfaces has been disregarded since the end surfaces have no operative connection with the separation of ore. Similarly disregarded is any lateral area extending beyond the ends of the pole faces. A suitable roll may have a diameter of 2-7/16 inches and a length of 18 inches.

Fig. 5 shows diagrammatically the preferred relative arrangements of the pole pieces 5 and 8 and roll 4, together with an exemplary ore path. The arrangement is such that a maximum area of minimum width air gap is provided at each pole face. The lower surfaces of pole pieces 5 and 8, respectively, lie in imaginary planes tangent to the roll surface and at 45 degrees from the horizontal. The back pole face 15 is in the shape of a curvilinear arcuate segment of the lateral surface of a cylinder having a radius greater than the radius of the roll by the amount of the desired air gap 14. This face, accordingly, conforms to the roll surface throughout the face area. The front pole face 13 is arranged to have an upper portion shaped in accord with a similar, though smaller, curvilinear arcuate segment of a cylindrical surface, the radius of curvature of this portion being the sum of the radius of the roll and the desired front air gap 12. It will be understood that the centers of curvature for the ~~arcs~~ of both pole faces will be at the axis of the cylindrical roll. The lower portion of the front pole face 13 is cut back along a plane at 45 degrees to the horizontal and meets the arcuate surface portion tangentially. The upper arcuate portion and lower planar portion meet along a line, accordingly, and are contiguous at this line, and the line is, of course, in the direction of a radial plane from the roll axis which extends at 45 degrees above horizontal. The thickness of the pole pieces 5 and 8 may be slightly less than the diameter of the roll. For example, the roll may be two and seven sixteenths inches in diameter, while the pole pieces may be two inches thick. With these dimensions, slightly more than one-half of each pole will fall below an imaginary 45 degree plane through the roll axis, and the inner ends of the pole pieces, at the upper edges of the pole faces, will be separated by about one-half inch, assuming that the sharp edges are rounded off on a one-sixteenth inch radius. More specifically, twenty five-thirty seconds of an inch of the pole piece thickness will lie above and one and seven-thirty seconds of an inch will lie below such plane. The one-half inch separation between the inner ends of the pole piece permits the ore particles falling over the shoulder of the feed box, as controlled or regulated by the flow control plate, to drop on to the uppermost portion of the roll in a thin sheet. The ore or mineral particles thus deposited on the roll jostle about for several reasons. There is some bouncing due to the drop on to the roll surface; the roll surface is moving preferably at a rate of between about 150 and about 200 feet per minute, and the particles tend to tumble about as they gather speed in the direction of movement of the roll surface, finally to assume substantially the same rate of speed approximately as they reach the air gap area under the upper edge of pole face 13; and the position of the pole faces is such as to concentrate enough magnetic flux, through and about the surface of the roll where the ore particles strike it, that the more magnetic particles even at this position tend to migrate toward the magnetic lands of the roll, and particularly toward

the corners of the lands.

As the ore particles are carried by the roll beneath pole face 13, the more magnetic grains are attracted and held relatively more firmly to the roll surface, while the less magnetic grains are attracted less to the surface. If it be assumed that a less magnetic grain has a permeability equal to that of air, such grain will tend to leave the roll surface at a point at which the rate of increase of the downward component of the velocity of the roll surface is greater than the acceleration due to gravity. The grain at this point will have a horizontal velocity which will carry it away from the roll, toward the right as seen in the drawing, and it will drop along the approximately parabolic path followed by free falling bodies having horizontal velocity. The less magnetic grains are, for the most part, free to fall from the roll in this manner since the more magnetic grains will have been pulled toward the surface of the roll more strongly from the moment of striking the roll and will tend to underlie the less magnetic grains. Furthermore, the attraction of the more magnetic grains to the roll surface will be high, when the roll speed is properly adjusted, until after the less magnetic grains have left the roll. The more magnetic grains, accordingly, will be deflected by the magnetic attraction below and to the left of the path of the less magnetic grains as seen in Fig. 5.

The prior art teaches that it is desirable to concentrate substantially all of the flux in an induced roll separator at the extreme uppermost portion of the active or front pole, at what has been defined as a "prealignment" area, and it has also taught to the contrary that the flux should be concentrated in what may be termed the "leaving point" area, at which area the less magnetic particles fall away from the roll. In contradistinction to both of these suggestions, my invention contemplates greatly improved results of a different order of magnitude which are obtained by maintaining as high total flux as possible through the roll through the whole area in which the less magnetic particles are in contact with the roll, by maintaining a substantial flux intensity below this area, and by providing as high total flux as possible in the roll. I accomplish these purposes by my novel core construction wherein the pole pieces approach the roll substantially 90 degrees apart, and each 45 degrees from the horizontal, and by proportioning the pole pieces of the core to have a lower outer side along a 45 degree plane tangent to the roll and a thickness such that the upper edges of the pole faces clear each other at the uppermost portion of the roll by only that distance reasonably sufficient to permit the introduction of an ore stream or sheet therebetween on to the top of the roll. The objective is further accomplished by making the roll, in relation to existing machines, less in diameter and shorter and by driving it at a higher revolution rate. The objectives are further accomplished by providing a solid, stiff roll and by reducing the length of and making more constant, the front and back air gaps, to cover a greater proportion of the total roll surface. The objectives are still further accomplished by making the roll of overall lower reluctance due to the shallowness of the grooves filled with non-magnetic material, whereby an appreciable amount of flux passes through the non-magnetic material, and due to the greater amount and lower reluctance, proportionately, of steel in the solid roll, as compared to a roll of built-up discs of alternately magnetic and non-magnetic materials. Another important contributing factor lies in the arrangement whereby the maximum amount of paramagnetic steel of the pole pieces is brought as close as possible to the roll surface, thereby to provide air gaps as short as possible and covering the maximum roll surface area. The failure of prior art machines to approach the results of my invention has been partly due to an attempt to concentrate or crowd flux into a reduced cross sectional area pole piece through a substantial distance, which, because of oversaturation in such area, seriously reduced the amount of flux passing through the rotor, even if an attempt were made in the prior art machines to increase the flux across the air gap.

In the core structure or magnetic circuit, the members 5 and 8 have been termed pole pieces, and these pole pieces terminate toward the roll in pole faces. Such terminology is intended to make clear the functions of the core portions adjacent the roll and is not intended to limit the structural arrangement of the core. While the construction suggested has certain advantages, the members 5, 6, 7 and 8 could be formed of one piece of steel or of several pieces as desired. In practice, some means of adjusting the air gaps 12 and 14 will be found convenient and perhaps essential to obtain optimum results. The term pole piece will be understood, accordingly to refer to sections or portions of the core adjacent to and extending toward the roll surface, while the exciting means for the core will comprise a coil or coils preferably spaced from the immediate vicinity of the roll because the coil and roll both tend to develop heat.

The portion of the core which bridges between outer portions of the parts functioning as pole pieces, which as shown comprises coils 11 and their cores and member 6, may be thought of as means to excite these pole pieces, and, of course, to excite the roll therebetween. The function of the upper core member 6 is to complete the magnetic exciting circuit between the members 5 and 8. The member 6 may be thought of as an extended portion of the pole piece comprising member 8, or as an extended portion of the core or cores of the coil or coils, since its function is accurately included in either concept.

In respect to the apertures 76, it is necessary that the location be such that ore to be treated may flow therethrough into the space surrounded by the core structure, or defined by the square core structure, and above the roll. It is thus not material to my invention whether members 6 and 8 be formed as one member, rather than being affixed together by bolts 20, if the portion of the core carrying the apertures is sufficiently above the roll. Such portion will normally be in a position such that it may be thought of as a part of the exciting means for the pole pieces or a part of a magnetic bridge connecting the outer or upper portions of the pole pieces and extending over the pole pieces and, of course, over the roll.

With the exemplary dimensions herein recited, it will be seen that the arcuate upper portion of pole face 13 conforms to approximately one-tenth of the total (lateral) surface of the roll, from which surface it is equidistantly spaced by about one-sixteenth inch throughout this one-tenth portion. This portion of the roll surface extends from substantially the 45 degree direction from the roll axis to within about 10 degrees of the extreme upper roll surface portion. In other words, the area covered by the arcuate portion of the pole face extends from about 45 degrees above horizontal to about 80 degrees above horizontal, as measured about the roll axis. The back pole face conforms to a portion of the roll surface, separated therefrom by the back air gap, comprising about one-quarter, or a little more, of the total roll surface, from a direction about 15 degrees below the horizontal to a direction about 10 degrees to the left of vertical as seen in Fig. 6. It is desirable to round off the sharp edges of the pole faces, as indicated in Fig. 6, and the proportions recited are calculated and determined for a rounding of these edges at a one-sixteenth inch radius. Somewhat less rounding is permissible, and slightly greater effective pole face areas will result from sharper edges. No more rounding should be provided than is found necessary to prevent accumulation of ore particles at such edges.

It will be seen that the disposition of the core members, including pole pieces 5 and 8 in the square, box-like, configuration provides ease and simplicity of construction and a short magnetic circuit, and, of great importance, a front pole face which departs little from a right angular relation to the direction of flux in the portions of the pole piece immediately adjacent the pole faces. Some variation from the 45 degree direction specified for pole piece 8 may be permissible insofar as maintaining the desired relation between orientation of the front pole face and the direction of the flux in the front pole piece in the portion thereof adjacent the pole face. For example, the front pole piece may extend at 50 degrees from the horizontal without substantially affecting the desired flux distribution, but such position might tend to complicate the core structure. It is possible to achieve the improved results and to follow the principles of this invention by utilizing a front pole piece extending from the roll at any angle between substantially 45 degrees above the horizontal to an angle greater than 45 degrees by approximately one-half as many degrees as are covered on the roll surface by the arcuate upper portion of the front pole face.

In the example given, the upper arcuate pole face portion covers 35 degrees, approximately, on the roll surface, and the front pole piece might, therefore, extend from the roll at as much as 62.5 degrees above the horizontal. Within these limits, between 45 and 62.5 degrees, the front pole piece will extend perpendicularly to a portion of the pole face in a manner to permit abrupt expansion of the flux lines throughout the pole piece immediately adjacent the pole face. The direction of the pole piece, if arranged at 62.5 degrees, would be perpendicular to plane tangent to the center of the arcuate upper portion of the front pole face. At 45 degrees, the pole piece would be perpendicular to a plane tangent to the arcuate portion of the pole face where the arcuate upper and planar lower portions meet, and this plane would, of course, include the planar lower face portion. At the mentioned upper limit of optimum front pole piece angle, that is, 62.5 degrees, the back pole piece might extend from the roll at an angle of 27.5 degrees above the horizontal, but even at this limit position for the front pole piece, the front pole face should be proportioned, shaped and arranged as heretofore described, with the lower portion of the face extending in a plane 45

degrees from the horizontal and joining and tangent to the upper arcuate portion in the 45 degree radial direction from the roll axis, while the arcuate upper portion extends upwardly therefrom across 35 degrees of roll surface, approximately, to the 80 degree radial direction.

In any case, the arcuate front pole face portion should approach as closely to the vertical direction from the roll axis as may be permitted by the requirement that the supplied ore particles should fall freely on to the roll at its uppermost portion without striking any part of either pole piece.

The back pole face may be disposed to be co-extensive with the roll surface anywhere along the back side of the roll opposite the front or active side. For maximum efficiency, however, the back pole piece will lie within the two imaginary planes which are both tangent to the roll surface and parallel to the direction of the back pole piece. When so arranged, the back pole piece will extend in a direction perpendicular to some portion, preferably a portion spaced from the upper and lower edges, of the back pole face. It is further preferred that the upper edge of the back pole face lie near the top of the roll, and that the face area be at least about one-quarter of the lateral surface area of the roll.

As shown in diagrammatic form in Fig. 6, the roll 4 rotates clockwise in a high flux field between pole pieces 5 and 8. The pole pieces, of mild steel, carry a flux of approximately 100,000 lines of force per square inch which saturates the pole pieces throughout the major portion thereof. For example, if the pole pieces have a rectangular cross sectional area of 2 inches by 18 inches, as recommended hereinabove, the total flux should be approximately 3,600 kilolines. At the upper arcuate portion of the front pole face 13 spanning the upper portion of the air gap 12, above the planar lower portion of the pole face, the flux concentration is about 156,000 lines per square inch, with an air gap of approximately one-sixteenth of an inch, and with a roll 4 having a copper or bronze spiral in a groove as described in connection with Fig. 4. The flux concentration in the upper portion of the pole face 13 may be as high as 200,000 lines per square inch over small areas opposite the lands of the roll, but the oversaturated condition of the front pole piece at the pole face is limited in extent, since the effective cross sectional area of the pole piece increases abruptly almost at the pole face and the flux lines concentrated in the arcuate area can spread immediately into the lower portion of the pole piece. The flux concentration does not vary appreciably from top to bottom of the arcuate portion of the front pole face, as demonstrated by the flux plot of Fig. 6.

The flux across the back air gap 14 is distributed evenly from top to bottom of pole face 15, whereby the average flux across the air gap 14 is about 100,000 lines of force per square inch, although there is some disturbance and concentration over small areas in the direction parallel to the roll axis due to the copper spiral of the roll.

The disposition of the pole pieces or core members 5 and 8 so as to extend from the roll in directions 90 degrees apart, and 45 degrees, or up to 62.5 degrees and as little as 27.5 degrees for the front and back pole pieces, respectively, from the horizontal, and the shapes and dispositions of pole faces 13 and 15, provide a high flux concentration across the air gap throughout that portion of the roll, indicated at 81, in which the more magnetic and less magnetic particles are in contact with the roll, and a high but gradually diminishing flux below the area at which the less magnetic particles start to leave the roll. This leaving area, as explained heretofore, starts approximately as the face 13 becomes flat, which is substantially at the intersection of an imaginary plane through the axis of roll 4 inclined at 45 degrees and cutting the face 13 about 1-7/32 inches from the lowermost edge of the face, assuming that the ~~pole~~ core members are two inches thick. The particular arrangement of the core members and roll and the shapes of the pole faces result in a very low leakage flux, as indicated in the flux plot of Fig. 6.

The flux field in a machine in accord with my invention may be so intense that substantial heating of certain ore particles occurs even during the very small time in which the particles are in the field. Thus when an ore comprising bastnasite and barite was passed through a single stage, it was found that the more magnetic bastnasite was heated to approximately 110° F., while the barite product was still at substantially the 80° F. original temperature of the materials before separation.

Machines in accord with my invention have accomplished minerals separations heretofore found impossible on a commercial basis. For example, a plant in Corona, New Mexico, had been unable to produce a commercially pure bastnasite product from a mixture including the mineral barite. Some inadequately pure and commercially unacceptable separation of these two minerals can be noticed when using a cross-belt type magnetic separator.

Machines according to my invention, on the other hand, accomplish a separation yielding bastnasite product with less than two per cent contaminating barite after one or two passes over the roll.

Ilmenite is a soluble titanium mineral, while rutile and luecoxene are insoluble titanium minerals much higher in titanium. Separated, rutile and luecoxene are many times as valuable as ilmenite. Unseparated, rutile and luecoxene comprise a troublesome and undesired contaminant of ilmenite. By means of passage through one stage of a machine according to my invention, the total recovery of rutile and luecoxene may be made very high and the percentage of these contaminants in the ilmenite product of separation plants treating typical ores containing these minerals may be made as little as about 0.1 per cent.

The heretofore expensive and ~~difficult~~ difficult separation of staurolite from kyanite, sillimanite, zircon and quartz has been readily and relatively inexpensively accomplished by machines according to my invention. Staurolite is a complex aluminum iron silicate, similar in magnetic and other physical properties to a garnet, and useful in the Portland cement industry. Its relatively low value per ton has inhibited economic separation by magnetic machines, but a single stage of a machine in accord with my invention provides separation treatment of about one ton of ore per hour per 18 inch roll, or 3 tons per hour on a 3 roll machine such as is shown in Figs. 1 and 2 hereof, producing staurolite of commercially acceptable purity in one pass over a roll.

The mineral monazite, which is now in large demand for its rare earth and thoria content, of acceptable commercial grade can be produced on existing cross-belt type magnetic separators, but the high initial and operating costs of these machines has been a serious deterrent. In typical operations, as much as about 40% monazite may exist in tailings from a cross-belt separator, this monazite apparently being too weakly magnetic to be picked up by the magnetic field. Machines in accord with this invention, however, have been found capable of recovering substantially all of the monazite from such cross-belt machine tailings. In the case of an operation in Brazil, wherein monazite comprises about 8% of the tailings, passage of the tailings through a single stage of a machine in accord with this invention has resulted in a substantially complete recovery of the monazite.

In several instances the introduction of my new induced roll magnetic separator ahead of a relatively very large and costly cross-belt separator will cut the feed to the cross-belt separator by one third to one half, thereby largely increasing production of existing equipment. It has been impossible heretofore to produce a finished monazite product by the use of induced roll separators alone. This is important in the industry from the standpoint of tonnage and initial cost, and many times determines whether or not the particular operation is commercially feasible. Finished acceptable grade monazite product has been produced by the use of my new induced roll magnetic separator alone. My invention has even made possible the use of a simple magnetic induced roll machine alone as a test instrument for use in determining the values and amounts of monazite in ores of unknown constituency, thereby making unnecessary the elaborate and complex metallurgical test steps heretofore required.

The intended operation of the machine according to my invention will be apparent to those skilled in the art from the above discussion. Ore particles supplied through the feed box will be split into streams in accord with the relative magnetic properties of the constituents, and the splitter bar should be adjusted to provide separate collection of these constituents. The roll rotation should be adjusted in most instances to give surface speed of between about 20 and 275 feet per minute, or between 230 and 400 revolutions per minute. Approximately one horsepower will be found necessary to drive a roll of the dimensions given at suitable speeds with suitable flux intensities.

The exciting coils should be designed and supplied with direct current sufficient to provide a maximum total of approximately 14,000 ampere-turns, or 7,000 ampere-turns apiece. To afford extreme sensitivity, to separate ore particles of very small magnetic reluctance or susceptance, the maximum field strength is used, while the roll may be adjusted to rotate at a speed of 30 or 40 r.p.m., more or less. For maximum selectivity, to separate slightly magnetic materials of only slightly differing susceptances, maximum field strength and somewhat higher speeds of rotation should be employed. To separate particles having reluctances as high as those heretofore separable on induced roll separators from particles of much less reluctance, high roll speeds up to 400 r.p.m., with substantially less than maximum flux, will provide a tonnage per hour per inch of roll length approximately twice that obtained by prior art machines under similar circumstances. In such operation the flux intensity is preferably decreased by increasing the length of the

front air gap above one-sixteenth of an inch, to one-eighth or, for particles of the order of five per cent of the reluctance of iron, to as much as one-half inch. It will be understood that such increases in the front air gap length should be made in small increments to obtain the best overall results to meet the particular circumstances. In general, the greater gap will yield greater tonnage per hour but less effective separation, but with high rotor speed and a medium or large gap, satisfactory separation may often be accomplished at a rapid rate and with low power requirements in dealing with particles of widely differing reluctance, the particles to be magnetically deflected being more magnetic than what might be termed extremely weakly magnetic.

The particular advantages of machines in accord with my invention lie in their ability to separate extremely weak magnetic particles, as well as in their ability to handle large tonnage per hour per inch of roll length, from bearing to bearing. As a partial corollary of the last mentioned advantage, and because of the core design, the overall bulk and weight of the core, roll, coils, frame, motor, and other parts of the machine, are much less in relation to tons per hour capacity than for prior art induced roll separators. Illustrative of the advantages of machines in accord with the invention is the wide divergence between the streams of more and less magnetic particles as they fall from the roll. Even with particles so weakly magnetic as barely to be influenced in prior art machines, it is possible to obtain splitting such that a substantial wedge almost devoid of particles is seen in machines according to my invention.

While I have shown only certain preferred embodiments of my invention by way of illustration, many modifications will occur to those skilled in the art, and I therefore wish to have it understood that I intend, in the appended claims, to cover all such modifications as fall within the true spirit and scope of my invention.

What I claim is:—

1. An induced roll magnetic ore separator comprising, a driven cylindrical roll disposed with its axis horizontal, a substantially rectangular, solid, front pole piece, a substantially rectangular, solid, back pole piece, said pole pieces extending upwardly and outwardly from said roll in perpendicular relative directions with said front pole piece extending upwardly from said roll at approximately 45 to 62.5 degrees from the horizontal, core means bridging over and between upper portions of said pole pieces, said means comprising exciting means for said pole pieces and an apertured core portion, the inner ends of said pole pieces being separated sufficiently to permit the passage of ore particles therebetween, and means being provided for feeding ore particles to be separated through said aperture and between said inner ends of said pole pieces onto an upper part of the surface of said roll.

2. An ore separator according to Claim 1, wherein said pole pieces extend upwardly and outwardly from opposite sides of said roll in perpendicular relative directions.

3. An ore separator according to Claim 1 or 2, including means to feed a sheet-like stream of comminuted ore particles to be separated to the uppermost portion of said roll, the construction being such that less magnetic ore particles tend to remain on the surface of said roll through a predetermined distance around said roll from said uppermost portion and thereafter to leave said surface, the front pole face of said core structure being shaped to conform to the whole surface portion of said roll within said predetermined distance and spaced therefrom by a predetermined air gap which is constant throughout said last surface portion.

4. An ore separator according to Claim 3, wherein said front pole piece extends from said face in a radial direction in respect to said roll and is of increasing cross-sectional area measured at right angles to said direction with increasing distance from said face until a predetermined cross-sectional area is reached which is at least about one and one-half times the area of said pole face, and said back pole face is spaced equidistantly throughout said back pole face from the surface of said roll by a small air gap and has an area at least as great as said predetermined area.

5. An ore separator according to Claim 1 or 2, wherein each pole piece has a thickness adjacent said roll measured perpendicularly to its said lower surface equal to at least about three-quarters of, but less than, the diameter of said roll, said back pole piece terminating toward said roll in a pole face having the shape of a section of a cylindrical surface concentric with said cylindrical roll surface and spaced from said roll surface by a small air gap, said back pole face having a chordal dimension approximately equal to and not less than said thickness, said front pole piece terminating toward said roll surface in an upper pole face portion shaped in accord with a section of a cylindrical surface concentric with said cylindrical roll and in a planar lower pole face portion extending downwardly in a direction perpendicular to said lower surface

front air gap above one-sixteenth of an inch, to one-eighth or, for particles of the order of five per cent of the reluctance of iron, to as much as one-half inch. It will be understood that such increases in the front air gap length should be made in small increments to obtain the best overall results to meet the particular circumstances. In general, the greater gap will yield greater tonnage per hour but less effective separation, but with high rotor speed and a medium or large gap, satisfactory separation may often be accomplished at a rapid rate and with low power requirements in dealing with particles of widely differing reluctance, the particles to be magnetically deflected being more magnetic than what might be termed extremely weakly magnetic.

The particular advantages of machines in accord with my invention lie in their ability to separate extremely weak magnetic particles, as well as in their ability to handle large tonnage per hour per inch of roll length, from bearing to bearing. As a partial corollary of the last mentioned advantage, and because of the core design, the overall bulk and weight of the core, roll, coils, frame, motor, and other parts of the machine, are much less in relation to tons per hour capacity than for prior art induced roll separators. Illustrative of the advantages of machines in accord with the invention is the wide divergence between the streams of more and less magnetic particles as they fall from the roll. Even with particles so weakly magnetic as barely to be influenced in prior art machines, it is possible to obtain splitting such that a substantial wedge almost devoid of particles is seen in machines according to my invention.

While I have shown only certain preferred embodiments of my invention by way of illustration, many modifications will occur to those skilled in the art, and I therefore wish to have it understood that I intend, in the appended claims, to cover all such modifications as fall within the true spirit and scope of my invention.

What I claim is:—

1. An induced roll magnetic ore separator comprising, a driven cylindrical roll disposed with its axis horizontal, a substantially rectangular, solid, front pole piece, a substantially rectangular, solid, back pole piece, said pole pieces extending upwardly and outwardly from said roll in perpendicular relative directions with said front pole piece extending upwardly from said roll at approximately 45 to 62.5 degrees from the horizontal, core means bridging over and between upper portions of said pole pieces, said means comprising exciting means for said pole pieces and an apertured core portion, the inner ends of said pole pieces being separated sufficiently to permit the passage of ore particles therebetween, and means being provided for feeding ore particles to be separated through said aperture and between said inner ends of said pole pieces onto an upper part of the surface of said roll.

2. An ore separator according to Claim 1, wherein said pole pieces extend upwardly and outwardly from opposite sides of said roll in perpendicular relative directions.

3. An ore separator according to Claim 1 or 2, including means to feed a sheet-like stream of comminuted ore particles to be separated to the uppermost portion of said roll, the construction being such that less magnetic ore particles tend to remain on the surface of said roll through a predetermined distance around said roll from said uppermost portion and thereafter to leave said surface, the front pole face of said core structure being shaped to conform to the whole surface portion of said roll within said predetermined distance and spaced therefrom by a predetermined air gap which is constant throughout said last surface portion.

4. An ore separator according to Claim 3, wherein said front pole piece extends from said face in a radial direction in respect to said roll and is of increasing cross-sectional area measured at right angles to said direction with increasing distance from said face until a predetermined cross-sectional area is reached which is at least about one and one-half times the area of said pole face, and said back pole face is spaced equidistantly throughout said back pole face from the surface of said roll by a small air gap and has an area at least as great as said predetermined area.

5. An ore separator according to Claim 1 or 2, wherein each pole piece has a thickness adjacent said roll measured perpendicularly to its said lower surface equal to at least about three-quarters of, but less than, the diameter of said roll, said back pole piece terminating toward said roll in a pole face having the shape of a section of a cylindrical surface concentric with said cylindrical roll surface and spaced from said roll surface by a small air gap, said back pole face having a chordal dimension approximately equal to and not less than said thickness, said front pole piece terminating toward said roll surface in an upper pole face portion shaped in accord with a section of a cylindrical surface concentric with said cylindrical roll and in a planar lower pole face portion extending downwardly in a direction perpendicular to said lower surface



of said front pole piece and tangent to said upper pole face portion at the juncture of said upper and lower pole face portions, whereby said upper front pole face portion has a chord equal to at least about one-quarter of, and less than one-half of, said roll diameter.

6. An ore separator according to any one of the preceding claims, wherein said front pole face has an upper portion comprising at least one-third and not more than one-half of the thickness of the pole piece, said upper portion being curvilinear and equidistantly spaced from the surface of said roll by an air gap adjustable between approximately one-sixteenth and one-half of an inch, and having a substantially planar lower portion tangent to said upper portion at the contiguous lower edge of the upper portion, said back pole face being curvilinear and equidistantly spaced by about one thirty second to about three thirty seconds of an inch from said roll surface.

7. An ore separator according to Claim 1 or 2, wherein the front pole face extends from a position immediately adjacent said roll surface portion on which said particles are deposited downwardly and conforms to said roll surface, and is separated by a constant air gap from said roll surface, over at least about one tenth of said roll surface.

8. An ore separator according to any one of the preceding claims, wherein said front pole piece presents to said roll surface a curvilinear upper pole face portion conforming to and separated by a constant air gap from an area of said roll surface between the ends of said roll surface and lying between imaginary parallel lines on said roll surface separated by substantially 35 degrees around said roll surface.

9. An ore separator according to any one of the preceding claims, wherein said roll has a helical surface groove filled with non-magnetic material.

10. An ore separator according to any one of the preceding claims, wherein said front pole piece extends in a radial direction from said roll at approximately 45 degrees above the horizontal, said front pole face comprising a planar lower portion perpendicular to said direction and an arcuate curvilinear upper portion tangent to said lower portion and shaped and disposed to conform to a portion of said roll surface and to define said air gap between said upper portion and said surface which is constant throughout said upper portion and extends from said 45 degrees radial direction upwardly to within approximately 8 to 15 degrees of the uppermost roll surface portion.

11. An ore separator according to any one of the preceding claims, comprising two substantially identical separator units arranged one above the other, each said unit comprising a rotatable cylindrical roll having a horizontally disposed axis, front and back pole pieces extending upwardly and outwardly in front and back directions, respectively, from said roll, core means bridging over and between upper and outer portions of said pole pieces therewith to complete a magnetic core circuit and to define an open space surrounded by said circuit and above said roll, a non-magnetic ore conduit, said core means being apertured downwardly toward said space and said ore conduit extending therethrough downwardly into said space, a partially open feed box in said space above said roll positioned to receive ore particles from the lower end of said conduit and to supply a stream of said particles downwardly onto said roll; a splitter bar disposed in a position to separate less magnetic ore particles from more magnetic ore particles falling from said roll of said one unit, a pair of side-by-side upper troughs separated by a wall, said wall being positioned below said splitter bar, said troughs being arranged to receive, respectively, said more and less magnetic particles from respective sides of said bar, a lower wall for one of said troughs inclined upwardly in the direction away from the other said trough and a lower wall for said other trough inclined in the same direction as said first lower wall and extending lower than said first lower wall, a lower trough arranged below both of said lower walls, an aperture in each said lower wall through which ore particles may fall from the respective upper trough into said lower trough, said lower trough having a wall of which respective apertured portions are aligned with said lower wall apertures, a conduit device to fit a selected one of said lower wall apertures and to extend through and seal the aligned aperture of said lower trough wall by contact externally of said conduit device with the respective said portion of said lower trough wall, a closure device to seal the aperture of the other portion of said lower trough wall, a lower portion of said lower trough being apertured to communicate with said first non-magnetic ore conduit of said other unit, said ore conduit being positioned and arranged in respect to said last aperture to receive ore particles from said lower trough for delivery to said feed box of said other unit.

12. An ore separator according to any one of claims 1 to 10, comprising an upper first roll, a lower second roll, a splitter bar

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for the output streams from said upper roll, feeding means for said lower roll, and magnetic core means, an ore feeding system which comprises a trough having a dividing partition, said partition extending under said splitter bar and dividing said trough into respective sections for receiving more and less magnetic particle streams, respectively, as separated by said upper roll, the lower portion of each said section having an aperture, a second trough below said apertures of said first trough, said lower trough having an aperture aligned with each of said first trough apertures, a conduit member positioned to receive particles through a selected one of said upper trough apertures and extending through and externally sealed in said aligned aperture of said lower trough, said lower trough having an additional outlet aperture, conduit means associated with said additional aperture adapted and arranged to supply particles which fall through the other said upper trough aperture into said lower trough to said feeding means for said lower roll, and collecting means for receiving particles from said conduit member, whereby either the more or less magnetic particles as separated by said first roll may be selected for feeding to said second roll.

13. The ore separator substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

STEVEN LANGNER, PARRY & ROLLINSON,
Chartered Patent Agents,
Agents for the Applicants.

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