

Dec. 8, 1925.

1,564,731

J. WEATHERBY

METHOD AND APPARATUS FOR SEPARATING ORE PARTICLES

Filed July 21, 1922

4 Sheets-Sheet 1

Fig. 1.

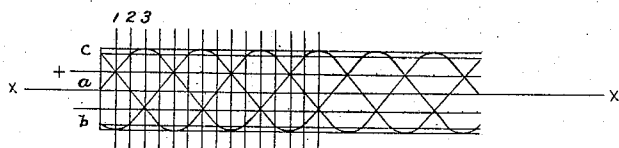


Fig. 2.

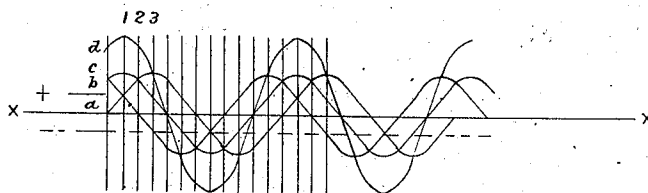


Fig. 3.

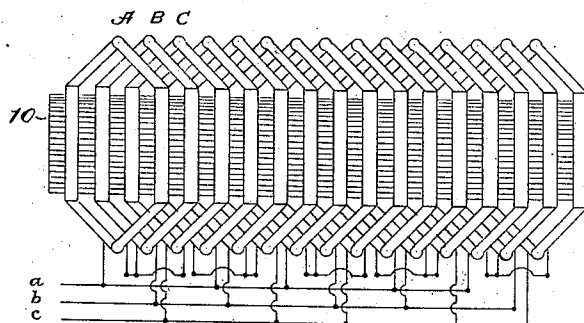
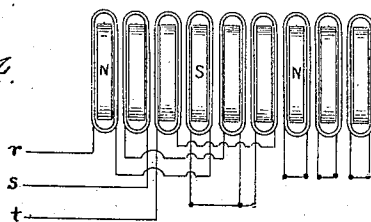


Fig. 4.



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4 Sheets-Sheet 2

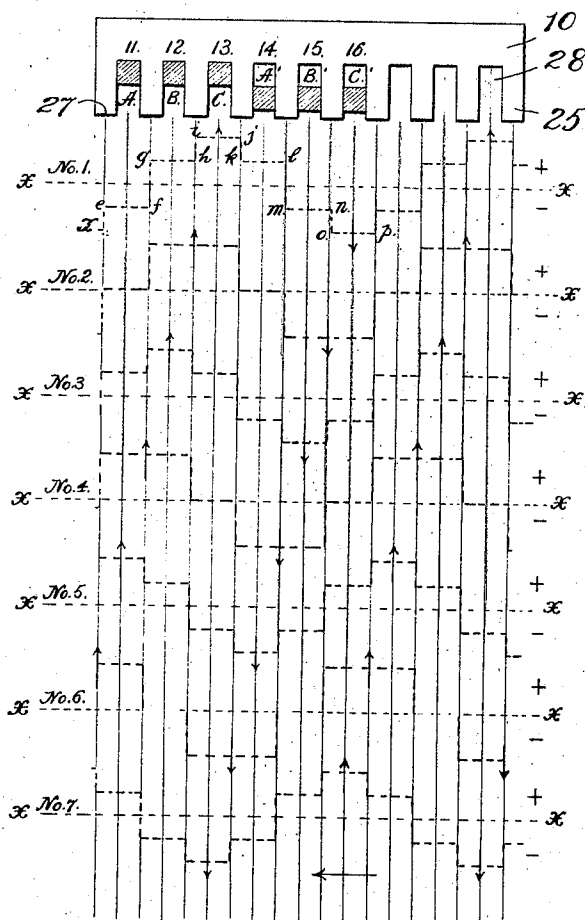


Fig. 5.

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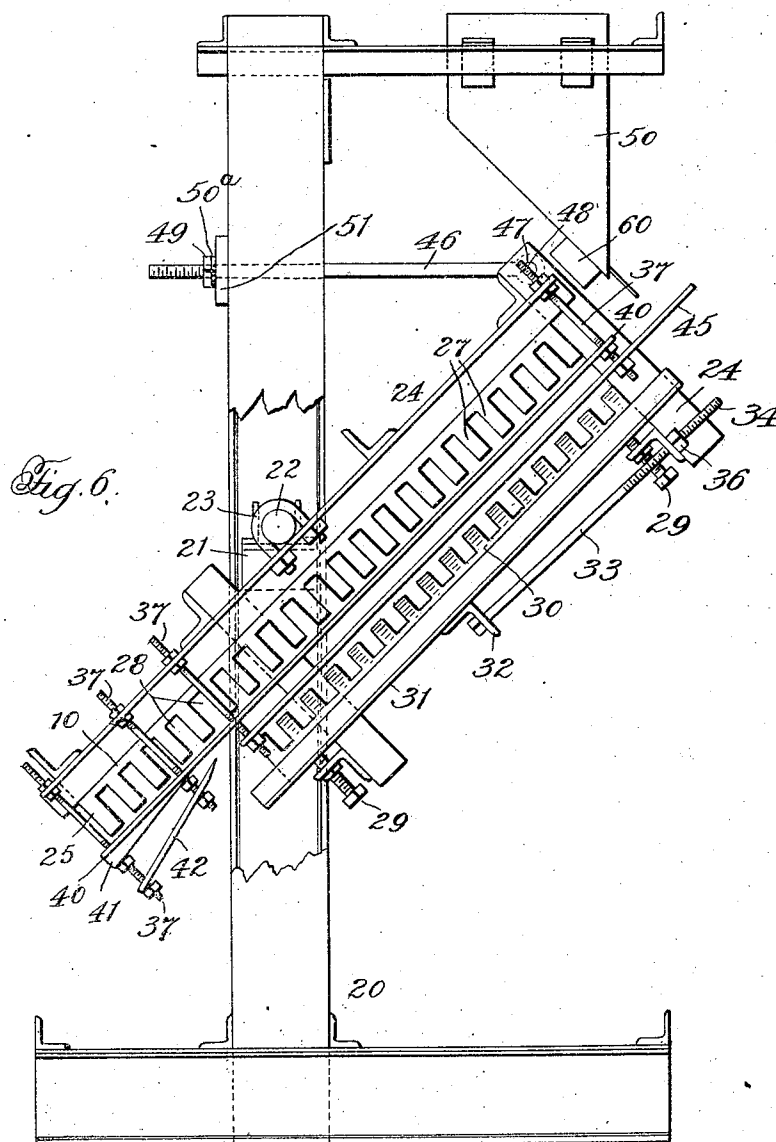
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4 Sheets-Sheet 3



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METHOD AND APPARATUS FOR SEPARATING ORE PARTICLES

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4 Sheets-Sheet 4

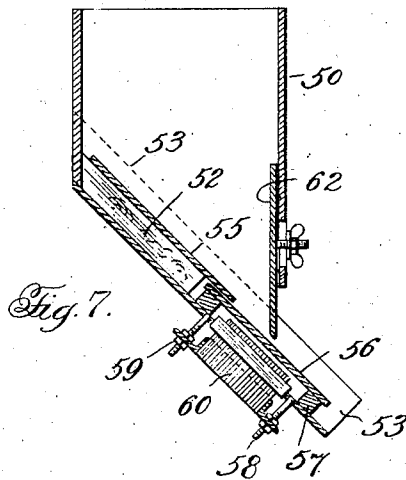


Fig. 8.

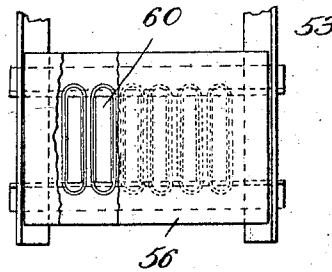
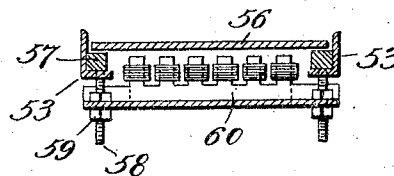


Fig. 9.



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Patented Dec. 8, 1925.

1,564,731

UNITED STATES PATENT OFFICE.

JOSEPH WEATHERBY, OF NEW CUMBERLAND, PENNSYLVANIA, ASSIGNOR, BY DIRECT AND MESNE ASSIGNMENTS, TO WEATHERBY ORE SEPARATOR COMPANY, OF PHILADELPHIA, PENNSYLVANIA, A CORPORATION OF DELAWARE.

METHOD AND APPARATUS FOR SEPARATING ORE PARTICLES.

Application filed July 21, 1922. Serial No. 576,622.

To all whom it may concern:

Be it known that I, JOSEPH WEATHERBY, a citizen of the United States, residing at New Cumberland, in the county of Cumberland and State of Pennsylvania, have invented certain new and useful Improvements in Methods and Apparatus for Separating Ore Particles; and I do hereby declare the following to be a full, clear, and exact description of the same, reference being had to the accompanying drawings, forming part of this specification.

My invention relates to an improved method of separating ore particles from their gangue, and one ore from another, depending on their susceptibility to alternating current magnetic flux and their permeable or nonpermeable qualities.

My invention more particularly relates to the separation of ore particles from their gangue and of one particular ore from another, by the use of multi-phase alternating current in the type of magnetic separator shown in drawings attached and described in the following specification.

I have found that by passing an alternating magnetic flux through most minerals and metals, a counterelectro-motive force is set up within such minerals and metals regardless of their magnetic permeability, but seemingly dependent on ohmic resistance and what I will term responsive frequency and also a power factor of the mineral or metal at certain frequencies.

For instance, a piece of iron is attracted to an alternating current magnetic pole and pulsates in step with the frequency, while a piece of copper is repelled away from the pole due to the counter-electromotive force set up within it and in accordance with Lenz's law that "Electromagnetically induced currents always have such a direction that the action of the magnetic fields set up by them tends to stop the motion which produces them." A further form of Lenz's law is that "An induced current is always in such a direction that its field opposes any change in the existing field" this explaining why copper or other non-magnetic metals are repelled by an alternating field, while

iron due to its magnetic permeability is attracted.

I have further found that all magnetic permeable substances such as would be attracted by a hand magnet, respond to an alternating current magnet with a varying degree of speed dependent on their reluctance and the frequency used, i. e., if three or more magnetic substances be mixed together, such as ore particles from different localities, iron filings, etc., all will jump and strongly adhere to a hand magnet and they all appear to be equally attracted, but if these same particles are subjected to an alternating magnetic field, they will not all respond alike to the magnetic attraction for while one may respond quickly to a certain alternating frequency another would be sluggish and still others would only vibrate in the field.

By changing the alternating magnetic frequency to a slower rate however these sluggish or reluctant particles will respond quickly to the attraction. This may possibly be due to other causes, but I will herein call it the responsive frequency of the ore particle, or the frequency to which the ore particle will best respond. Particles of a high magnetic permeability respond to an alternating field much more feebly than those of low permeability, and this must be borne in mind, to avoid confusion between magnetic permeable ores and non-magnetic metallic substances in the following specification.

Some magnetic ore particles will respond freely to 25 cycles and feebly to 60 cycles alternating current field, while a piece of copper or aluminum or other non-magnetic metal which is of minus permeability will be repelled violently, seemingly dependent upon their ohmic resistance or capacity and not upon their magnetic qualities.

A magnetic ore particle having an alternating current magnetic flux passing through it will respond with a counterflux either in phase with the current that energizes it, or lagging behind the current at an angle determined by the power factor of that ore particle. The ore particle will be

quick or sluggish dependent upon the frequency that energizes it and if its responsive frequency is lower than the frequency that energizes it then it will lag to the alternating magnetic attraction.

If an ore particle's responsive frequency is faster than that of another ore particle it can be separated from such other ore particle by the fact of it responding to magnetic attraction away from the reluctant particle. If one ore particle has magnetic permeability and another one has minus magnetic permeability but is metallic, then the one particle is attracted and the other one is repelled, and both can be separated from a gangue material which is neutral to electrical or magnetic action.

I have now described the action of minerals and metals influenced by an alternating magnetic flux, and will now describe them and their action when they are influenced by several alternating currents spaced apart, but acting as a whole, and known to the art as multi-phase alternating currents.

Reference will be made to the attached drawings which describe the positions of currents and magnetism at various instances, together with mechanical devices to take advantage of the phenomena for the useful purpose of separating minerals one from the other as will hereinafter be clearly described.

Three phase alternating current is used to describe this case as it is most convenient for this purpose, but it is to be understood that any multi-phase current answers equally well when suitable electrical connections and arrangements are provided.

Figure 1 is a sine wave diagram of three phase alternating current.

Fig. 2 is a diagram combining the three phases to form one magnetizing current.

Fig. 3 shows the diamond shaped overlapping coils of the field magnets where one side of the coil is in the top of one slot of the field magnet, and the other side of the coil in the bottom of a further slot to form north and south poles, and also showing the electrical connections suitable for three phase alternating current.

Fig. 4 shows a section of an armature with its single pole wound coils and electrical connections.

Fig. 5 is a cross section through the core and coils of Fig. 3 with one side of each coil in the bottom of one slot and the other side in the top of a following slot, also showing instantaneous values of the magnetic field.

Fig. 6 is a side elevation of the separator.

Fig. 7 is a central vertical elevation of the alternating current magnetic feed hopper.

Fig. 8 is a fragmentary view of the feed hopper looking down at the magnets that

energize the diaphragm that keeps the ore in motion.

Fig. 9 is a cross section thru the hopper armature.

A multi-phase current is a rotating or a progressing current, that is, one current follows another spaced a definite distance apart, as for instance as shown in Fig. 1 which illustrates a sine wave three phase alternating current where each of the three alternating currents, *a*, *b* and *c* differ in phase by one third of a cycle or 120 electrical degrees. By reversing the direction of the current in the coils of one phase, *b* for example, from the direction of that in the other two phases these three currents are combined to form one magnetizing current and a rotating magnetic field such as that shown in curve *d* of Fig. 2 will result.

10 is a field magnet built of thin sheets of iron bolted together and arranged with teeth and slots as shown, and A, B and C are properly connected coils placed on the teeth or in the slots as shown in Figs. 3 and 4, the electrical connections to the coils being so arranged that the first coil A is connected to a phase lead, the second coil B is connected to *b* phase lead and the third coil C to *c* phase lead forming a rotating or progressing magnetic field. Permeable ore particles are attracted to the poles or teeth and are caused to progress with the rotating field to a discharge by no other mechanical means than the rapidly moving magnetic field, while minus permeable metallic particles are repelled from the advancing field.

This can best be described by referring to Fig. 5 which shows a cross section cut through the core and coils of field magnet, Fig. 3, with one side of each coil in bottom of slots 11, 12 and 13, and marked A, B, and C, and their other sides in the top of slots 14, 15 and 16, and marked A', B', and C', respectively. By means of Fig. 2 and Fig. 5 taken together it is possible to build up small pictures of the magnetic field from instant to instant and show how it moves in the core and air gap.

These small pictures, of which one series is shown in Fig. 5, can very well be compared to the individual small pictures of a moving picture film as they appear when the film is at rest, and the rotating magnetic field as it really exists could be compared to the same film when in motion and thrown on the screen.

A current is now assumed to be flowing in each coil, and the value of that current is taken from the curve marked with the same letter in Fig. 2. For example, at the time represented by the vertical line 1 in Fig. 2 curve *b* is at its maximum value, which is +1, because it is above the horizontal reference line, and curves *a* and *c* are each at a value of

+0.5 since they are half their maximum value and are also above the reference line X X. Similarly, at the time represented by the vertical line 2 which is called position 2 in Fig. 2 the values of a and b are +0.866 each and the c curve is at zero. The value 0.866 is obtained because the current curves are all what are known as sine curves and the reference points or positions 1, 2, 3, etc. are taken $\frac{1}{12}$ of a complete cycle apart. A complete cycle is 360 electrical degrees similar to the 360 degrees of a circle, and hence the reference positions 1, 2, 3, etc. are $\frac{1}{12}$ of 360 degrees or 30 degrees apart.

From a table of natural sines, it will be found that the sine of $30^\circ = 0.5$, sine of $60^\circ = 0.866$, sine of $90^\circ = 1$, sine of $120^\circ = 0.866$, sine of $150^\circ = 0.5$, sine of $180^\circ = 0$. Continuing from 180° to 360° the same values recur with a except that they have a minus sign since they are measured below the horizontal reference line. It is these values which are used in plotting the pictures in Fig. 5 and the values for the different positions.

Starting from any arbitrary point as at x Fig. 5, position 1, the line moves in direction and amount according to the value of the current in slot 11. Slot 11 contains the A coil and the value of the current is +0.5 as is shown by the vertical line position one, in Diagram 2 and since the direction of the plus is up, the line is drawn upward from x to e and ef is drawn horizontally representing by its height above x the current in slot 11, and the magnetic field at that point. From f the line goes up to g making fg twice as long as de because the B coil is in slot 12 and the value of the current in B coil is +1, or twice that in A, and the line gh is drawn horizontally, representing by its height above x the current in slot 11 plus slot 12 and therefore the magnetic field at that point. From h the line goes up to i because the C coil is in slot 13 and the current in the C coil as shown at that instant is +0.5. The line ij is drawn horizontally, representing its height above x the combined currents in slots 11 plus slot 12 plus slot 13 and therefore the magnetic field at that point.

From j the line drops down to k because the A' conductor is in slot 14 and the A' conductor is the other side of the A coil and hence the current in it is in the opposite direction of that of the A side. If the current in the A side was considered +0.5, the current in the A' side must be -0.5 and hence the curve drops down for a minus value from j to k . Similarly it drops twice as far from k to m since B equals +1 and therefore the other side of B coil or B' must equal -1. Following the curve in this manner to n and o , it completes one cycle of one north and south pole. The

north pole is considered as that part above the horizontal reference line and under the line g, h, i, j, k and l . The center of the north pole is indicated by the vertical arrow pointing up. The center of the south pole by the vertical arrow pointing down. In an actual machine the magnetic field would not have such sharp curves but would be smoothed out into practically a sine curve such as the current in Fig. 2, but for the purpose of illustrating the rotating field the square shouldered curves are to be considered as shown.

Seven positions of the three phase current are shown in Fig. 5 and it will be noted that the center of the north and corresponding south poles have traveled three slots to the left which in this case means 180 electrical degrees.

It will now be seen that if a magnetic or permeable substance be introduced into the influence of this rotating magnetic field, the substance will be attracted to the teeth or poles and will then advance or progress with, and in the direction of the progressing or rotating magnetic field at a speed dependent on the frequency of the electric current energizing the magnetic field.

If a non-magnetic, but a metallic substance, such as copper, silver, aluminum, zinc, etc. be introduced into the influence of this alternating rotating magnetic field, electric currents will be induced into them by the action of the alternating magnetic flux, and according to Lenz's law.

Since the magnet is a fixed body but the currents within are moving the magnetic field, the non-magnetic metallic substances acted upon are free to move. They are repelled away from the teeth or poles and move in an opposite direction to the rotating magnetic field at a speed dependent on the frequency of the magnetic current.

Types of separators suitable to the separation of magnetic or non-magnetic metallic substances from a gangue material, or one from another by the use of multi-phase alternating currents will now be described, with a further description of the ores and method of treatment in connection with such separators.

Reference will now be had to Fig. 6. On the inner sides of the uprights of the frame 20 are brackets 21 on which rests a shaft 22 which is free to turn on the brackets. Suspended from the shaft but rigidly blocked to it by U-bolts 23 is a frame work 24. Within the frame work, and comprising a part of it, is a field magnet 25 which is composed of many sheet iron punchings or laminations, securely compressed and bolted together to form units 26. The units are spaced apart to permit ventilation and radiation of heat and are more clearly shown in Figs. 7 and

8. The units are all bolted together to form a single field magnet. The field magnet 25 has many teeth that form poles 27 and slots 28 to accommodate the windings or coils. For the sake of clearness the windings are not shown in Fig. 6, but are shown in Figs. 3, 4 and 5.

Adjustably spaced below field magnet 25 and resting in the frame 20 on adjusting bolts 29 is an armature 30. The armature is a duplicate in construction of field magnet 25 with the exception as to length, it being shorter to permit the free discharge of ore concentrates. Across the base 31 of armature 30 and securely bolted to it is an angle bar 32. Holes are bored in angle 32 to accommodate the adjusting bolt 33 to slip through up to its head. At its other end 34 bolt 33 is threaded and passes through frame work 24 and is so arranged that by turning adjusting nut 36 the armature will slip forward or backward in the frame parallel with field magnet 25 permitting the proper adjustment with magnetic relation between the teeth or poles of the armature and the field magnet. By turning adjusting bolts 29 the armature 30 may be adjusted closer to or farther from field magnet 25, thus changing the air gap between them.

Adjustably hung below the field magnet 25 and supported from the frame 24 by adjusting hanger bolts 37 is a board 40 composed of a non-magnetic and non-metallic substance such as glass, wood or any suitable insulating composition. This board has two functions, one to keep the ore concentrate a proper distance from the pole teeth in the air gap, and second to provide a surface on the under side of which the ore concentrate follows the rotating magnetic field to a point of concentrate discharge.

Attached to the lower end of board 40 is a wedge shaped section 41 or the board can be bent or shaped at its lower end to conform. When the ore concentrate arrives at this section in its progression with the rotating magnetic field, it is forced to move farther away from the pole teeth and as the current at this section is weakened, the ore will freely drop away from the field to its discharge, being guided by the adjustable platform 42.

Directly above armature 30 and adjustably hung from the frame 24 by adjustable hanger bolts 37 is an ore feed distributing board 45. The functions of this board are to receive the ore to be treated or separated at its top, supporting the gangue material as it slides by gravity to its bottom discharge and supporting the ore at its proper distance between the field and armature in the air gap. This board can be independently adjusted toward or further away from the

armature or field. The armature can also be independently adjusted toward or further away from the feed board by adjusting bolts 29. Fastened to the upper part of magnet frame 24 is an adjusting bolt 46 having an eye 47 at one end through which a bolt 48 passes that holds it to frame 24 in such a way that it is free to turn, while the other end is threaded, and has a nut 49 and washer 50. This bolt passes through a hole in the projection 51 on frame 20 and is arranged so that by screwing the nut in one direction or the other the magnet frame 24 together with its enclosed members can be tilted on an angle to permit the free flow of ore by gravity down and over the feed board 45.

Mounted within the frame 20 at its top is an alternating current magnetic hopper 50 best shown in Figs. 7, 8 and 9. The hopper is so arranged that it will discharge its granular ore feed to the top of feed board 40. The hopper is actuated in such a way to prevent fine ores or granular materials from packing or arching, and permits an accurate and granular feed to pass under its gates even under severe conditions such as moisture in the feeding materials that tend to agglomerate and stick the feed materials in lumps, balls, etc. The ore or other feed material rests on the angular base 52 of the hopper box as shown. On each side and projecting from the lower part of the hopper are angle bars 53 which are reinforcement for the sides and support the bottom and the following mechanism.

In the bottom of the hopper is an iron plate 55 which acts as a lining and in turn projects over a vibrating spring, steel diaphragm 56. This diaphragm rests on and is fastened to corner blocks 57 in such a way that it is free to vibrate, and the blocks in turn are rigidly fastened to the inner legs of angles 53. Adjustable but securely hung from angle bars 53 by threaded stud bolts 58 is an alternating current magnet 60 composed of laminated iron punchings forming poles for the coils which energizes it. The coils can have either single phase or multi-phase alternating current to energize them, but as it is always possible to use single phase from a multi-phase circuit, single phase is preferred. The alternating current magnet is directly under the diaphragm and is adjustable to or away from it by the nuts 59 on the stud bolts 58. When the alternating current is switched on the windings or coils the diaphragm is attracted to the magnet and released from it by the action of the alternating current changing from positive to negative and violently vibrates it according to the frequency of the current that energizes the magnet. When the magnet 60 is adjusted toward or away from the

diaphragm 56 the vibrations are stronger or weaker.

The front of the hopper 50 has a gate 62 which is composed of some non-magnetic material such as brass. The gate is raised or lowered to or from the diaphragm to permit the proper feed of material to pass under it. It is also arranged to bisect the diaphragm so that a part of the diaphragm is inside and part outside of the hopper. On the part inside, the ore or other feed rests upon the diaphragm while the outside section guides the feed to the discharge. The action is as follows: The hopper 50 is filled with the granular ore or other material to be fed which rests partly on the bottom plate 55 and the diaphragm 56. The gate 62 is raised to permit a sufficient feed to pass under, between it and the diaphragm 56 and side walls. The current is switched on and the diaphragm violently vibrates. This vibration not only passes through the material resting on the diaphragm but also to the surrounding material, thus preventing packing and arching, and at the gate itself. The material no matter how finely ground will be violently agitated and will pass under the gate whether in a thin granular ribbon or in a thick stream. After passing the gate the discharge is still kept in granular shape and in motion by the outward extending portion of the diaphragm 56.

The field magnet alone may be used as a separator, and may be placed above or below an ore feed board, or by proper electrical connections the armature and field can be considered as one and arranged so that certain poles in the field, for instance, every other one, will be field poles for like adjacent poles in the armature and the following poles be armature poles to like field poles in the armature. That is, the susceptible ore particles following the rotating field will first jump up to a field magnet tooth or pole and then down to the next armature tooth or pole, which is changed to a field tooth or pole, and then up, and so on to a discharge as would be the case in Fig. 6 if single pole coils were used as shown in section in Fig. 4, the first tooth in the field magnet having an A coil, the second tooth in the armature having a B coil, the third tooth in the field having a C coil, the fourth tooth in the armature having an A' coil, etc., all the coils being properly connected together in proper phase relation while the coils on the teeth between can have their coils short circuited, thus forming armature teeth or poles for either section. The object of the armature is merely to intensify or concentrate the magnetic field to improve the power factor and further to increase the distance in which ore is susceptible to the field influence.

The field magnet 25 has coils and is connected as shown in section Fig. 3, while the armature 30 has single pole coils and is connected as shown in section Fig. 4. It will be noted that the diamond shaped coils on the field magnet are connected three phase star multiple. It is just as well to state here that the coils may be connected in any of the well known ways, such as in star series, delta, delta series, etc. It will also be noted that the armature coils in Fig. 4 are in part connected series star while the rest are closed circuited. Either type can be used on either armature or field to meet different conditions in the ore to be separated, as each type has peculiar features that can be used advantageously in various ways.

In the following description I describe the diamond overlapping coil on the field and the single pole coil on the armature, this being the preferable construction. Now consider that a three phase alternating current has been switched on the field magnet and current is flowing in all the coils A, B and C, etc. An adjustable resistance or an impedance is used on the last few coils of the field magnet to taper their magnetic strength in such a way that each following tooth or pole is weaker in magnetic strength than the one before it. This is done to permit magnetic susceptible ore particles to be released and to drop away from the rotating or progressing field. This is not necessary in the case of non-magnetic metallic substances as they are repelled by and away from the rotating field, while the magnetic substances are attracted to and advance with the rotating field.

No provisions have as yet been made for the connection of the terminal wires leading from the armature with the exception that the coils on the last three teeth or poles of the armature have their terminals short circuited or closed. Current is now flowing in all the field coils and all the teeth or poles are energized with a rotating magnetic field as was described for diagrams Fig. 5.

Magnetic flux is now flowing through the field magnet out the tips of the poles or teeth and across the air gap to the armature teeth through the armature, back through the teeth and air gap to the field poles or teeth again. This sets up a strong magnetic field in the armature teeth by induction which rotates in step with that of the field magnetism that energizes it. The current is alternating, therefore the magnetic flux alternates back and forth across the air gap at a speed equal to the frequency and the poles or teeth of both the field magnet and the armature reverse their polarity changing from north to south and back to north again very rapidly, as for instance in 60

cycle current they would change polarity 7200 times per minute.

When the coils on the armature are open circuited no current flows through them.

5 The armature iron is magnetized by the field flux flowing through it. Magnetic permeable particles have a tendency to bridge between the armature poles and the field poles, even though they are spinning in step
10 with the frequency.

When the armature coils are closed circuited as shown in the last three coils of Fig. 4, current flows in them causing a counterflux to be set up in the armature
15 which opposes the field flux that energizes it, thus causing the permeable ore particles to be repelled in the direction of the field poles as they travel with the rotating field.

Since non-magnetic metallic substances
20 are repelled away from the magnetic field in any case, it makes little difference whether the armature coils are open or closed for non-magnetic metallic substances. By intermittently opening and closing the armature coils permeable ore particles are caused
25 to jump up and down violently during their progression, as well as to spin thus freeing themselves from the gangue material which tends to adhere to them.

30 It will now be considered that all the armature coils are closed circuited and that the field magnets are tilted to such an angle that ore will freely flow down the feeder board 45 in the air gap between the field
35 and armature, to a discharge.

It is to be noted that there are no moving parts on this type of separator and that all ore moves by gravity alone, or is forced to
40 travel with or against gravity by the rotating magnetic field.

The gate of the hopper 50 is now opened and a granular stream of ore permitted to flow to the feeder board 45. The gangue material which is non-metallic and is not affected by the alternating current flux, flows
45 down the feeder board to its discharge at the bottom.

The permeable magnetic particles on entering the field even though they are as fine as dust, have natural polarity and will start to spin rapidly when the alternating flux passes through them trying to present their poles in proper relation to the lines of force,
50 thus freeing themselves from gangue material, and one from the other. They are also repelled from the armature poles and in the direction of the field poles and they are influenced to travel with the rotating
55 magnetic field. They travel down on the under side of spacer board 40 at great speed, much faster than the gangue that is flowing by gravity on the feeder board 45. When they reach the bottom of the spacer board
60 40 they are forced away from it by the

wedge shaped section 41 and as the current in the lower coils is tapered and weakened, they drop away from the rotating field to the discharge.

It often happens that magnetic materials
70 are sluggish and will not travel in step with the rotating field dropping back in phase or slipping, and in such a case it is required that a more violent agitation be imparted to the magnetic material traveling with the
75 rotating field. In such a case it is arranged that the armature coils be intermittently opened and closed, which causes the ore particles to violently jump up and down between armature and field as well as spin
80 while they are traveling to their discharge with the rotating field currents, as the armature is first attractive when the coils are opened and then repellant when the coils
85 are closed.

What I claim is:

1. The art of electrically separating magnetically permeable particles from gangue which consists in passing a mixture of particles and gangue between a progressive
90 multi-phase magnetic field and an induced field.

2. The art of electrically separating magnetically permeable particles from gangue which consists in passing a mixture of particles and gangue between two progressive
95 multi-phase fields.

3. The art of electrically separating magnetically permeable particles from gangue which consists in passing a mixture of particles and gangue between two progressive
100 multi-phase fields, the current in one of said fields being induced by the current in the other field.

4. The art of separating magnetic particles from gangue which consists in passing the mixture of particles and gangue across a multi-phase progressive field which moves with the path of the mixture, in
105 increasing the frequency of said field until maximum movement of the particles is secured, and in continuing the current in the field at said maximum responsive frequency.

5. The art of separating non-magnetic metallic substances from magnetic substances and from gangue which consists in passing the mixture over a relatively thin inclined non-magnetic surface under which is placed an electromagnet excited by a multi-phase alternating current so that the rotating or progressive field moves with the passage of the mixture down said inclined surface.
115

6. The art of separating magnetic ore particles from gangue which consists in passing a mixture of gangue and particles between a multi-pole electromagnet and an armature, said magnet having a multi-phase
120 progressive magnetic field moving parallel

to the path of said mixture, said armature being particle-repellant.

7. The art of separating magnetic ore particles of different permeabilities which consists in passing a mixture of such particles successively past multi-phase rotating fields of different frequencies.

8. The art of electrically separating magnetically permeable particles from gangue which consists in passing the mixture of particles and gangue through the margin only of a progressive field moving in the direction of material flow.

9. The art of electrically separating magnetically permeable particles from gangue which consists in passing the mixture of particles and gangue through the curved portions only of the lines of force of a progressive field moving in the direction of material flow.

10. The art of electrically separating magnetically permeable particles from gangue which consists in passing the mixture of particles and gangue between two progressive fields moving in the direction of the flow of the material while restraining said mixture from crossing the straight and nearly straight portions of the lines of force of each of said fields.

11. The art of electrically separating magnetically permeable particles from gangue which consists in passing the mixture of particles and gangue between two insulating surfaces, each spaced from a progressive field whereby the mixture is constrained to move in the region of the curved lines of force of each field.

12. The art of electrically separating magnetically permeable particles from gangue which consists in passing the mixture of particles and gangue along a non-metallic surface spaced from a progressive field whereby the mixture is caused to move in the margin only of said field.

13. In a separator, an electro-magnet core having parallel teeth, windings for said teeth, multi-phase alternating current for energizing said coils to produce a moving magnetic field, and a non-magnetic plate below the toothed pole faces and providing a guiding surface for the material being separated.

14. The device of claim 13 characterized by the plate being adjustable toward and away from the magnet.

15. The device of claim 13 in combination with an armature for the magnet.

JOSEPH WEATHERBY.