Nov. 8, 1966 C. D. SLOAN 3,283,900

V-SHAPED MAGNETIC SEPARATOR ASSEMBLY

Filed July 18, 1963 2 Sheets-Sheet 1

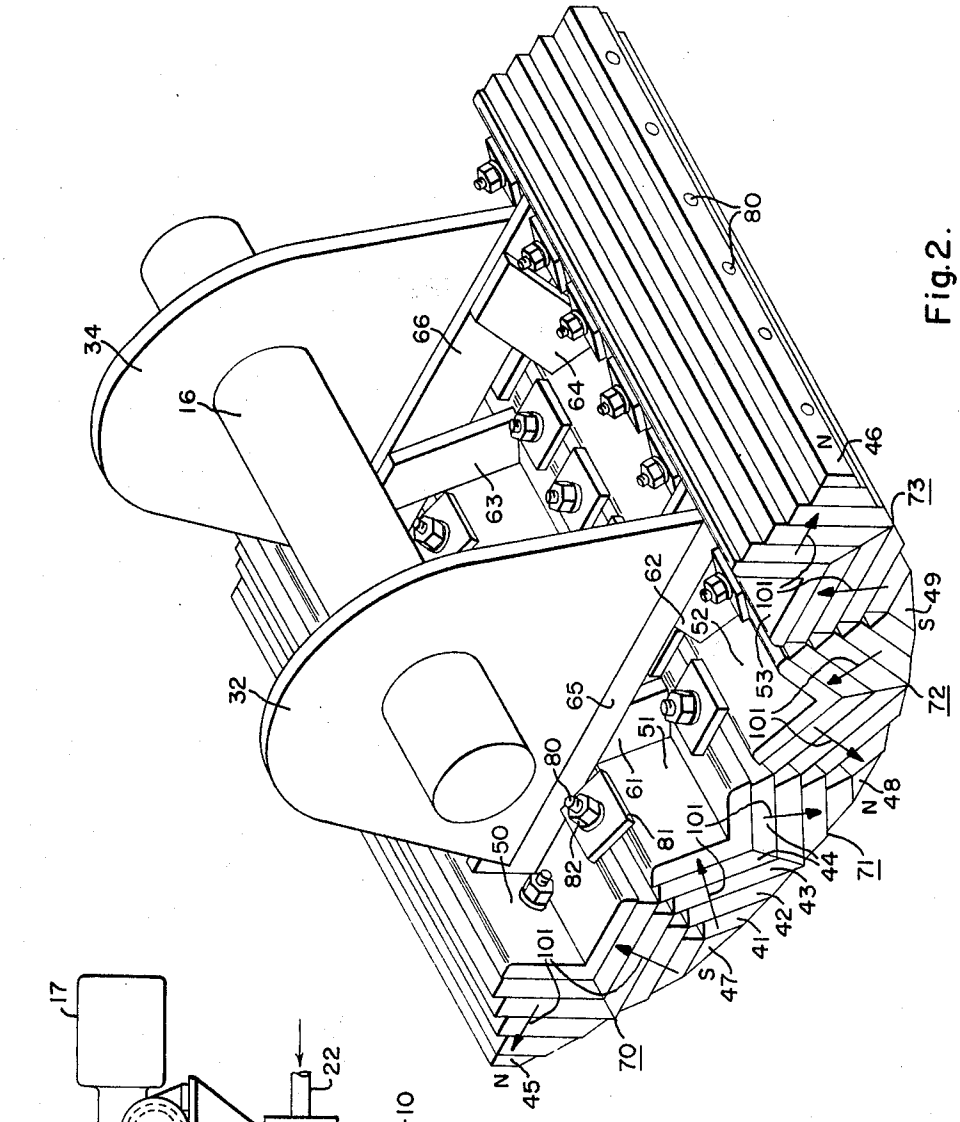


Fig. 2.

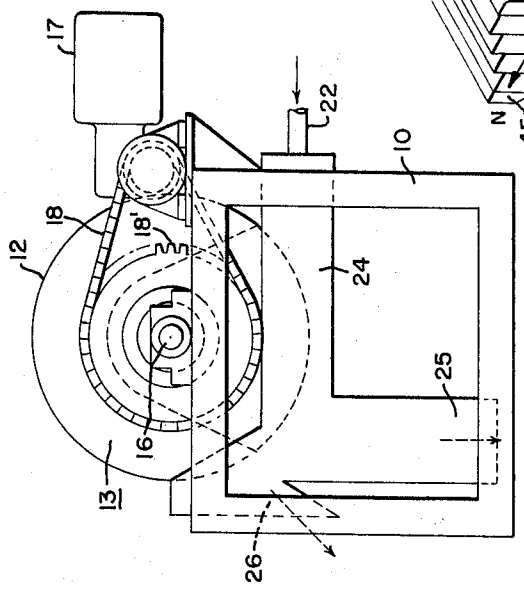


Fig. 1.

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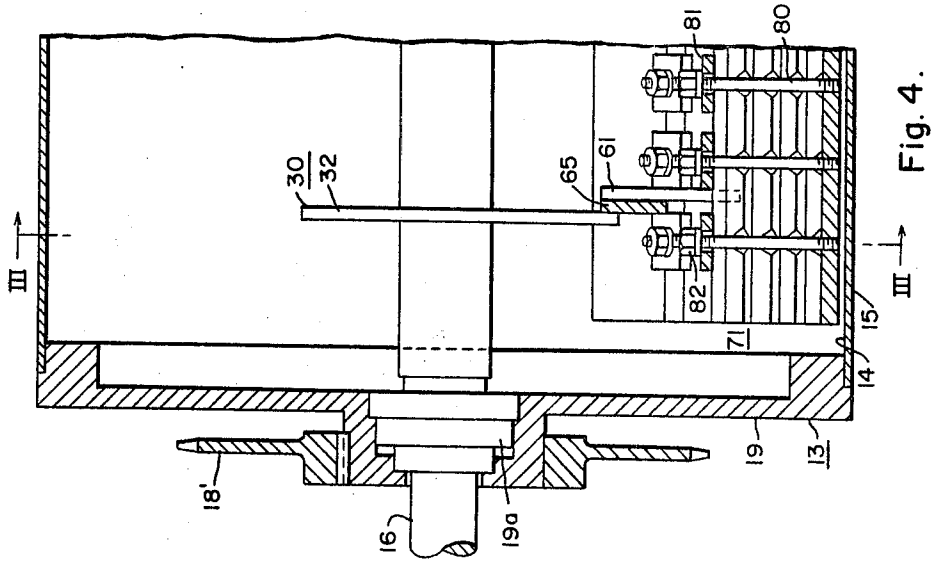


Fig. 4.

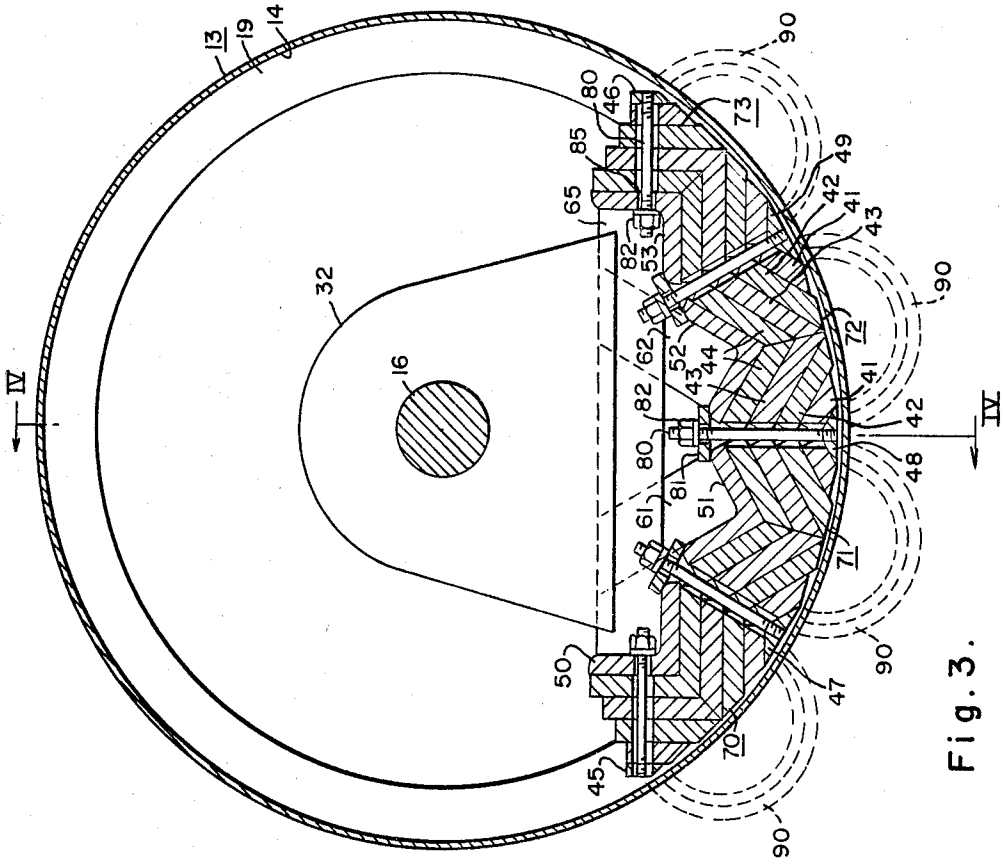


Fig. 3.

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V-SHAPED MAGNETIC SEPARATOR ASSEMBLY

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Filed July 18, 1963, Ser. No. 296,041
10 Claims. (Cl. 209—223)

This invention relates to magnet assemblies particularly useful, by way of example, in magnetic separators for the resolution of magnetic ores into a desired fraction and a gangue fraction. It also concerns apparatus that includes such magnet assemblies.

There are presently available commercially a number of different type magnetic separators. In those devices, which are of a drum configuration, permanent magnets and pole pieces are arranged relative to an outer surface of the drum, designated the separation surface, to exert a magnetic influence along that surface whereby magnetic ores, for example, are attracted and held there and can thus be separated from remaining constituents, commonly designated as gangue. The magnetic conveyor or surface generally is rotated relative to the magnet arrangement and the separated materials are removed from the gangue to a place where they can be collected.

Analysis of the prior art magnet arrangements in those devices demonstrates the existence of significant drawbacks by which about ½ to ⅓ of the magnetic flux is not utilized. Thus, in many such devices, substantial spaces are located between the permanent magnets and magnetic flux exists in those spaces. Since the spaces are within the drum and between adjacent magnets, it is evident that this internal flux constitutes a leakage or a loss of flux compared to the total that should be available to effect magnetic separation. In still other designs, the spaces between magnets have been avoided by placing the pole pieces therein; that eliminates internal flux between the magnets. However, in that arrangement, magnetic flux passes between the pole pieces rearwardly of the magnets. Hence, while a portion of the flux extends externally of the conveyor surface and is useful, another and significant portion appears rearwardly of the magnet and pole assembly and thus is wholly removed from any area where it can exert a useful influence for the intended purposes. That arrangement, therefore, simply relocates internal flux leakage and does not eliminate it. Similar problems exist with regard to magnet chucks or assemblies used in conveyors, in sheet spreaders and other applications.

The present invention is an improvement on the device disclosed in my copending application Serial No. 254,223, filed January 28, 1963, now U.S. Patent No 3,209,912, issued October 5, 1965.

It is the primary object of the present invention to provide an arrangement of magnets and pole pieces particularly useful in magnetic apparatus and in which optimum utilization of magnetic material is approached in that the flux density in all sections of the magnet material closely corresponds to that of the maximum energy product.

Another object is to provide magnetic separator, conveying and spreading apparatus including an assembly of permanent magnets and pole pieces in accordance with the foregoing object.

Other objects and advantages of the invention will be apparent from the following detailed description and drawings, in which:

FIGURE 1 is a diagrammatic illustration of a magnetic drum separator;

FIG. 2 is a perspective view away, showing a permanent magnet assembly for use in a drum separator, the

assembly of magnets being arranged in accordance with this invention;

FIG. 3 is a sectional view taken along line III—III of FIG. 4; and

FIG. 4 is a sectional view taken along line IV—IV of FIG. 3.

Basically, the objects are attained in the present invention by a magnet assembly including at least one pair of permanent magnets, or at least one pair of stacks of permanent magnets, that are arranged, magnetically, in series.

Broadly, the magnetic assembly of this invention is a structure composed of soft magnetic pole pieces or members and pairs of permanent magnetic material members or bodies, shaped, arranged and assembled to provide a first elongated pole face of one polarity, and a second elongated pole face of the opposite polarity spaced from said first pole face and substantially parallel thereto. The pole faces, defining the extremities of the working face of the magnetic assembly, usually are arranged parallel to a plane or curved surface of large radius.

More specifically, the magnetic assembly of this invention is characterized by a V-shaped yoke of low reluctance, the arms of the V extending rearwardly away from the working face of the assembly and having magnetic bodies fitted on the forward side thereof, in which the arms of the yoke provide a low reluctance path between the magnet bodies and connect said magnet bodies in series. Pole pieces are arranged at the end of the magnetic bodies opposite to the end in contact with the yoke. The pole pieces and yoke are held in fixed spaced relation to each other and to the bodies of the magnetic material which are secured between them. The bodies of permanent magnet material are positioned so as to confer one polarity upon one magnetic pole piece and the opposite polarity upon the other pole piece. Thus, the yoke supports the rear surfaces of the magnet bodies and the pole pieces abut the forward surfaces of the magnet bodies. The magnet bodies are magnetized in a direction that is perpendicular to the planes of the aforementioned surfaces.

Accordingly, the yoke provides a pair of inclined convergent surfaces forming an apex in the direction of the working face. The magnet bodies are fixed to the forward side of these inclined surfaces and extends to the working face of the assembly. Consequently, the yoke may alternatively be formed of a solid bar of triangular, square, sector or rectangular cross section.

It will be understood that the yoke arms may be flat or curved surfaces with correspondingly shaped magnet bodies fitting closely thereagainst, and the pole pieces also fitting into the space at the upper end of the magnet bodies.

In utilizing the basic assembly described, ordinarily a plurality of assemblies will be used depending upon the number of poles desired. For example, a five-pole arrangement may be obtained by employing four of the described yoke-magnet bodies and pole piece assemblies. In a relatively simple fashion, a magnet assembly is achieved in which the flux density in all sections of the magnet body closely correspond to that of the maximum energy product. Further the efficiency achieved approaches 100 percent, based on the better utilization of the magnetic flux relative to the working face, for the structural and magnetic arrangement of the present invention eliminates substantial open spaces between permanent magnets and concentrates and conducts the magnetic flux into the area where it can be utilized almost entirely to effect a desired object, for example, a magnetic separation.

In a preferred embodiment, the magnetic assembly

of this invention takes a form which may be designated the V type. In this type, the yoke is V shaped in cross section with the arms of the V set at about 90° with respect to each other and the pole pieces are triangular in cross section with one surface thereof parallel to one surface of said yoke. A pair of magnets or a pair of stacks of slab-shaped magnets are secured between the yoke and the pole pieces. The magnets associated with each arm of the yoke are magnetically in series and the yoke provides a low reluctance coupling so that all the magnets of the assembly are magnetically in series.

The invention will be further described in detail with reference to the utilization of V type magnetic assemblies in drum type magnetic separators for resolving magnetic ores. However, it is to be understood that this is for purposes of illustration and is not to be construed as limiting the invention.

Referring now to the drawings, the magnetic separator shown comprises a supporting frame **10** on which is mounted the active separator unit indicated generally by the numeral **12**. As will be apparent in the detailed description hereinafter, the separator unit structually comprises a generally cylindrical drum **13** of non-magnetic material (such as stainless steel) surrounding an assembly of magnets and pole pieces located along, but spaced from, a portion of the inside surface **14** (FIGS. 3 and 4) of the cylindrical wall **15** of the drum **13**. The magnet arrangement is supported independently of the drum **13** so that the drum can be rotated while the assembly of magnets remains stationary.

Accordingly, the drum **13** is supported on the frame **10** by a shaft **16**. A motor **17** operatively connected to the drum **13** through a sprocket and chain arrangement **18** attached to the end walls **19** of the drum **13** is also supported on frame **10**. Shaft **16** suitably supports the drum **13** by means of bearings **19***a* attached to the end walls **19**.

Internally of frame **10**, there is structure by which feed to be resolved is directed to the external surface of the cylindrical wall **15** of the drum of the magnetic separator unit, and by which the fractions into which the feed is resolved can be separately removed. For this general purpose, a conduit **22** leads into an L-shaped chamber **24** at one side of the frame **10**. The materials in the feed that are non-magnetic and thus not influenced by the magnet assembly pass downwardly along the L-shaped chamber **24** and are withdrawn through an outlet conduit **25** and are stored or otherwise disposed of as desired. The magnetic materials in the feed are attracted and held to the external surface of the sidewall **15** of the drum until they are carried beyond a point where they could fall into the path to the outlet conduit **25**. Once they have been carried beyond this point, they are permitted to drop into a bin or outlet conduit **26** provided to receive them.

Within the drum **13** is the permanent magnet assembly, indicated by the numeral **30** in FIG. 2. The arrangement of the permanent magnets and pole pieces in this embodiment of the invention is shown in FIGS. 2 and 3. This unit includes a pair of supporting end plates **32** and **34** having cross bar means **65** and **66**, respectively, associated with each by which the magnet assemblies can be supported. If desired, adjustable means, such as set screws (not shown) may be provided to lock the end plates **32** and **34** in any desired fixed position on shaft **16**. The permanent magnets and pole pieces preferably are maintained as close as possible to the inside surface **14** (FIG. 3) of the drum side wall consistent with the free rotation of the drum relative to the magnet assembly.

An arrangement of permanent magnets to operate, magnetically, in series in accordance with this invention is achieved by aligning at least two permanent magnets, or two stacks thereof, generally to a V form. In the embodiment shown, each stack of magnets is composed of four slab magnets **41**, **42**, **43** and **44** of increasing width from bottom to top. The actual width of each magnet preferably is determined to that available volume between the yoke and the pole pieces is substantially entirely filled with magnetic material and voids, if any, are minimized. A pole piece **48** of the shape to be received in the V defined by the smallest magnet slab **41** and the working face of the magnet assembly is located therein.

The magnet assemblies as just described may be made and employed as individual assemblies and conventional means may be used to secure the several elements together. However, in devices employing several magnet assemblies, it is convenient and desirable to construct the device so that adjacent magnet assemblies share pole pieces and means for securing the elements together.

In FIGS. 2 and 3, there is shown a five pole magnet strip assembly, which includes a plurality of magnet assemblies secured together and affixed to the end plates **32** and **34** of the magnetic separator. The device shown is provided with four magnet assemblies **70**, **71**, **72**, **73** each having a yoke **50**, **51**, **52** and **53**. The two middle magnet assemblies **71**, **72** share three pole pieces **47**, **48** and **49** which are triangular in cross section while the end magnet assemblies **70**, **73** each have one pole piece **45** and **46**, respectively, which is not shared. The magnetic strip is held together in part by a plurality of threaded means **80**, located between adjacent magnet assemblies **71** and **72**, which is threaded at one end into a pole piece **47** and at the other end is provided with a collar **81** which extends into abutting relation with the rearward edge of adjacent arms of the yokes **51**, **52**. It will be noted that by tightening the nut **82**, the magnet stacks of adjacent magnet assemblies can be drawn firmly to their respective yokes. The support of the flank magnet stacks of the end magnet assemblies **70** and **73** requires that a hole **85** be drilled in one arm of the yoke and the magnet stack so that the fastening means **80**, **82** may effectively draw the pole piece **46** and the magnet stack to the yoke.

To secure the magnet assemblies to the end plates **32** and **34**, the horizontal cross bars **65** and **66**, respectively, are welded or otherwise secured thereto. The cross bar **65** is provided with downwardly extending struts **61** and **62**, and the cross bar **66** is similarly provided with struts **63** and **64**. The struts are welded or otherwise secured to the cross bars. As will be seen in FIGS. 2 and 3, the ends of the cross bars **65** and **66** closely fit into the 90° angle provided by the rear surfaces of the end yokes **50** and **53**. The cross bars are preferably welded to the yokes. Downwardly extending struts **61** and **63** closely fit into the 90° angle provided by the rear surfaces of yoke **51**. Similarly, the struts **62** and **64** mate with the rear surfaces of yoke **52**. The struts are preferably welded to the yokes. It is clear that an extremely strong structure has thus been provided.

In the embodiment shown in FIG. 2, there are four V arrangements of magnets that, in the aggregate and in view of their arrangement, contribute five poles. Additional magnet assemblies each contribute one more pole, and accordingly, any odd or even number of poles desired can be easily provided. Where a 360° arc of magnet assemblies is employed, an even number of poles is obtained, for the final magnet assembly merely closes the circle and contributes no separate pole. While the magnetic assembly of the invention has been described primarily in terms of a V configuration, in which the yoke arms are fixed at a 90° angle to each other, other angles, smaller or greater, may be used.

To assure optimum utilization of permanent magnet material, it is necessary that all sections of the material be operated at a flux density as closely as possible corresponding to that of the maximum energy product of the material. The maximum flux in a magnetic circuit occurs in the magnet material approximately midway between the poles. It is clear that the series magnet arrangement of the present invention provides a natural reduction in the cross sectional area adjacent the pole

pieces (magnetic slabs **41**) and a substantially larger cross sectional area midway between the poles (magnetic slabs **44**) in the region of maximum flux. A relatively uniform flux density therefore exists at all sections of the magnetic circuit.

For a drum type magnetic separator of the type being discussed, a diameter of 30 to 36 inches frequently is used and the drum may be as much as 4 to 6 feet in length. The individual permanent magnets used would be functionally of substantially similar length, though that length can be achieved by using a plurality of magnets each of a smaller length so that in the aggregate the 4 to 6 feet of magnets is attained. Of course, the pole pieces also extend the full length, and similarly, the full length required may be achieved by using a plurality of smaller pole pieces in contact with each other.

The materials used to produce the permanent magnets and pole pieces in accordance with this invention can vary widely, as is apparent to those skilled in the art. Preferably, they are made from ceramic permanent magnet high coercive force material such as the barium ferrites, or strontium ferrites or other materials of like character, since the arrangement provides a large magnet area in relation to the magnet length. However, the metallic permanent magnet materials such as Alnico, and the like also can be used. Similarly, the pole pieces can be made of any soft magnetic material desired. Particularly, suitable are iron and common soft steel.

While the invention has been described primarily as employing oriented magnetic material, and indeed this is the preferred material, it is also contemplated that isotropic high coercive force permanent magnetic material may be used in the magnetic assemblies of the invention. In using such material, the arrangement is such that directions of strong magnetization of the permanent magnetic material essentially impart one polarity thereof to one of the pole pieces of the magnet assembly, and the other polarity to the other pole piece.

As has already been indicated, the pairs of magnets, or pairs of stacks of magnets are magnetically coupled in series. Consequently, if the south pole of one magnet (or stack) is adjacent one pole piece, the north pole of the same magnet is adjacent the yoke, while for the companion magnet (or stack) of the same magnet assembly, the south pole is adjacent the yoke and the north pole is adjacent the other pole piece. The direction of magnetization of adjacent stacks of magnets is shown by arrows **101** in FIG. 2. The two magnets or stacks of magnets of each magnet assembly are magnetically in series due to their opposite magnetic orientation and to the presence of the yoke which provides a low reluctance path between the stacks.

In consequence of the just described arrangement of pole pieces and magnets, internal flux leakage is minimal because it occurs only at the ends of the magnet assemblies, along one side of each flank magnet assembly, and at bolt locations and mismatched magnet joints. Moreover, there is little flux leakage rearwardly of the magnet arrangement since the flux behind the magnets is concentrated in the yokes and is conducted by the yokes from one magnet (or stack) to the other. Hence, the flux is principally located in front of the magnets in an arc between the pole pieces and thus substantially all of it, for practical purposes, is available to effect the desired separation.

Operation of a magnetic separator as just described follows that of prior art devices. Thus, where an ore is being separated from a gangue, the ore that is to be resolved is comminuted to a relatively small size, for example, from fines ranging up to particles of ¼ to ½ inch or more. For wet operation, the finely divided ore, is dispersed in a carrier fluid, normally water, and fed to the separator through the inlet conduit. With the conveyor or drum surface rotating, the feed passes into contact with it and the magnetic material is attracted to and

held on the drum surface. The remaining materials pass to the first outlet conduit. The drum surface and its magnet assembly are of such size that the magnetic force is maintained on the particles on the surface until they are carried beyond the area in which they would pass outwardly with the tailings. Once they are beyond that point, the end of the magnetic chuck or separator arrangement is reached and the particles fall away from the drum surface under the influence of gravity and the failure, due to remoteness, of sufficient magnetic force to retain them. The falling magnetic particles are directed to a separate outlet conduit provided for them. The alternate polarities of the magnetic poles to which the particles are subjected as the drum surface passes relative to the magnetic drum arrangement, tends to vibrate these particles on the surface, reorientating them and permitting entrapped nonmagnetic material to fall away.

In the resolution of materials with a separator as in this invention by what can be termed a dry process, the feed usually is arranged to pass over the rotating surface under the influence of gravity. Normally for dry separations, more magnetic assemblies are used, often covering on the order of 50 percent or more of the surface of the separating drum. In such practice, the feed may be introduced into contact with the separating drum near its top and the feed inlet, commonly a simple funnel arrangement to which a vibrator may be attached if necessary or desirable, is supported from the frame above the drum. The tailings fall free of the drum at its side to an outlet provided for them, while the magnetic particles are held to the surface beyond that point and are separately removed.

Another arrangement, especially suited to dry separations or conveying applications, utilizes a drum having magnet assemblies along the entire inner surface of the sidewall of the drum. In such instance, the drum sidewall, which is driven, may provide all or part of the motive power for the conveyor.

Magnet assemblies as described are useful for many other industrial applications. For example, they can be used in conjunction with conveyors by which cans may be held to a conveyor and moved as desired. Further, they are useful as spreaders of metal sheets arranged in stacks.

From the foregoing discussion and description, it is apparent that the present invention is a significant advance in magnet assemblies. The V shape of the element assembly contributes a mechanical advantage of strength and a structural advantage of mounting simplicity in addition to the magnetic benefits already noted. These advantages can be attained even with variations of the details of the invention. Thus, it will be evident that sizes, number of elements and the like can be changed. Furthermore, the face of the magnet assembly can be made flat or even concave, rather than convex as shown, for particular applications. Tips can be added to the pole pieces to aid in directing the flux as desired. In all events, the materials of construction for different parts of apparatus with which the magnet assembly is used should be chosen such that no materially adverse influence on the utilization of essentially all the available flux exists.

Having illustrated and described the invention in detail for purposes of exemplification, it should be understood that the invention may be practiced otherwise and is not to be limited by the details expressed.

I claim as my invention:

1. An assembly of magnets for use in separating procedures and conveying applications comprising a pair of elongated magnetic pole pieces of opposite polarity defining between them the working face of said magnet assembly, an elongated yoke member of low reluctance material having a pair of convergent inclined surfaces extending the length thereof, the convergence of said surfaces forming an apex in the direction of said working face, each of said elongated pole pieces lying parallel to and spaced

from one of said inclined surfaces, a pair of bodies of oriented permanent magnet material each substantially filling the space between one of said inclined surfaces and the pole piece associated therewith and extending to the working face, the oriented permanent magnet bodies being arranged with their polarities magnetically coupled in series through the yoke member.

2. The magnetic assembly of claim 1 wherein the angle between the convergent surfaces is about 90° and the oriented permanent magnetic material consists of a plurality of stacks of ceramic permanent magnets in slab form.

3. A highly efficient magnetic assembly having a pair of magnetic poles at a working face thereof, comprising an elongated yoke of V-shape in cross section composed of permeable soft magnetic material and having the arms of the V extending rearwardly away from the working face of the magnetic assembly, a pair of pole members of permeable soft magnetic material disposed at the working face, each in fixed spaced relation and parallel to an arm of said yoke, at least a pair of oriented permanent magnet bodies substantially completely filling the space between the yoke and the pole members and extending to the working face of the assembly, the arrangement and directions of strong magnetization of the permanent magnet material being such as to couple said magnet bodies in series through the yoke whereby the pole members are of opposite polarity.

4. The magnetic assembly of claim 3 wherein the angle between the arms of the yoke is about 90° and the oriented permanent magnetic material consists of a plurality of stocks of ceramic permanent magnets in slab form.

5. In a magnetic separator comprising a conveyor having a material receiving surface for conveying materials to be separated and a permanent magnet assembly having two poles at a working face thereof to attract magnetic material to be separated towards said surface, the conveyor being movable relative to the permanent magnet assembly, the improvement comprising forming said assembly of a V-shaped yoke of permeable soft magnetic material having two arms extending rearwardly away from the working face of the magnetic assembly, a pair of pole members of permeable soft magnetic material disposed at the working face, each in fixed spaced relation and parallel to an arm of said yoke, at least a pair of oriented permanent magnet bodies substantially completely filling the space between the yoke and the pole members and extending to the working face of the magnetic assembly, the arrangement and direction of strong magnetization of the oriented permanent magnet material being such as to couple said magnet bodies in series through the yoke whereby said pole members are of opposite polarity.

6. In a magnetic separator in accordance with claim 5, at least two such assemblies of permanent magnets arranged so that adjacent assemblies share a common pole, the oriented permanent magnetic material consisting of a plurality of stacks of ceramic permanent magnets in slab form and the working faces of said assemblies being closely adjacent the surface of said conveyor.

7. In a magnetic separator, a drum having a cylindrical sidewall composed of a non-magnetic material and mounted for rotation on a shaft, a permanent magnet assembly having two poles at a working face thereof adapted to attract magnetic material to be separated towards the external surface of the sidewall of the drum and mounted within the drum, said working face being positioned in close proximity to the internal surface of said sidewall, the magnetic assembly comprising a V-shaped yoke of permeable soft magnetic material having two arms extending away from the working face thereof, a pair of pole members of permeable soft magnetic material each spaced from and parallel to an arm of said yoke, bodies of oriented permanent magnetic material substantially completely filling the spaces between the arms of the yoke and the pole pieces and extending to the working face of the magnetic assembly, the arrangement and direction of magnetization of the oriented permanent magnet material being such as to couple said magnetic bodies in series through said yoke.

8. In a magnetic separator in accordance with claim 7, at least two such permanent magnet assemblies adjacent one another and sharing a common pole, the oriented permanent magnet bodies consisting of ceramic permanent magnet material.

9. An assembly of magnets for use in separating procedures and conveying applications comprising a generally V-shaped yoke having about a 90° angle between the arms thereof, a pair of magnetic pole pieces external of said V-shaped yoke, each pole piece lying parallel to and spaced from one of said arms, at least a pair of permanent magnets between said yoke and said pole pieces, said magnets substantially filling the space between said pole pieces, said magnets magnetized in directions perpendicular to the arm of the yoke with which they are associated and arranged with their polarities magnetically coupled in series.

10. An assembly of magnets for use in separating procedures and conveying applications comprising a generally elongated yoke of low reluctance material having a pair of convergent inclined surfaces extending the length thereof, the convergence of said surfaces forming an apex extending toward the working face of said assembly, a pair of spaced magnetic pole pieces at said working face, each pole piece lying parallel to and spaced from one of said inclined surfaces, at least a pair of permanent magnets between said yoke and said pole pieces, said magnets being in contact with said yoke and said pole pieces and extending between said pole pieces to the said working face and magnetized in directions perpendicular to the inclined surface of the yoke with which they are associated and arranged with their polarities magnetically coupled in series, the cross sectional area of the magnets adjacent the yoke being relatively greater than adjacent the pole pieces, whereby efficient utilization of magnetic material is obtained.

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