

[54] **MAGNETIC SEPARATOR**
 [75] Inventors: **Saburo Yashima**, No. 20,
 Aza-Nikenjaya, Minamime,
 Hara-machi, Sendai; **Haruo**
Manabe, Hitachi; **Takuma Ito**,
 Saitama; **Keishi Namikawa**, Ageo,
 all of Japan

[73] Assignees: **Saburo Yashima; Nippon Mining**
Co., Ltd., both of Tokyo, Japan

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[51] **Int. Cl.**..... **B03c 1/12**

[58] **Field of Search**..... **209/232, 219, 223, 218,**
209/227, 220, 222, 224, 226; 210/222, 223

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Primary Examiner—Robert Halper

Attorney, Agent, or Firm—Sughrue, Rothwell, Mion,
 Zinn & Macpeak

[57] **ABSTRACT**

A wet type magnetic separator has a generally cylindrical stationary magnet device with its axis fixed and extending substantially horizontally with a cut away recess open from the top of the cylindrical body and to one side along its periphery. Sets of plural permanent magnets and yokes having a similar configuration to said magnets are coaxially aligned in side-by-side arrangement so that adjacent yokes have opposite polarities. A rotary drum is disposed coaxially and rotatably to the stationary magnet device and adjacent about the stationary magnet device, and is covered with substances of high magnetic permeability functioning as a group of induced poles. Thus, the magnetic separator can separate magnetic particles by means of magnetic force from non-magnetic particles of the raw materials, which are supplied to the top of the rotary drum.

9 Claims, 15 Drawing Figures

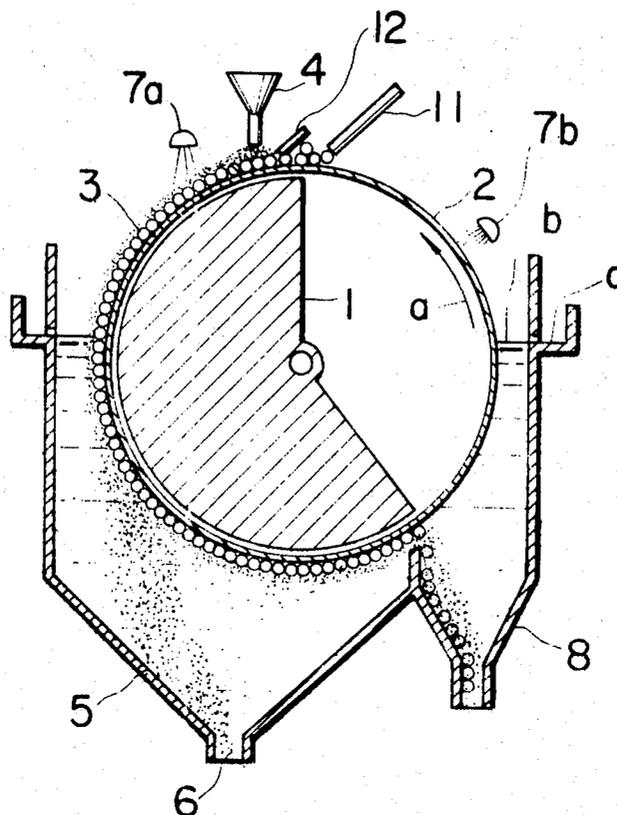


FIG. 1A

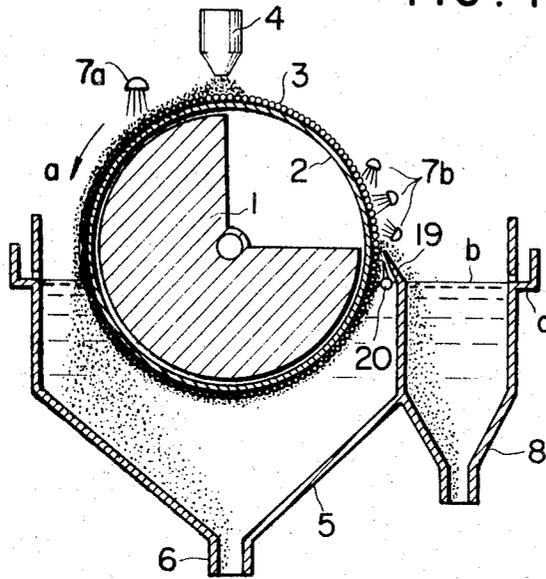


FIG. 1B

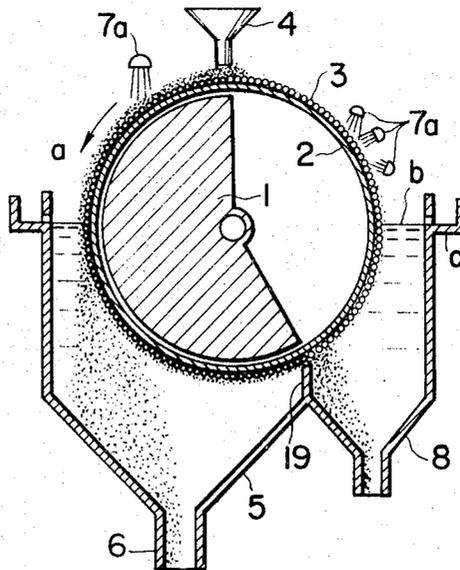


FIG. 2

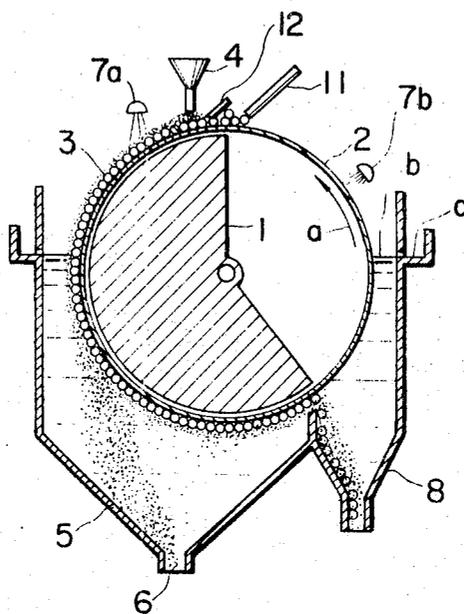


FIG. 3A

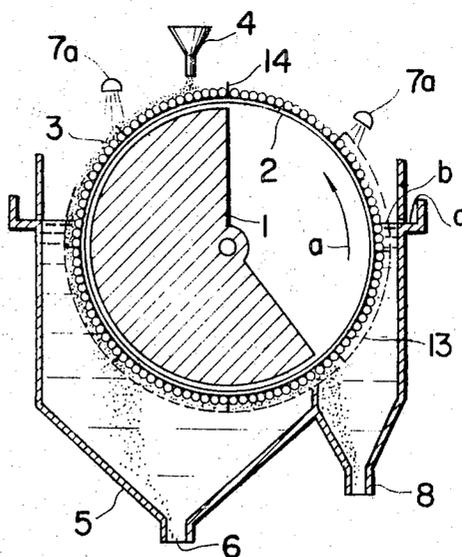


FIG. 3B

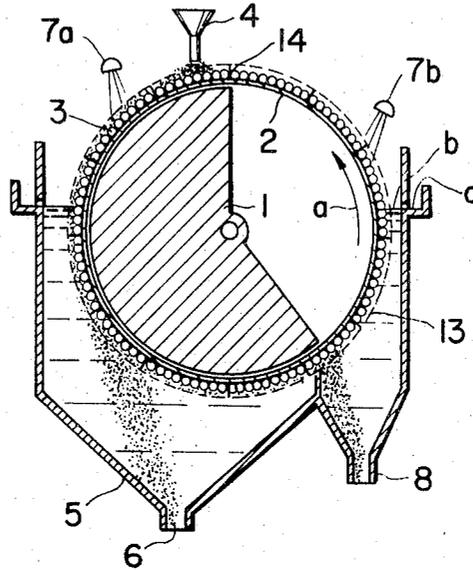


FIG. 4

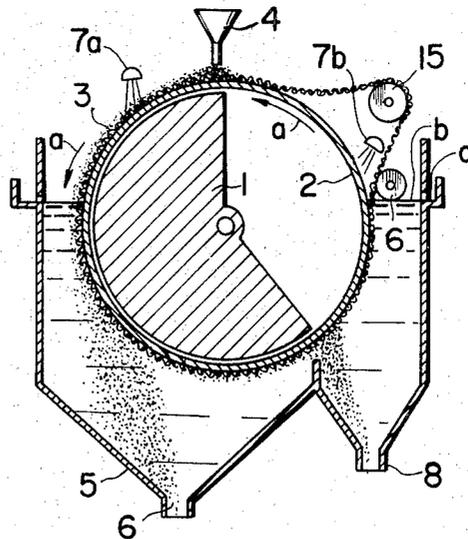


FIG. 5

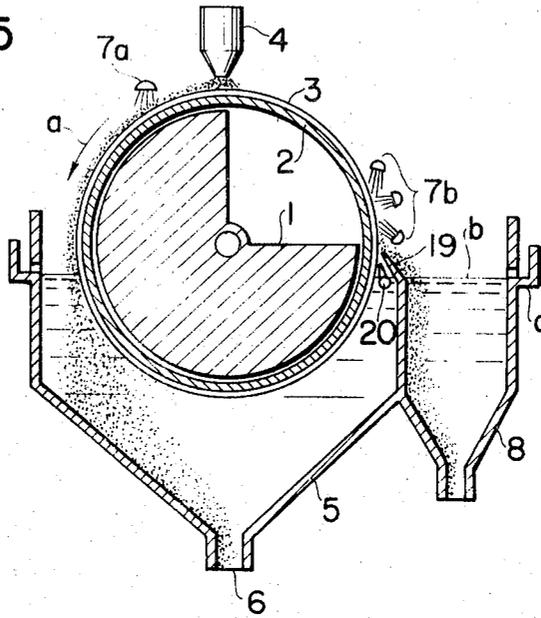


FIG. 6

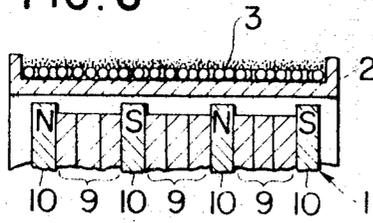


FIG. 7

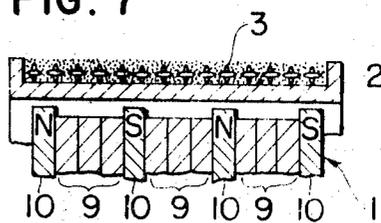


FIG. 8

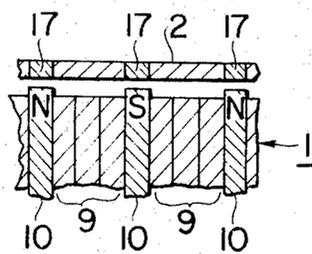


FIG. 9

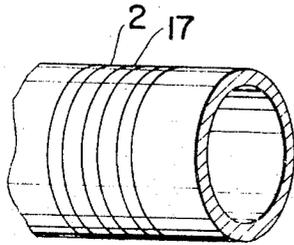


FIG. 10

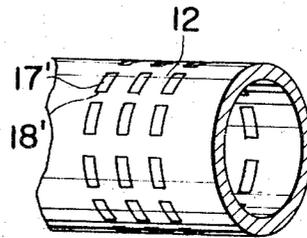


FIG. 11

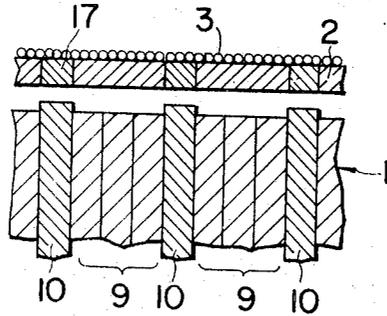


FIG. 12

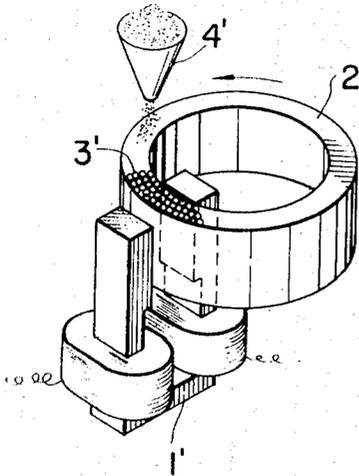
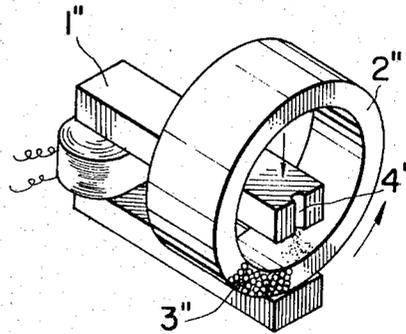


FIG. 13



MAGNETIC SEPARATOR

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION:

This invention relates to a magnetic separator and, more particularly to a wet type magnetic separator for separating magnetic particles from raw ore materials.

2. DESCRIPTION OF THE PRIOR ART:

Recently, in the field of wet type magnetic separator, in difference to a typical conventional machine wherein an effective zone for separation of raw materials is induced by use of simple flat pole piece surfaces, a system has been developed which includes members having such configuration as a ball or a rod made of a substance of high magnetic permeability and low residual magnetization (hereinafter represented as a group of induced poles), such as soft iron, disposed in a magnetic field created by a high intensity electromagnet (which is generally in excess of 20,000 gauss), and performs magnetic separation while supplying particles to be separated into the magnetic field formed in the space between these members.

However, magnetic separators have been known prior to the present invention, typical ones of which are shown in FIGS. 12 and 13 of the attached drawings, have the drawbacks that the effective area for receiving raw particles to be separated is very small relative to the overall dimension of the machine, the supplied particles tend to stay in the aforementioned group of induced poles, and supplying of raw particles and removing of concentrated particles can not be performed smoothly.

These shortcomings of the prior system will now be explained specifically with reference to FIGS. 12 and 13.

In one conventional magnetic separator exemplarily illustrated in FIG. 12, a generally doughnut-like pole box 2' is rotated while kept horizontally so as to pass through the magnetic field created by an electromagnet 1', with pole box 2' filled by a group of induced poles 3' comprising a number of twisted short rods or balls. Raw particles to be separated are fed from an ore supply conduit 4' to the pole box 2' at a point before crossing the magnetic field, thus, the non-magnetic particles of the raw material do not receive the strong magnetic action of the electromagnet 1' and fall downward immediately to be discharged, while magnetic particles are attracted by the group of induced poles within the pole box 2' and carried as the pole box 2' rotates. Then, as a given portion of the group of induced poles comes out of the magnetic field, induced by the electromagnet 1' to thereby decrease its magnetic force, these magnetic particles are released from the group of induced poles and fall down where they are collected. In this type of magnetic separator, the effective separating zone is very small relative to the overall dimension of the machine because the zone is limited to only a portion of the doughnut-like pole box 2' of a small crosssection area. It is impossible to increase the supply rate of raw particles because the length of the doughnut-like pole box 2' in the axial direction is relatively long and the separation performance is poor because raw particles stay partly in the space of the group of induced poles within the pole box. In addition, by the

drop of raw particles, magnetic particles tend to be carried away with non-magnetic particles.

Also, in another conventional magnetic separator illustrated exemplarily in FIG. 13, a cage drum 2'' of the trommel type rotates; passing through the magnetic field created by an electromagnet 1'', and a group of induced poles 3'' fills the drum 2'' as in the machine of FIG. 12. Raw material to be separated is fed through a narrow groove 4'' formed on an electromagnet core with its center line crossing the center of the drum 2'' into the inside of the drum and magnetic particles of the fed raw material are attracted upon the surface portions of the group of induced poles and carried forward as the drum 2'' rotates, and then, at the point where a given portion of the group of induced poles leaves the magnetic field of the electromagnet 1'' and have a decreased magnetic force, these magnetic particles are released from the group of induced poles to be collected. On the other hand, the non-magnetic particles are not attracted, thus, fall down immediately whereby they are discharged. This type of magnetic separator does not utilize effectively the space of the drum 2'' because the raw material is fed only to a portion of the inner periphery of the drum, and provides a very poor separation performance characteristic, like the separator shown in FIG. 12.

In addition to the afore-mentioned shortcomings, as the common problems of the two types of prior magnetic separators, it is indispensable in design to construct the electromagnets 1' (1'') in such a form that the opposing pole pieces of the electromagnet hold therebetween, a portion of the doughnut-like pole box or drum in order to cause the group of induced poles filling the drum to rotate and move through the magnetic field created by the pole pieces. Therefore, the size of the electromagnet 1' (1'') is limited in a structural point of view and a large number of magnets can not be mounted in the machine. As a result, the effective working zone of the magnetic field formed by the electromagnet 1' (1'') is limited to only a portion of the pole box or drum, resulting in a small effective zone for particle separation. Further, since it is necessary to dispose one of the electromagnet pole pieces outside the pole box or drum, the machine has a disadvantage that its structure is large and complex.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a wet type magnetic separator having a novel arrangement and overcoming all the drawbacks of the conventional magnetic separator as noted above.

It is another object of the present invention to provide a wet type magnetic separator having a novel structure by which the characteristic property of a group of induced poles can be fully utilized.

It is a further object of the present invention to provide a wet type magnetic separator having an improved magnetic field configuration of the group of induced poles.

It is a still further object of the present invention to provide a wet type magnetic separator having remarkably improved separation efficiency and performance characteristic.

A wet type magnetic separator according to the present invention comprises a generally cylindrical stationary magnet device having a cut away recess open from

the top of the cylindrical body to one side along its periphery and an axis which is so fixed that it holds substantially horizontally, a rotary drum disposed coaxially with and rotatably about in close proximity said stationary magnet device, and a group of induced poles made of substance of high magnetic permeability are provided around said rotary drum to effect separation of magnetic particles of supplied raw material.

The aforesaid stationary magnet device consists of sets of plural permanent magnets each having the same cut away recess and yokes having a similar configuration to said magnets in which they are coaxially aligned in side-by-side arrangement and assembled by putting in order their cut away recesses into an integral body such that said sets of plural permanent magnets are sandwiched between respective yokes with adjacent yokes having opposite polarities.

In the above described magnetic separator of the present invention, raw particles to be separated are fed to about the top of the rotary drum and then move together with the group of induced poles along the circumference of the stationary magnet device in accordance with the rotation of the rotary drum. Among the raw particles, non-magnetic particles are not subjected to the attraction force of the magnetic field generated from the stationary magnet device, so that the non-magnetic particles are permitted to fall down at a certain rotating position of the rotary drum, whereas magnetic particles are attracted and held about the rotary drum by the group of induced poles magnetized by the stationary magnet device and then fall down from the rotary drum at a second rotating position of the rotary drum, where the rotary drum passes through the cut away recess of the stationary magnet device because the magnetic force of the stationary magnet device and the group of induced poles is decreased at that position, with the magnetic particles washed away by means of shower devices.

The aforesaid rotary drum is generally made of non-magnetic substance, but, in order to enhance the separation performance, a substance of high magnetic permeability is preferably provided to portions of the rotary drum corresponding to the yokes of the stationary magnet device to form another group of induced poles (hereinafter represented as a second group of induced poles, therefore, the aforesaid group of induced poles except the second group of induced poles are represented as a first group of induced poles hereinafter).

The other objects, features and advantages of the present invention will become apparent from the following description taken in conjunction with the accompanying drawings wherein like elements of the embodiments carry like numerical designations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is an elevational cross-sectional view of a first embodiment of a magnetic separator according to the present invention.

FIG. 1B is an elevational cross-sectional view of a modification of the first embodiment shown in FIG. 1A.

FIG. 2 is an elevational cross-sectional view of a second embodiment of the magnetic separator according to the present invention.

FIG. 3A is an elevational cross-sectional view of a third embodiment of the magnetic separator according to the present invention.

FIG. 3B is an elevational cross-sectional view of a modification of the third embodiment shown in FIG. 3A.

FIG. 4 is an elevational cross-sectional view of a fourth embodiment of the magnetic separator according to the present invention.

FIG. 5 is an elevational cross-sectional view of a fifth embodiment of the magnetic separator according to the present invention.

FIG. 6 is an axial enlarged partial cross-sectional view of the embodiments shown in FIGS. 1A, 1B, 2, 3A and 3B.

FIG. 7 is an axial enlarged partial cross-sectional view of the embodiment shown in FIG. 4.

FIG. 8 is an axial enlarged partial elevational cross-sectional view of another embodiment of the present invention using the rotary drum shown in FIG. 9 or FIG. 10.

FIG. 9 is an explanatory perspective view of a modification of the rotary drum.

FIG. 10 is an explanatory perspective view of another modification of the rotary drum.

FIG. 11 is an axial enlarged partial elevational cross-sectional view of another embodiment of the present invention including the stationary magnet device, the rotary drum shown in FIG. 8 or FIG. 9 and the first group of induced poles having a circle configuration in their section.

FIGS. 12 and 13 are explanatory perspective views of the typical prior art magnetic separators explained hereinabove.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1A, a first embodiment of the present invention is described as follows.

Numeral 1 shows a generally cylindrical stationary magnet device which has a cut away recess and which is so fixed that its axis is held substantially horizontal. The elevational cross-sectional view of the stationary magnet device taken along the axis thereof is as shown in FIGS. 6, 7, 10 and 11, that is, the stationary magnet device 1 comprises sets of plural discal permanent magnets 9, which are so assembled that the said plural discal permanent magnets made of, for example, an isotropic ferrite each having the same cut away recess are coaxially aligned in side-by-side arrangement and respective cut away recesses are put in order. Yokes 10 made of, for example, iron plate, each having a similar configuration to the said magnets, are coaxially aligned in side-by-side arrangement and assembled into an integral body such that respective sets of plural discal permanent magnets are sandwiched between respective yokes by putting in order their cut away recesses so that respective adjacent yokes have opposite polarities. Thus constructed stationary magnet device 1 generates on the outside a strong magnetic field extending radially continuously and stripedly in the axial direction. About the stationary magnet device 1, a hollow rotary drum 2 is coaxially disposed with respect to the stationary magnet device and rotatably in the arrow a direction and in close to the periphery thereof. The rotary drum 2 is normally made of non-magnetic substance, but the rotary drum 2 is suitably improved as described below. Upon the outer surface of the rotary drum 2 there are provided a first group of induced poles 3 made of substance of high magnetic permeability, such

as soft iron, Fe-Ni alloy (permalloy), or Fe-Co alloy (permendur). This first group of induced poles 3 functions to induce a high intensity magnetic field in spaces or gaps between respective members of the first group of induced poles 3 in response to the magnetic action of the stationary magnet device. For this purpose, the first group of induced poles 3 having such a configuration as ball, rod, ring, endless chain or endless net can be employed, among which ball-like members are preferably employed. Further, there is no limitation as to means for equipping and the method for arranging the first group of induced poles 3 onto the periphery of the rotary drum 2.

The first group of induced poles 3 used in the first embodiment of the magnetic separator of the present invention has a ball-like configuration and it is fixed to the peripheral surface of the rotary drum 2 with adhesives or welding as shown in FIG. 1A. By thus fixing the first group of induced poles onto the peripheral surface of the rotary drum 2, any means for preventing breaking away and falling down of the first group of induced poles 3 is not required in such magnetic separator as the first embodiment described above which employs a ball-like or rod-like members as the first group of induced poles to the peripheral surface of the rotary drum 3, since the first group of induced poles 3 never break away and fall down from the rotary drum 3.

Further, as a following second embodiment shown in FIG. 2, some means for separating the magnetic particles from the first group of induced poles 3, when a magnetic separator that the first group of induced poles 3 is not fixed onto the peripheral surface of the rotary drum, is used because the first group of induced poles 3 is withdrawn together with the magnetic particles from a second hopper 8 for collecting the magnetic particles, on the contrary, in the magnetic separator such as the aforesaid first embodiment, separating means are not required.

Raw particles to be separated are fed from a raw material supplying device 4 disposed above the rotary drum 2 onto the rotary drum 2 and are carried by the rotary drum 2 during which time, they are subjected to a separation operation. That is, since non-magnetic particles of the raw material do not receive the magnetic action from the stationary magnet device, they fall down into the liquid at a certain rotating position of the rotary drum 2 and are collected by a first hopper 5 for collecting nonmagnetic particles where they are removed through an ejecting port 6. On the other hand, magnetic particles are attracted by the first group of induced poles 3 provided around the rotary drum 2, magnetized by the stationary magnet device 1 and, thus, pass to the underside the stationary magnet device 1 in response to rotation of the rotary drum 2. And then, the time when the rotating position of the rotary drum 2 passes coincides to the cut away recess of the stationary magnet device 1, the magnetic particles break away from the rotary drum 2 and the first group of induced poles 3 because of the reduction of magnetic force and by means of shower devices and fall down into the second hopper 8. Thus, the magnetic particles are withdrawn.

Pulp is stored into a casing consisting of the first hopper 5 and the second hopper 8 in order to perform effectively the separating operation for magnetic particles and non-magnetic particles. The rotary drum 2 and the first group of induced poles 3 are partially im-

mersed in pulp. The level of pulp fluid b is preferably selected high in order to reduce the influence of flowing pulp and to enhance detachability of non-magnetic particles from the rotary drum surface and of magnetic particles from the first group of induced poles 3 and collection efficiency; but, it is also necessary to select the pulp level depending upon the supply rate of the raw particles in a manner such that the pulp does not flow away from the rotary drum surface.

Numerals 7a and 7b show a shower device or nozzle. The shower device 7a is disposed at the left-hand upper portion of the rotary drum 2 in close to the rotary drum 2 and functions to magnetically and positively adhere magnetic particles among raw material to the first group of induced poles 3 and to the rotary drum 2. On the other hand, the shower device 7b disposed at the right-hand portion in the vicinity of the rotary drum 2 is required to enhance the separating of magnetic particles from the rotary drum 2 and the first group of induced poles 3. A turned-up shower device 7b functions to enhance separation of the magnetic particles from the rotary drum 2 and the first group of induced poles 3 and to prevent the thus separated magnetic particles from flowing back into the first hopper 5. It should be noted that the number of showers to be employed in the magnetic separator of the present invention can be selected freely as occasion arises.

In addition, a partition board 19 may be disposed between the hoppers 5 and 8 at a position at the beginning of the cut away recess of the stationary magnet device 1, in order to effectively achieve separation and collection of non-magnetic and magnetic particles, which extends axially of the rotary drum 2 and upwardly above the pulp level b and in close to the periphery of the first group of induced poles 3 about the rotary drum 2. By use of board 19, the magnetic particles carried by the magnetic force of the fixed magnet device 1 and the first group of induced poles 3 can be prevented from flowing back into the hopper 5.

Further, it is preferable in order to perform effectively, the separation and collection, to dispose an air duct 20 extending in the axial direction between the partition board 19 and the rotary drum 2 with the first group of induced poles 3 and to spurt out compressed air through the gap between them in the magnetic separator at the beginning of the cut away recess of the stationary magnet device 1 which is disposed above the pulp level b as the first embodiment shown in FIG. 1A.

FIG. 1B shows a modification of the first embodiment of the present invention shown in FIG. 1A wherein the partition board 19 is fully immersed in the pulp. It is an advantage of this modification that the partition board 19 may be easily disposed and the air duct 20 is not required. This type magnetic separator is preferably used in case of separation of such raw material having considerably large particle size.

FIG. 2 shows a second embodiment of the magnetic separator according to the present invention, wherein members comprising the first group of induced poles 3 are fed continuously from a first group of induced poles feed device 11 to the outer periphery of the rotary drum 2, which feed device 11 is disposed in a position in the vicinity of the top of the rotary drum 2 where the magnetic force of the stationary magnet device 1 begins to act on the first group of induced poles, that is, this feed device 11 is located slightly before the posi-

tion where the periphery of the stationary magnet device 1 begins to have the full radius and behind in the direction of the drum rotation the position where the raw material is fed. In the zone corresponding to the full-radius peripheral portion of the stationary magnet device 1, magnetic particles of the supplied raw material, are attracted and held upon the drum surface by the magnetic force of the fixed magnet device 1 and carried forward as the rotary drum 2 rotates. As a given portion of the rotary drum 2 reaches the cut away recess of the fixed magnet device, members of the first group of induced poles 3 fall down into the hopper 8 as well as the separated magnetic particles and are collected together. Thereafter, the members comprising the first group of induced poles are separated from the magnetic particles by another, different separator or comb-like means (not shown) and collected, and, then, returned to the first group of induced poles feed device 11 to be fed again onto the surface of the rotary drum 2. A device 12 is disposed adjacent the first group of induced poles feed device 11 as a means for evenly aligning the members of the first group of induced poles fed upon the surface of the rotary drum 2 into the form of a layer. Device 12 is located immediately in front of the first group of induced poles feed device 11 and behind the raw material supplying device 4. According to this second embodiment, it not only takes time for fixing the first group of induced poles 3 onto the periphery of rotary drum 2, but allows one to select the most preferable first group of induced poles in response to the state and composition of raw material to be separated.

FIG. 3A shows a third embodiment of the magnetic separator of the present invention; this embodiment has a number of holder plates 14, each having substantially the same height as the depth of the first group of induced poles layer employed on the peripheral surface of rotary drum which are radially placed onto the periphery of the rotary drum 2 at appropriate intervals one after another, in order to pressure the first group of induced poles 3. In addition to this, a net 13 covers at least the lower half periphery of the rotary drum 2 in close proximity thereto and fixed to the base body, etc.

By thus providing the net 13, even when given members of the first group of induced poles reach the bottom side of the rotary drum in response to rotation of the rotary drum 2, and further reach the magnetic field reducible zone, corresponding to the cut away recess of the stationary magnet device 1, only the magnetic particles are permitted to break away and fall down into the second hopper 8, while the members of the first group of induced poles 3 are completely prevented from breaking away and falling from the periphery of the rotary drum 2. They are further moved continuously upwardly in response to the rotation of the rotary drum 2 by the action of the aforesaid pressured holder plates 14. Therefore, the magnetic separator according to this third embodiment can obtain a separation efficiency similar to that of the embodiments shown in FIGS. 1A and 1B which fix the first group of induced poles 3 onto the peripheral surface of the rotary drum 2 and further can prevent injury of decreasing the magnetic force on the rotary drum 2 which is caused by accumulation of raw material, particularly non-magnetic particles, among the first group of induced poles 3 because the first group of induced poles 3 moves forward

by being stirred between the peripheral surface and the net 13, so that this type magnetic separator can form continuously fresh induced poles on the peripheral surface of the rotary drum 2.

FIG. 3B shows a modification of the above-described third embodiment of the magnetic separator of the present invention wherein the net 13 covers the whole periphery of the rotary drum 2. In this type magnetic separator, the holder plates 14 are not necessary. It will be understood by those skilled in the art that, in case of use of the net 13, the size of mesh of the net 13 is selected to be larger than the size of particles of the raw material, while smaller than the size of members of the first group of induced poles.

In the foregoing embodiments, ball or rod members comprise the first group of induced poles 3, but, the present invention can use endless net-like members or a number of chain members, in place of the aforementioned members, to form the first group of induced poles in which case they are hung upon the drum surface between end flanges of the rotary drum.

FIG. 4 shows a fourth embodiment of the magnetic separator of the present invention. The first group of induced poles 3 used in this embodiment comprises an endless chain net covering the whole periphery of the rotary drum 2 between either flanges thereof or a plurality of endless chains covering the whole periphery of the rotary drum 2 each arranged side-by-side like a chain feeder. Numerals 15 and 16 show a sub drum for controlling the first group of induced poles 3 as described above, and a press drum, respectively, however, both sub drum 15 and press drum 16 are not always necessary.

In this fourth embodiment, the chain-like first group of induced poles 3 rotates together with the rotary drum 2 in such a manner that a part of the group 3 adheres magnetically to the peripheral surface of the rotary drum 2, while another part hangs down slightly from the peripheral surface of the rotary drum 2 by the action of gravity. Thereupon, the magnetic particles are magnetically adhered and held at the adhered part of the chain-like first group of induced poles 3 after they are separated from nonmagnetic particles, and then they break away and fall down from the chainlike first group of induced poles 3 at the hung down part thereof. The characteristic of this type magnetic separator is that the magnetic particles magnetically adhered to the chain-like first group of induced poles 3 effectively break away from the peripheral surface of rotary drum 2 and the chain-like first group of induced poles 3 without magnetic particles remaining between respective spaces of the chain-like first group of induced poles 3 and between the chain-like first group of induced poles 3 and the peripheral surface of the rotary drum 2 by existence of a slight gap formed between the chain-like first group of induced poles 3 and the peripheral surface of the rotary drum 2 at the hung down part of the chain-like first group of induced poles 3.

FIG. 5 shows a fifth embodiment of the magnetic separator of the present invention. The first group of induced poles 3 employed in this embodiment comprises a plurality of rings having the same inner diameter as the outer diameter of the rotary drum 2 or slightly smaller inner diameter than the outer diameter of the rotary drum 2 and are mounted on the periphery of the rotary drum 2 close to one another. The characteristic of this fifth embodiment is that manufacture and equip-

ment of the first group of induced poles is easy and the magnetic particles magnetically adhered to the first group of induced poles 3 can easily break away because no space or gap is formed between respective members of the first induction pole group 3.

FIG. 6 shows the relation among the stationary magnet device 1, the rotary drum 2 and the ball-like first group of induced poles 3 in the embodiments shown in FIGS. 1A, 1B, 2, 3A and 3B. As clear from FIG. 6, the members of the first group of induced poles 3 are arranged at random.

FIG. 7 shows the relation among the stationary magnet device 1, the rotary drum 2 and the chain-like first group of induced poles 3 in the fourth embodiment shown in FIG. 4.

The present invention provides also improved structures of the rotary drum 2 as shown in FIGS. 8 and 9 which are improved structurally and fundamentally over the magnetic separator. That is, in order to prevent decaying of the magnetic field generated by the stationary magnet device 1, even at the outer surface of the rotary drum 2, rather to strengthen the same, the present invention provides a rotary drum of the type in which a second group of induced poles made of substance of high magnetic permeability is mounted on portions of the rotary drum 2 facing or corresponding to yokes 10 of the stationary magnet device.

By providing the second group of induced poles, it is possible to reduce the magnetic reluctance in the path from the yokes 10 to the rotary drum, to increase the magnetic flux emitted from the yokes 10, and to concentrate the magnetic flux passing to the second group of induced poles.

FIG. 8 is an enlarged partial elevational cross-sectional view of the combination of the stationary magnet device and the rotary drum with the second group of induced poles taken along the axis thereof. In this drawing, it will be noted that the positions of the rotary drum 2 made of non-magnetic substance corresponding to or facing the yokes 10 magnetized by the permanent magnets 9 are replaced by members of the second group of induced poles 17. Preferably, the width of each member of the second group of induced poles 17 is selected to be equal to the width of the respective yokes 10, but it can be selected desirably if it is satisfied that the second group of induced poles does not come too near the adjacent ones aligned axially and polarized oppositely. Generally, the second group of induced poles 17 is distributedly provided substantially on all the several circumferential portions of the rotary drum opposing the yokes 10, wherein they may be constructed in the continuous ring shape as shown in FIG. 9 in perspective view or in the form of separate strip-like plates 17' spaced with a gap 18' as shown in FIG. 10. Further, this second group of induced poles can be attached on the desired portions of the outer surface of the rotary drum 2 by means of adhesive or welding, or it can be secured to the rotary drum by fitting it in grooves or through-holes formed in the desired corresponding portions. Of course, other well known methods can also be employed.

It should be noted that some unevenness will appear on the outer periphery of the rotary drum by fitting the second group of induced poles thereto, but, such slight unevenness does not obstruct the separation performance of the present invention.

In the foregoing description, the two basic types of magnetic separators according to the present invention have been explained, that is, the first type including the rotary drum made wholly of non-magnetic substance with the first group of induced poles provided therearound, and the second type including the rotary drum made generally of non-magnetic substance with its selected surface portions corresponding to the yokes 10 replaced by the second group of induced poles not including the first group of induced poles. The present invention provides further another type of magnetic separator which is a combination of the rotary drum of the above second type of magnetic separator with the first group of induced poles employed in the first type of magnetic separator.

FIG. 11 is an axial enlarged partial elevational cross-sectional view of a main portion of a magnetic separator according to the present invention, which employs the rotary drum having the second group of induced poles shown in FIG. 8 and the first group of induced poles in the form of ball members.

The inventors of the instant application have done the following two experiments in order to evaluate the difference in intensity of magnetic field in locations about the rotary drum between one drum including the second group of induced poles and another drum having no second group of induced poles.

EXPERIMENT 1

We prepared two rotary drums: first rotary drum D_1 of the hollow cylinder type made wholly of non-magnetic substance and having a thickness of about 4 mm, inside which, the yokes are disposed at a distance of about 5 mm from the outer circumference thereof to the inner periphery of drum D_1 , and a second rotary drum D_2 having the same dimension and arrangement as that of first rotary drum D_1 except that the circular bandlike portions of second rotary drum D_2 corresponding to the yokes are replaced by soft iron ring plates of about 4 mm thickness, functioning as the second group of induced poles. By measuring the magnetic flux density on the outside of each rotary drum, the data shown in Table 1 below, was obtained, where the instrument used was a "Model 900 Gaussmeter" made by Empire Scientific Corporation. The measurement points were selected from points in a plane including the yokes and normal to the axis of the drum, and the indicated distance was measured from the outer surface of the drum:

Table 1

| Measure points, distance (mm) | | 0 | 5 | 10 |
|-------------------------------|------------|------|------|-----|
| Magnetic flux | Drum D_1 | 1920 | 960 | 540 |
| Density (gauss) | Drum D_2 | 3050 | 1520 | 840 |

As will be noted from the data in Table 1, if a rotary drum having the second group of induced poles distributed in portions corresponding to the yokes is employed, one can get a stronger magnetic field than the field created by a drum made wholly of non-magnetic substance by about 1.6 times, resulting in increased capability of separation.

EXPERIMENT 2

We prepared two types of rotary drum: a third rotary drum D_3 of the hollow cylinder type made wholly of

non-magnetic substance and having the thickness of about 4 mm, inside which the yokes were disposed at a distance of about 5 mm from the circumference thereof, to the inner periphery of drum D₃, and a fourth rotary drum D₄ having the same dimension and arrangement as that of drum D₃ except that the circular band-like portions of drum D₄ corresponding to the yokes were replaced by soft iron ring plates of about 4 mm thickness functioned as the second group of induced poles. Upon the periphery of each drum above were applied soft-iron balls of about 11 mm diameter, functioning as the first group of induced poles. We measured the magnetic flux density between adjacent iron balls induced by the stationary magnet device inside the drum and obtained the data shown in Table 2 below, where the instrument used was the same instrument as used in Experiment 1, the measurement points were the intermediate point between two adjacent balls aligned in the axial direction of the drum and disposed on the drum surface symmetrically with respect to the center line between two adjacent yokes while varying the spacing between two balls with the indicated distance being the spacing between two adjacent balls:

Table 2

| Distance between balls (mm) | | 2 | 3 | 4 |
|-----------------------------|---------------------|-------|------|------|
| Magnetic flux | Drum D ₃ | 6900 | 4800 | 2900 |
| Density (gauss) | Drum D ₄ | 14000 | 9300 | 4300 |

As will be noted from the data in Table 2, if a combination of a rotary drum having a second group of induced poles and a first group of induced poles provided around the drum, one can get a very strong magnetic field outside the drum surface, resulting in a further increased capability of separation.

In each of the afore-described embodimental magnetic separators according to the present invention, it is possible to employ either an electromagnet or a permanent magnet as the fixed magnet device, however, the permanent magnet device is preferable for getting a desired intensity of magnetic field under a given dimensional limitation, because the permanent magnet permits free selection of the number of pole pieces and of their size and does not consume electric power.

As described above, the present invention utilizes effectively the properties of the first and/or second group of induced poles, simply strengthens the intensity of magnetic field on the drum surface, utilizes effectively the induced high intensity of magnetic field, and improves remarkably the selection performance of the magnetic separator. According to the present invention, the whole outer peripheral surface of the rotary drum is utilized as the effective separation area, the yokes are constructed in the ring form extending circumferentially, and the oppositely polarized yokes are aligned alternately in the axial direction, so that the area of receiving the raw particles is very wide and the

field effective area is also large whereby the selection functioning area is remarkably increased.

Further, the magnetic separator constructed according to the present invention has the advantage that since the attracted magnetic particles can be continuously collected and removed, the processing rate per unit time is large; since the raw particles are supplied to the top of the rotary drum with the result that they first fall down onto the drum surface and, then, only non-magnetic particles fall down calmly into water in response to rotation of the drum, all particles surely have the chance that they receive magnetic attraction action in the initial stage; since all particles float over the water and fall down thereinto, and thereby the particles are calmly separated in the water; and because of a high efficiency of collection of magnetic particles and an increased intensity of magnetic field, the present separator can separate and concentrate effectively very fine magnetic particles and poor-magnetic particles that could hardly be separated in the conventional magnetic separators. Specifically, the instant magnetic separator can separate particles of smaller than 1 micron in size.

Hereinafter, some embodimental magnetic separators, having been constructed in accordance with the present invention, will be described with test data thereof.

EXAMPLE 1

Model A magnetic separator of the arrangement as shown in FIG. 1A including: a stationary magnet device comprising eight permanent magnet bodies each consisting of three discal anisotropic ferrite permanent magnets of 798 mm diameter and 12 mm thickness with a cut away or recess of 110° open angle, and nine yokes of 798 mm diameter and 6 mm thickness with a cut away or recess of 110° open angle, these permanent magnet bodies and yokes being aligned alternately in the axial direction in side-by-side arrangement with their cut aways registered; a rotary drum made of non-magnetic stainless of 800 mm inner diameter and 3 mm thickness; and soft iron balls of 10 - 11 mm diameter employed as the first group of induced poles.

Table 3 shows the results of a separation test done in connection with above Model A magnetic separator of the present invention and one typical conventional magnetic separator as shown in FIG. 9 by use of the same raw particles, where the raw material used in the test was fine powder obtained by grinding ore and adding fine ferro-nickel thereto the powder size of which was in the order that a comb of 20 microns passes 80% of the total. In the actual separation process, double separation steps were performed with respect to the conventional separator, while a single separation step was performed in Model A separator, where the "Concentrate" in Table 3 defines the twice separated and concentrated magnetic particles and the "Tailing" defines the sum of non-attracted remainder in the two separation processes in the conventional separator.

Table 3

| Machine | Product | * | Weight percentage (%) | Ni Content (%) | Ni Recovery (%) |
|--------------|-------------|-----|-----------------------|----------------|-----------------|
| Conventional | Feed | 100 | 100.0 | 0.64 | 100.0 |
| | Concentrate | | 10.6 | 2.92 | 48.3 |
| | Tailing | | 89.4 | 0.37 | 51.7 |
| Model-A | Feed | 100 | 100.0 | 0.64 | 100.0 |
| | Concentrate | | 18.4 | 2.73 | 78.3 |
| | Tailing | | 81.6 | 0.17 | 21.7 |

* processed amount per unit weight of the first group of induced poles (Kg/hr/10Kg)

As will be noted from the data in Table 3, the Model A separator according to the present invention is superior to the conventional magnetic separator in that the processable amount is higher than that of the conventional separator, and, since the data of Model A show the results of the single separation process, the present magnetic separator has been improved over the conventional separator in terms of separation performance and separation efficiency.

In this Example 1, the first group of induced poles having ball configuration were used, whereas similar results to those as shown in Table 3 were obtained when the first group of induced poles having other configurations, such as rod, ring or endless chain or net were used.

EXAMPLE 2

Model B₁ magnetic separator including: a stationary magnet device comprising eight permanent magnet bodies each consisting of three anisotropic ferrite magnets of 798 mm diameter and 14 mm thickness with a cut away of 45° open angle, and nine yokes made of soft-iron of 798 mm diameter and 6 mm thickness with a cut away of 45° open angle, these permanent magnet bodies and yokes being aligned alternately in the axial direction in side-by-side arrangement with their cut aways registered; and a rotary drum as shown in FIG. 10 made of non-magnetic stainless having an 800 mm inner diameter and 4 mm thickness which was cut off in portions of the outer periphery corresponding to the yokes to produce rectangular recesses each having 6 mm width and 200 mm length with the circumferential spacing of 10 mm, in which rectangular recesses, strip-shaped high permeable stainless plates of the same dimension as that of the recesses were fitted to provide the second group of induced poles while keeping the drum surface even.

Model B₂ magnetic separator having the same dimension and arrangement as those of Model B₁ separator above except that Model B₂ was devoid of the second group of induced poles so that the rotary drum was made wholly of stainless steel.

Table 4 shows the results of separation test performed in connection with Model B₁ and Model B₂ above without use of the first group of induced poles where the raw material used in the test was fine powder obtained by grinding ore and adding fine ferro-nickel thereto, the powder size of which was in the order that a comb of 20 microns could pass 80% of the total, and the density of pulp was set at 60%. In Table 4, the "Concentrate" is the amount of magnetically attracted and collected particles in the single separation process and the "Tailing" is the amount of particles not attracted magnetically.

Table 4

| Machine | Rate of Feed (Kg/hr) | Ni Content (%) | | | Ni Recovery (%) |
|----------------------|-------------------------|----------------|-------------|---------|-----------------|
| | | Feed | Concentrate | Tailing | |
| Model B ₂ | 1,300 | 0.71 | 2.03 | 0.52 | 36.0 |
| | 2,700 | 0.71 | 2.19 | 0.60 | 21.3 |
| | 5,300 | 0.71 | 2.27 | 0.64 | 9.8 |
| Model B ₁ | 2,700 | 0.71 | 1.43 | 0.41 | 59.3 |
| | 5,300 | 0.71 | 1.72 | 0.42 | 54.1 |
| | 10,700 | 0.71 | 2.15 | 0.44 | 47.8 |

As will be noted from the data in Table 4, the separator including the rotary drum with the second group of induced poles provides an increased amount of material processing.

In this Example 2, the second group of induced poles which are strip-shaped stainless plates of high magnetic permeability are used, whereas similar result to those as shown in Table 4 are obtained when continuous ring members are used as the second group of induced poles.

EXAMPLE 3

Model C₁ magnetic separator having an arrangement as shown in FIG. 1A and similar to Model B₁ separator in Example 2 except that one layer of soft-iron balls of about 10 mm diameter, plated on its surface with nickel of high magnetic permeability, were densely attached to the outer periphery of the rotary drum by means of adhesive to provide the first group of induced poles.

Model C₂ magnetic separator similar to the Model C₁ separator except that soft iron balls of about 10 mm diameter were employed in the Model B₂ separator in Example 2 was used.

Table 5 shows the results of separator test performed upon the Model C₁ and Model C₂ separators, where the raw material used in the test was fine powder obtained by grinding ore and adding fine ferro-nickel thereto, the powder size of which was in the order such that a comb of 20 microns could pass 80% of the total, and the density of pulp was set to 30%.

Table 5

| Machine | Product | * | Weight Percentage (%) | Ni Content (%) | Ni Recovery (%) |
|----------------------|-------------|----|-----------------------|----------------|-----------------|
| Model C ₂ | Feed | 90 | 100.0 | 0.60 | 100.0 |
| | Concentrate | | 39.8 | 1.19 | 78.9 |
| | Tailing | | 60.2 | 0.21 | 21.1 |
| Model C ₁ | Feed | 90 | 100.0 | 0.60 | 100.0 |
| | Concentrate | | 47.9 | 1.10 | 87.9 |
| | Tailing | | 52.1 | 0.14 | 22.1 |

Remark: * processed amount per unit weight of the first group of induced poles (kg/hr/10kg)

As will be noted from the data in Table 5, by combining the first and second groups of induced poles, the separation performance and efficiency of the magnetic separator are remarkably improved.

What is claimed is:

1. A wet type magnetic separator for separating magnetic particles from raw material particles, said separator comprising a generally cylindrical stationary magnet device in the form of a cylindrical body having a cut

away recess opening from the top of the cylindrical body to one side along its periphery and having an axis which is fixed substantially horizontally, said cylindrical body consisting of a plurality of sets of multiple discal permanent magnets each having a cut away recess and discal yokes each having a similar configuration to said magnets, said plurality of sets of permanent magnets and said yokes being coaxially mounted side by side with their cut away recesses coinciding and being assembled into an integral body with the sets of permanent magnets sandwiched between said yokes so that adjacent yokes have opposite polarity to each other, rotary drum disposed coaxially with and rotatable about and in close proximity to said stationary cylindrical body, said rotary drum including axially spaced nonmagnetic material portions separated by circumferential strips of material of high magnetic permeability, said strips being in alignment respectively with said yokes and forming low reluctance paths for the magnetic field across the gap between the drum and said cylindrical body and defining a first group of induced poles, and a single continuous layer of induced poles provided on the immediate outer periphery of said drum overlying said first group of induced poles and forming a second group of induced poles spanning the complete length and the periphery of the drum opposite at least the non-cut away portion of said cylindrical body; whereby, said magnetic particles are effectively separated from the nonmagnetic particles contained within raw material particles directed onto the rotary drum periphery during rotation thereof.

2. The wet type magnetic separator as specified in claim 1 wherein said second group of induced poles comprises ball members.

3. The wet type magnetic separator as specified in claim 2, further comprising a curved net disposed close to said rotary drum and covering at least the lower half portion of the peripheral surface thereof for preventing said second group of ball members from breaking away from the rotary drum surface, and holder plates se-

cured to the rotary drum surface to push said members in the rotation direction of said rotary drum and to maintain the same in position thereon.

4. The wet type magnetic separator as specified in claim 3, wherein said net covers the whole surface of said rotary drum and is fixed to said rotary drum so as to rotate therewith.

5. The wet type magnetic separator as specified in claim 1, wherein said second group of induced poles comprises rod members.

6. The wet type magnetic separator as specified in claim 1, wherein said second group of induced poles comprises at least one endless net holding capsule shaped members closely connected together in a lattice arrangement on the drum periphery.

7. The wet type magnetic separator as specified in claim 1, having means for adhering said second group of induced poles to the periphery of said drum.

8. The wet type magnetic separator as specified in claim 1, further comprising a raw material supplying device disposed near the top of said rotary drum, a first hopper device disposed in a first section of the circumferential path of said rotary drum for catching nonmagnetic particles of the supplied raw material, a second hopper device disposed in a second succeeding section of the circumferential path of said rotary drum for catching magnetic particles of the supplied raw material, a radial partition board for isolating said first and second hopper devices, and shower devices disposed in the vicinity of the outer periphery of said rotary drum for first adhering magnetic particles from among the raw material to the surface of the rotary drum and for secondly functioning to enhance separation of the magnetic particles from the rotary drum.

9. The wet type magnetic separator as specified in claim 1, wherein said second group of induced poles comprises at least one endless net holding ball members closely connected together in a lattice arrangement on the drum periphery.

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