United States Patent

[11] 3,618,864

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[54] **METHODS OF COMMINUTING PARTICULATE MATTER**
20 Claims, 8 Drawing Figs.

[52] **U.S. Cl.** **241/19,** 241/20, 241/43, 241/115
[51] **Int. Cl.** **B02c 15/08,** B02c 4/10, B02c 15/00
[50] **Field of Search** 241/19, 20, 43–45, 46.02, 46.15, 47, 109–110, 115, 119, 121–122, 124, 131

[56] **References Cited**

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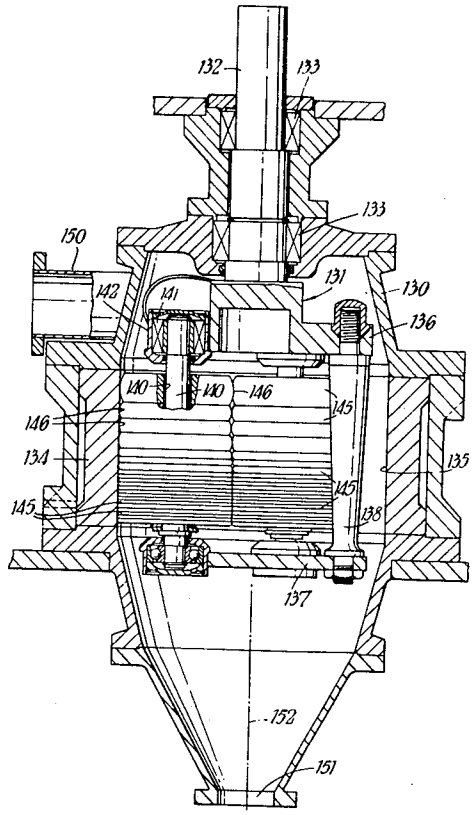
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Primary Examiner—Donald G. Kelly
Attorney—Pennie, Edmonds, Morton, Taylor and Adams

ABSTRACT: A method of comminuting particulate material in a mill having loosely mounted roller crushing masses that orbit inside a cylindrical chamber, the material being crushed between the masses and the chamber wall. The material is forced into one end of the chamber suspended in a carrier fluid, such as gas, liquid or a foamed substance, which is directed in a helical path along the chamber wall. The material in the carrier fluid is crushed progressively into smaller particles as it progresses through the chamber.



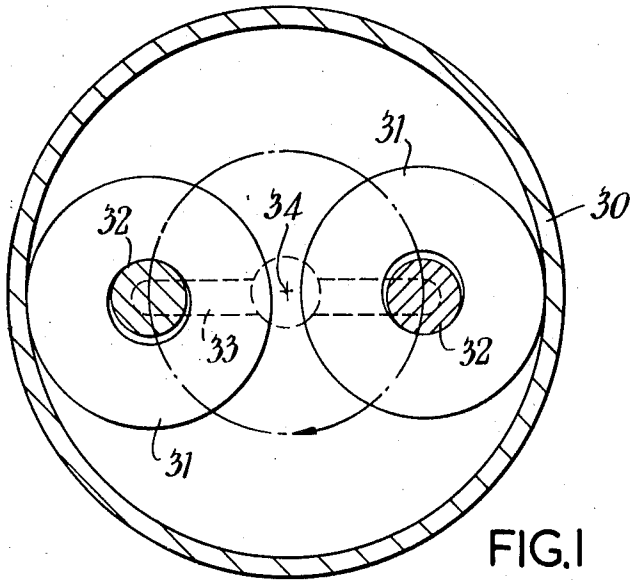


FIG.1

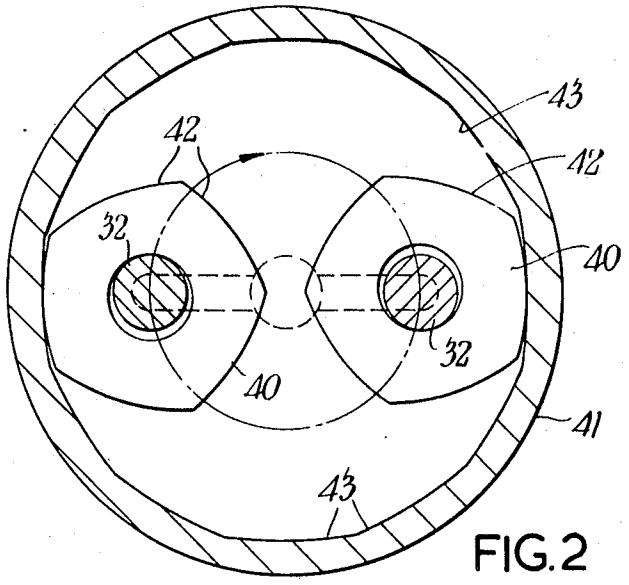


FIG.2

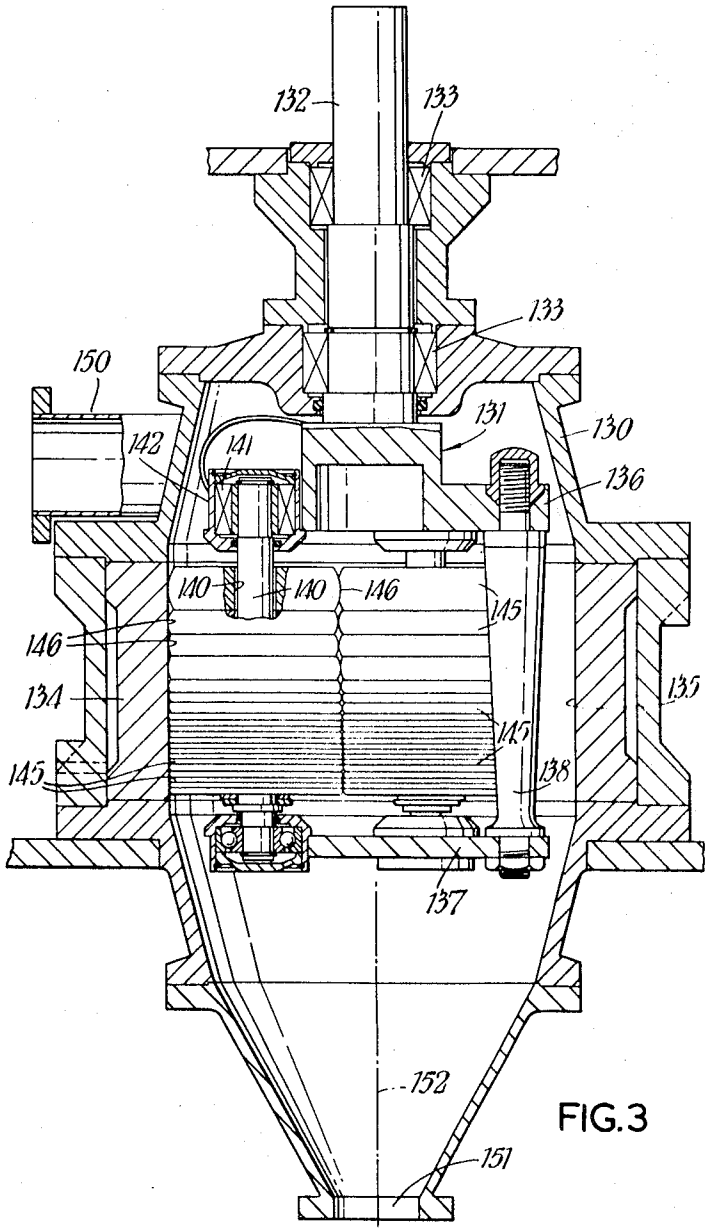

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FIG.3

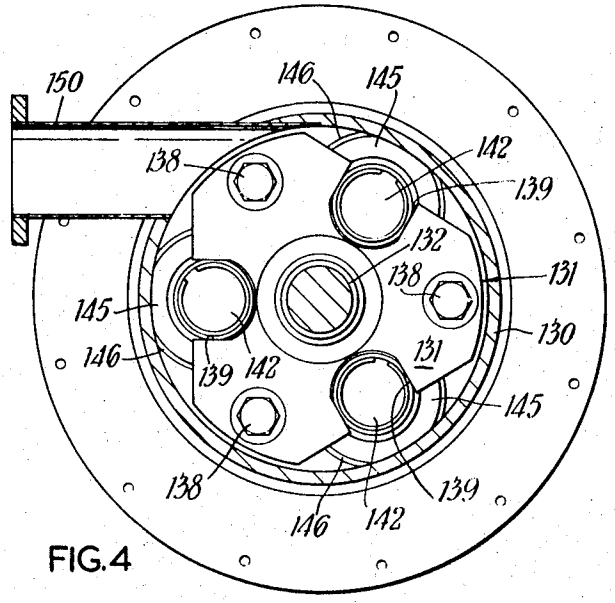

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FIG.4

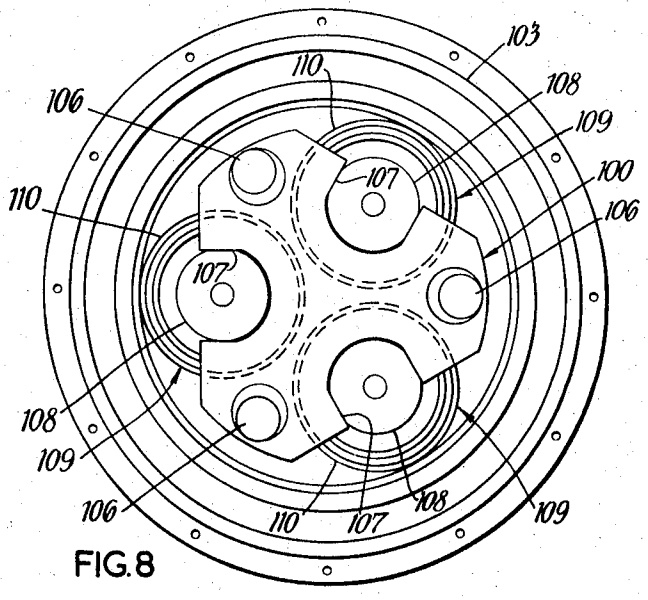

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FIG.8

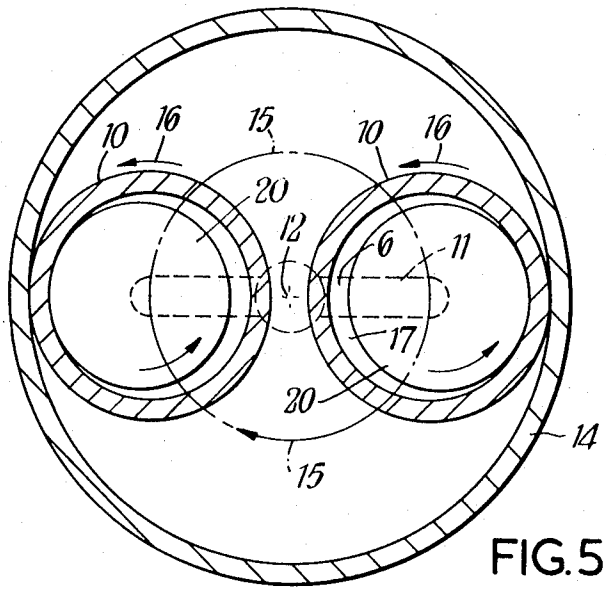

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FIG.5

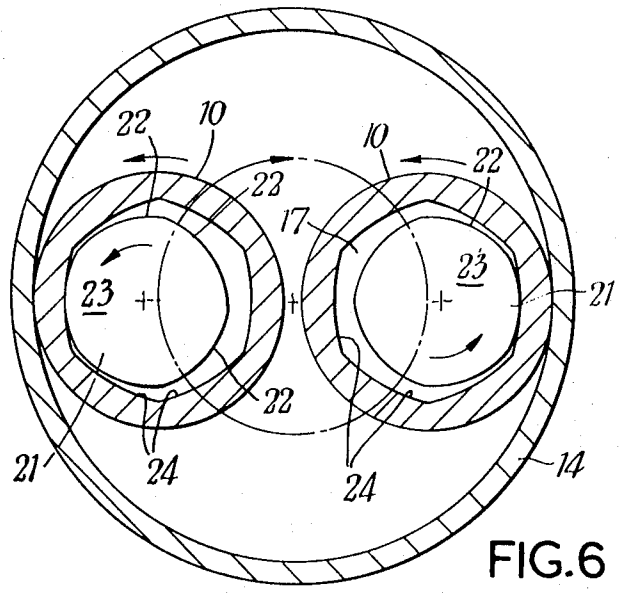

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FIG.6

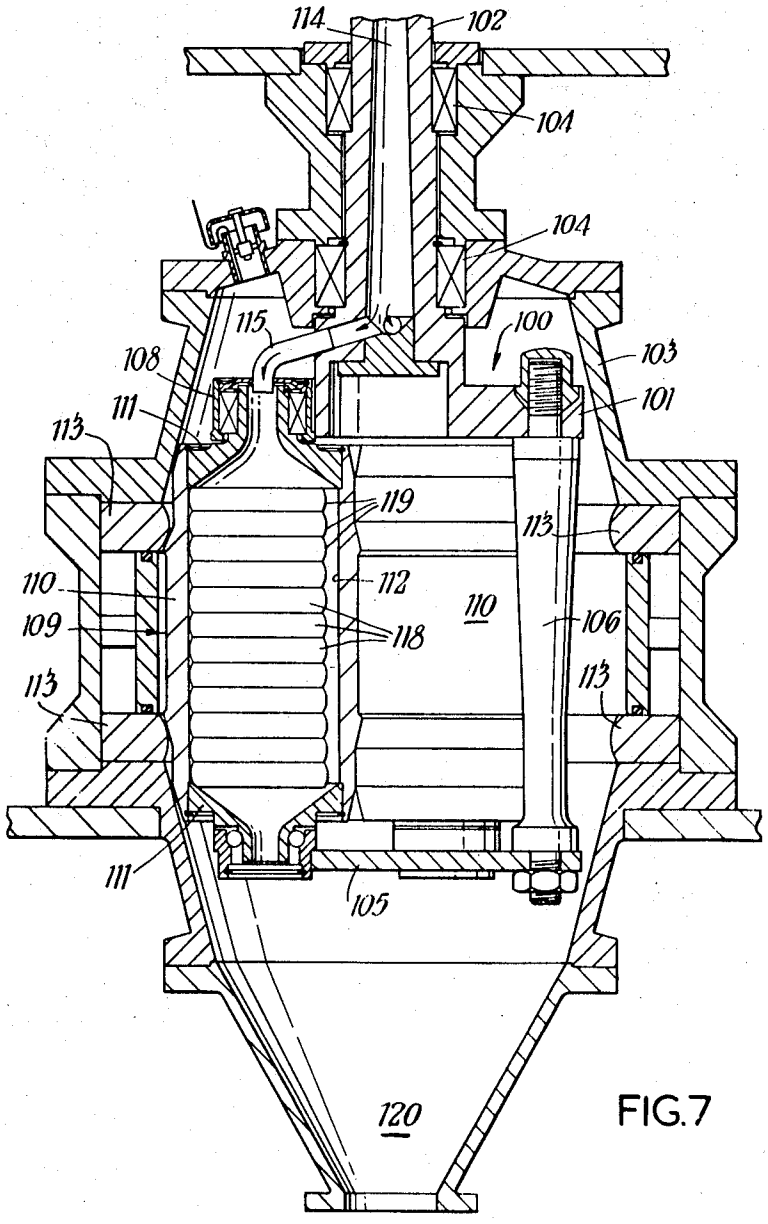

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FIG.7

METHODS OF COMMINUTING PARTICULATE MATTER

This invention relates to the comminution of particulate matter in roller-type mills and is concerned with providing both increased efficiency of comminution, that is to say increased rate of division of particulate matter to a more finely divided state in relation to power consumption of the mill, as well as the possibility of effecting a finer degree of comminution than can be achieved with ordinary ball or roller mills.

Comminuting mills are known having a crushing chamber with a wall formed by a surface of revolution and a number of disclike roller crushing masses arranged in stacks extending lengthwise of the chamber for following circular paths around the inside of the wall, the masses having freedom of movement for a distance radially inwardly of the wall. There is for example Guido Wenzel's German Specification No. 848,151 which shows such a construction. However, with that mill the material to be comminuted is merely dropped from a feed pipe into a trough that is rotating bodily with the carrier of the roller crushing masses. There is no positive stream of fluid that carries the material into the chamber in a vortex which gives the method of the invention its advantages as described below.

According to the principles of the present invention, the improvement is achieved by combining the actions of a properly designed centrifugal roller mill with a sweeping action of a carrier fluid which transports the particulate matter being comminuted from one end of the mill to the other in such manner that the particulate matter is, to some degree, self-classified as it is being comminuted. According to these principles, particles of like dimensions are subjected to intense pressures derived from cooperating surfaces in rolling contact with each other. These intense pressures cleave the particles into smaller particles. These smaller particles are then transported by the sweeping action of the carrier fluid to further cooperating surfaces which are in rolling contact with each other and again cleave the particles into even smaller particles. This process is repeated by as many further cooperating surfaces in rolling contact with each other as are required to produce the desired degree of comminution or smallness of the final product.

The material to be comminuted, already being in particulate or divided form, may be carried in a stream of air, a stream of neutral or inert gas, or in a flow of liquid, or even in a foam of gas bubbles dispersed in a liquid.

According to the present invention there is provided a method of comminuting particulate matter by a mill having a crushing chamber with a wall formed by a surface of revolution and a number of disclike roller crushing masses arranged in stacks extending lengthwise of the chamber for following circular paths around the inside of said wall, said masses having freedom of movement for a distance radially inwardly of said wall, characterized in that the particulate matter is carried into one end of said chamber and through to the other end of said chamber by a vortex of carrier fluid in such manner that a stream of particle-laden fluid follows a helical path along the wall and such that the roller crushing masses intercept the helical path of the stream of particle-laden fluid; the mass flow, the flow velocity and instantaneous directions of flow of the vortex of carrier fluid being proportioned in relation to the mass flow and initial mean size of the particulate matter so that the particles of material, as they are comminuted and made smaller by being crushed between the disclike roller crushing masses and the wall of the crushing chamber, are separated, with the more finely comminuted or smaller particles tending to move more rapidly in the component direction parallel to the axis of the crushing chamber than less finely comminuted or larger particles; the dimensions of the cooperating rolling members, their relative velocities with respect to each other and to the stream of particle-laden fluid being proportioned to maintain separation of the particles as they are comminuted and to ensure that particles comminuted at individual rolling paths spaced in the direction parallel to the axis of the crushing chamber tend to be of similar mean dimension.

In one embodiment of a roller mill which will achieve the self-classifying action which is the principle of the present invention, the roller masses are impelled to follow an orbital path around the central axis of the mill by a spinner, the roller masses being rotated as they follow this orbital path by frictional contact with the internal periphery of a stationary, essentially cylindrical, crushing chamber or, more properly, contact with particulate matter lining the internal periphery of said cylindrical crushing chamber and, at the same time, cleaving and comminuting the particulate matter by virtue of the crushing pressure derived from the centrifugal forces acting on the roller masses while they intercept the particulate matter lining the stationary internal periphery of the crushing chamber. In such an embodiment, the stream of carrier fluid bearing the particulate matter to be comminuted is brought into one end of the stationary crushing chamber in a direction which is essentially tangential to the internal periphery of the chamber. This sets the stream of carrier fluid into vortex motion, tending to fling the particulate matter which it bears into contact with the internal periphery of the stationary crushing chamber. The vortex motion, so created, is maintained by the impelling action of the spinner and roller crushing masses. The particulate matter is held close to the walls of the stationary crushing chamber only so long as it continues to spin in vortex motion and is, at the same time, subjected to the axial movement of the carrier fluid which moves (in helical paths) from one end of the mill to the other by virtue of the pressure difference existing between inlet and outlet of the mill. In general, the more finely comminuted particles will present a larger surface area to the carrier stream, in relation to their mass, than less finely comminuted particles and, since the centrifugal and frictional forces tending to retain the particles to the internal periphery of the crushing chamber are similar whether the particle be large or small, the more finely divided particles will more easily be swept along the mill in an axial direction than larger particles. A self-classifying action is thereby effected which removes already comminuted particles from one path of interception with the roller crushing masses to other paths further along the mill (in an axial sense) and tends to promote the effect where particles of similar size are being comminuted together at any given crushing path in the mill. If the roller crushing masses comprise stacks of coaxial discs, each disc free to move radially with respect to the central axis of the mill, the classified groups of particles (each group containing particles of different mean size from that contained by another group) will tend to be dealt with by individual discs at individual roller crushing paths spaced along the axis of the mill.

The efficiency of a mill constructed according to principles which promote the self-classifying effect, which is the essence of the present invention, is thereby enhanced in that comminution of larger particles finding themselves in one crushing path proceeds independently but simultaneously with comminution of smaller particles finding themselves in other crushing paths further along the mill. This principle promotes effective cleavage of the similar sized particles found at each individual crushing path (by virtue of the very high crushing pressures resulting from centrifugal multiplication of the masses of the individual discs which roll over them) and avoids attritive sliding between particle and particle and, more particularly between particle and wall of crushing chamber or between particle and periphery of the roller crushing mass or stack of discs. Avoidance of attritive sliding reduces generation of frictional heat, the production of which implies extra energy to drive the mill, and, at the same time, reduces unnecessary wear on the cooperating surfaces of the crushing members of the mill.

The self-classifying action, described above, is more effectively promoted in a preferred embodiment of roller mill where the crushing chamber, or rather a plurality of crushing chambers, rotates as well as the roller crushing masses. In this embodiment, apart from promoting more effective self-classifying action, the rate at which material can be put through a

mill of given size and be comminuted to a desired degree of fineness is greater than that in a similar sized mill with a single stationary crushing chamber because the number of crushing paths is increased and yet the crushing forces can be as great or greater by virtue of higher gyratory speeds and centrifugal forces acting on the roller (or stacked coaxial disc) crushing means. In this, preferred, embodiment, a plurality of essentially cylindrical crushing chambers are impelled to follow and orbital path around the central axis of the mill by a spinner, the crushing chambers being themselves rotated as they follow this orbital path by frictional contact with the internal periphery of fixed rings within the stationary body of the mill. Within each crushing chamber there are free roller crushing masses which will, preferably, comprise stacks of separate coaxial discs smaller in diameter than the internal diameter of the crushing chambers. These roller crushing masses will be rotated, in the same sense of rotation, as the crushing chambers by frictional contact with the particulate matter lining the internal peripheries of the crushing chambers and will cleave and comminute the particulate matter by virtue of the centrifugal forces derived from their orbital motion around the central axis of the mill in the same way as before. In this embodiment, the stream of carrier fluid bearing the particulate matter to be comminuted may be brought into the mill by a duct directed along the central axis of the mill, the duct rotating with the spinner which impels the crushing chambers (and the roller crushing masses which they contain) to follow an orbital path around the central axis of the mill. The duct branches into radially disposed pipes or smaller ducts each leading to one end of each crushing chamber, these smaller ducts forming in effect the channels of a centrifugal impeller and imparting both radial and tangential motion with respect to the central axis of the mill to the particulate matter as it leaves the ducts or channels. This combined radial and tangential motion carries the particulate matter against portions of the internal peripheries of the crushing chambers which are, instantaneously, remote from the central axis of the mill. On contact with the rotating internal peripheries of the crushing chambers, frictional forces will tend to drag the particulate matter along with the rotating internal peripheries of the crushing chambers. The particulate matter is thereby subjected to a complex of motions in space. The components of motion tangential to the surface of the crushing chambers will tend to hold the particulate matter against the internal peripheries of the rotating crushing chambers through centrifugal force derived from continuous inwardly deflected movement, (i.e. centripetal acceleration). Superimposed on these components of motion are components due to the orbital path of the crushing chambers themselves around the central axis of the mill, the latter components always tending to drive the particulate matter away from the central axis of the mill. The joint effect of the rotary and orbital motions creates forces which combine to hold the particulate matter firmly against those portions of the internal peripheries of the crushing chambers which are, instantaneously, remote from the central axis of the mill, but create forces which oppose each other and hold the particulate matter less firmly against those portions of the internal peripheries of the crushing chambers which are, instantaneously, closer to the central axis of the mill. As in the embodiment of the mill described earlier, where there is a single stationary crushing chamber, the carrier stream of air, gas, liquid or foam will move axially from the inlet end of the mill to the exit end and, in doing so, will tend to sweep the particulate matter in an axial direction from the inlet end to the exit end of each of the crushing chambers. As before, the more finely comminuted particles presenting larger surface area to the carrier stream in relation to their mass will tend to be swept preferentially in the axial direction towards different crushing paths presented by different discs in the coaxial stacks of discs forming the roller crushing masses. In this preferred embodiment, the self-classifying action is more certainly effected because the frictional drag of the particles against the internal peripheries of the rotating crushing chambers will tend to retain them against these peripheries until such time as they have been comminuted to small enough dimensions to present a large enough surface area in relation to their mass to be swept axially onwards by the carrier stream. Furthermore, the varying pressure of the particles against the internal peripheries of the crushing chambers due to the varying net centrifugal force (derived from the action of the mass of the particles themselves as they pursue the complex of orbital and rotary motion) tends to sort larger particles from smaller particles and expose the smaller particles to the carrier stream of fluid which always has a strong component of motion in the axial direction and will more rapidly pick up and carry further small particles presenting larger surface area in relation to their mass than larger particles.

In roller mills operating according to the self-classifying principles of the present invention, whether they be constructed according to the first described embodiment with a single stationary crushing chamber, or the later described embodiment with a plurality of rotating crushing chambers, the rate of comminution and degree of smallness of the final product will depend upon a large number of factors. These include the initial mean size and nature of the particulate matter, the nature and velocity of the carrier stream (or the pressure or head difference of this stream from the inlet to the outlet of the mill), the dimensions and rotational and orbital velocities of the roller crushing masses (or of the roller crushing masses and crushing chambers together in the later described embodiment), and the length of the mill or number of individual crushing paths, i.e. the number of individual discs in each stack of coaxial discs comprising one roller crushing mass. All these factors must be properly selected in order to achieve efficient comminution to the self-classifying principle of the present invention. With proper selection of these factors, the mill will be largely self-regulating in operation because fresh incoming particulate matter can only be admitted to the mill as rapidly as the more finely divided comminuted matter is carried out of the mill by the carrier stream of fluid and this material will not pass from one crushing path to the next until it is in a sufficiently finely divided state for the carrier fluid to sweep it onwards axially through the mill.

It is found possible with self-classifying mills, constructed and operated in accordance with the principles of the present invention to comminute material to mean particle size as little as 0.1 micron. Where malleable material is being comminuted, for example aluminum, tungsten, or alloys such as stainless steels, the comminuted material will be in the form of very thin flakes. The breadth/thickness ratio of such flakes may be as great as 50 to one or even 100 to one and the flake thickness can be as little as 0.01 micron. Where more brittle material is being comminuted, for example limestone, the comminuted product will be in the form of an amorphous dust.

The present invention of self-classifying roller comminuting mills may be carried into practice in numerous ways, but certain specific embodiments will now be described by way of example only with reference to the accompanying drawings in which:

FIG. 1 shows a diagrammatic plan section of a mill where two stacks of roller crushing masses perform rotary and orbital motion in contact with a single stationary crushing chamber;

FIG. 2 shows a diagrammatic plan section of a variant of the above;

FIG. 3 is a sectional elevation of a mill working on the principle of FIG. 1 or FIG. 2, but in this example incorporating three stacks of roller crushing masses;

FIG. 4 is a plan section through the mill shown in FIG. 3;

FIG. 5 shows a diagrammatic plan section of a mill where two crushing chambers and two stacks of roller crushing masses together perform rotary and orbital motions within a single stationary mill shell;

FIG. 6 shows a diagrammatic plan section of a variant of the above;

FIG. 7 is a sectional elevation of a mill operating on the principle of FIG. 5 or FIG. 6 but in this example incorporating three crushing chambers and three stacks of roller crushing masses;

FIG. 8 is a plan section through the mill shown in FIG. 7.

FIG. 1 shows diagrammatically a simple arrangement of an embodiment of mill which will effect the self-classifying principle of the present invention to some degree. There is a stationary crushing chamber **30**. Within this crushing chamber there are roller masses **31** which are loosely journaled on shafts **32** forming eccentric limbs of a spinner **33** whose axis of rotation is shown at **34**. Each roller mass comprises a stack of coaxial discs affording multiple lines (or points) of contact with the stationary crushing chamber **30**. The clearance between the bores of each of the coaxial discs forming the stack of roller masses **31** and the shaft **32** on which they are journaled provides the individual discs with the required freedom of radial movement so that, as the masses are urged into orbital motion about the axis **34** by the spinner **33** (driven by a motor not shown), the roller masses will be urged into engagement with the internal surface of the stationary chamber **30** by a centrifugal force and will be rotated about their own axis by frictional engagement with the chamber **30** so that they roll circumferentially around the internal surface of the chamber **30** with which they are in line (or point) contact.

FIG. 2 shows diagrammatically a modified form of the cooperating mill crushing members of the mill of FIG. 1 in which the roller crushing masses **40** are polyhedral in profile, their crushing surfaces being afforded by a series of part-cylindrical convex surfaces **42** which cooperate with concave part-cylindrical surfaces **43** forming the internal circumference of the stationary chamber **41**, the radius of curvature of each of the concave surfaces **43** being greater than the radius of the chamber **41** and also being greater than the radius of curvature of the convex crushing surfaces **42** on the roller crushing masses.

FIGS. 3 and 4 illustrate an embodiment of mill, operating according to the principles shown diagrammatically in FIG. 1, which will produce the desired self-classifying action of the present invention to some degree. The housing **130** of this mill provides support for a spinner **131** which is mounted on a shaft **132** journaled in bearings **133**. The crushing chamber **134** comprises a stationary cylinder mounted in the housing **130** and providing a cylindrical crushing surface **135**. The spinner comprises upper and lower end plates **136** and **137** held rigidly spaced apart by bolts **138** and three radial slideways **139** are formed in each end plate (shown in FIG. 4). Three shafts **140** are journaled in bearings **141** at top and bottom, the bearing housings **142** being slidably mounted in the slideways **139** so that the shafts can move radially through limited distance along the slideways **139**.

Each of the eccentric shafts **140** is threaded through oversize central apertures **144** in a stack of circular discs **145** all of equal diameter and, in this example, having convex part-spherical edge surfaces **146** constituting their crushing surfaces. The discs **145**, in this example, are of progressively smaller axial thickness from top to bottom in each stack.

An inlet duct **150** leads tangentially into the upper part of the housing **130** above the chamber **134** for the admission of a flow of carrier fluid (arranged for a flow of air or gas in this example) bearing the particulate matter to be comminuted in the crushing chamber. The carrier fluid, now bearing comminuted material, is discharged through a central discharge aperture **151** at the bottom of the housing.

The operation of the mill depicted as an example in FIGS. 3 and 4 is as follows. When the shaft **132** of the spinner **131** is driven by its associated driving motor (not shown), the three eccentric shafts **140** of the spinner will urge the three stacks of discs in an orbital path about the spinner axis **152** so that the discs will be individually urged radially outwardly by centrifugal force into contact with the cylindrical crushing surface **135** of the stationary chamber **134**. The radial slideways **139** and the oversize apertures **144** of the discs permit the discs to move radially freely into individual contact with the crushing surface **135** under centrifugal force. Moreover the frictional engagement of each disc with the crushing surface **135** (or, more properly, with particulate matter flung against that surface) under the normal pressure due to centrifugal force will cause the discs themselves to be rotated about their own axes on the eccentric shafts **140** so that the discs roll around the internal cylindrical surface **135** of the chamber as they are urged orbitally around the axis **152** by the spinner.

In this example, there are 21 discs progressively decreasing axial thickness in each stack, giving (in this example where the discs are shown with part-spherical edge surfaces) 21 regions of point contact of each stack with the chamber surface **135**, these points of contact lying in a straight line and (in this example) their spacing decreasing progressively from top to bottom (the mill being depicted in this case with a vertical axis). Crushing (or, more properly, cleaving) of the particulate matter takes place at all 21 points of contact of each stack as the three stacks of discs are rolled around the cylindrical surface **135**. Hence, as the particles being comminuted are passed progressively through the chamber from top to bottom (in this example), they will be progressively reduced in size by the successive rolling discs, each of which is free to exert its individual crushing or cleaving pressure under centrifugal force on the particles rolled between it and the chamber surface **135**. As the individual particles become progressively reduced in size, they require less energy for their continued reduction by subsequent discs.

The particulate matter is flung against the internal wall **135** of the crushing chamber by centrifugal force derived from the vortex motion of the carrier fluid, which motion is imposed initially by tangential entry of the carrier fluid bearing the particulate matter to the mill housing **130**, and which motion is maintained thereafter by continual urging from the spinner and the orbital motion of the roller crushing masses (the stacks of discs **145**). The stream of carrier fluid, as it pursues its vortex motion, will progress axially through the mill by virtue of pressure (or head) difference existing from the inlet to the outlet of the mill, and will thus tend to sweep the particulate matter along with it in this axial direction (as well as in a direction essentially tangential to the internal wall of the chamber **135**). Particulate matter which is in contact with the internal wall of the chamber **135** will tend to be retarded from vortex motion with the carrier stream and will also retard adjacent particles. Small, comminuted, particles will have a greater surface area in relation to their mass than larger, not yet so finely comminuted, particles. These small particles will be preferentially picked up and swept, in both tangential and axial direction with respect to the axis of the chamber **135**, by the carrier fluid. The larger, not yet so finely comminuted, particles will tend to remain to be intercepted by discs in the stacks of roller crushing masses **145** which are found closer to the inlet end of the mill, while the smaller, already comminuted particles will be swept in an axial direction (as well as a tangential direction) towards the paths of interception of discs in the stacks **145** which are found more remote from the inlet end of the mill. Thus, a degree of self-classification of the particulate matter is effected which promotes comminution of particles which are generally of similar size at any particular path of interception of individual discs in the stacks **145**. This, in turn, promotes pure cleavage of the particles by rolling action, under intense localized normal pressure, rather than the attritive sliding frictional actions which result when particles of widely differing sizes are comminuted together. This self-classification effect is the essence of the present invention.

The edge surfaces **146** of the individual discs comprising the stacks of roller crushing masses **145** have been illustrated in this particular example as having part-spherical form, thereby producing point contact with the cylindrical internal crushing surface **135** of the crushing chamber **134**. This part-spherical form may be desirable when comminuting hard materials where very high normal pressure is required to effect efficient (i.e. complete) cleavage of the particles. With materials which

are less hard, the edge surfaces 146 of the individual discs may be more nearly cylindrical, thereby producing line contact with the cylindrical crushing surface 135 and affording instantaneous contact with more than one particle per disc, but producing lower (but still very great) normal pressure.

The ratio between the diameter of the discs comprising the stacked roller crushing masses 145 and the internal diameter of the stationary cylindrical crushing surface 135 must be fixed with regard to the nature and the mean initial size of the particulate matter entering the mill to be comminuted so that the "angle of nip" (the angle between the tangent to the circumference of the discs and the tangent to the internal circumference of the cylindrical chamber wall) is fine enough to permit pure rolling rather than rolling and sliding of the cooperating crushing members. The variant of the form of these cooperating crushing members shown diagrammatically in FIG. 2 gives a wider choice in selecting this angle, for a mill of given dimensions, than is possible with the form of the cooperating crushing members shown diagrammatically in FIG. 1.

The above considerations of ratio of diameters of cooperating crushing members, taken together with the possibility of achieving the essential self-classifying effect to a higher degree and the ability to incorporate more crushing paths within a mill of given size, lead to preference for a slightly more complex manner of construction of the mill which is illustrated in the diagrams and embodiments now to be described.

FIG. 5 shows diagrammatically this more developed and preferred form of mill. Two (or more) hollow cylindrical crushing chambers 10 are loosely journaled with the separate eccentric limbs of a rotatable spinner indicated in chain lines at 11, and the spinner is mounted for rotation about its axis 12 by means of a driving motor (not shown). Thus, on rotation of the spinner by the driving motor, each crushing chamber 10 will be impelled into an orbital path around the axis 12 of the spinner. The loosely journaled mounting of each crushing chamber 10 with the spinner limb is designed to allow the chamber a limited freedom of radial movement whilst transmitting the drive to urge the chamber into an orbital path around the axis 12. The two crushing chambers 10 are enclosed within a stationary ring 14 secured to the housing of the mill so that, as the two chambers 10 are impelled orbitally around the axis 12, centrifugal force will urge them radially outwardly into frictional engagement with the stationary ring 14, the resultant frictional torque imposed by the ring on each loosely journaled mounted chamber 10 will cause each crushing chamber 10 to rotate about its own axis and the two chambers will roll around the internal circumference of the stationary ring 14 as they advance in their orbital path around the axis 12. The direction of rotation of the spinner and the direction of the orbital path taken by the crushing chambers is shown by the arrow 15 and the direction of rotation of the crushing chambers about their own axes is shown by the arrow 16.

Freely floating in each of the crushing chambers 10 is a roller crushing mass comprising a stack of circular, coaxial discs, 20, these discs being of smaller diameter than the internal diameter of the crushing chambers 10. As each chamber is impelled in an orbital path around the axis 12 by the spinner and as each chamber rolls around the stationary ring 14, the stacks of discs 20 will be urged radially outwardly from the axis 12 by centrifugal force towards the cooperating internal surface of their associated crushing chambers 10. Moreover, since the chambers 10 will themselves be rotating about their own axes, this rotation will apply a frictional torque to the stacks of coaxial discs 20 pressed against the internal rotating surfaces of the crushing chambers 10 whereby the stacks of discs 20 will also be rotated about their own centers and will roll around the internal surfaces of the rotating chambers 10. Particulate matter, introduced into each crushing chamber 10 in a stream of carrier fluid, will be flung against the internal walls of the crushing chambers and tend to be dragged around as these chambers rotate (being held to the internal walls of the chambers by centrifugal forces derived from the motion so imparted to the particles) and will form a layer of material intervening between the cooperating crushing surfaces presented, respectively, by the internal surfaces of the chambers 10 and the edge surfaces of the circular discs forming the stacks of roller crushing masses 20.

In the regions of multiple points (or lines) of contact between the individual discs forming the stacks of roller crushing masses 20 and the internal surfaces of the cylindrical crushing chambers 10, high normal pressure will be applied to the particles of material in the layer intervening between these respective crushing surfaces resulting in cleaving and comminution of the particulate matter by the rolling action of the cooperating crushing members 20 and 10. In this same region, the force holding the particulate matter to the internal walls of the crushing chambers 10 will be at its highest because the centrifugal forces derived both from rotation of the chamber 10 about its own axis and that derived from orbital motion of the same chambers about the central axis 12 of the mill will act in the same direction. In the regions, marked as 17, where the spaces between stacks of discs 20 and the internal peripheries of the crushing chambers 10 are largest, the force holding the particulate matter to the walls of the crushing chambers 10 will be lessened because the centrifugal forces derived from rotation of the chambers 10 about their own axes will be in opposition to the centrifugal forces derived from orbital motion of the same chambers about the central axis 12 of the mill.

FIG. 6 shows diagrammatically a modified form to the cooperating crushing members of the mill of FIG. 5 in which each of the roller crushing masses 21 is of polyhedral form having a series of (in this case 5) part-cylindrical convex crushing surfaces 22 each of greater radius of curvature than the radius of the roller crushing masses 21. The internal circumferential surface of each crushing chamber 10 is, in this case, formed by a greater number of part-cylindrical concave crushing surfaces 24 (in this case 6) each having a larger radius of curvature than the surfaces 22 of the roller crushing masses 21 and each being equal in arcuate width to each of the five convex crushing surfaces 22 on the roller crushing masses 21. Thus each roller crushing mass 21 can roll smoothly around the interior of its associated crushing chamber 10 with its convex crushing surfaces rolling, as it were, in meshing engagement with the concave crushing surfaces 24 of the chamber 10, there being line contact between the opposed surfaces 22 and 24 which are instantaneously in engagement with one another. This arrangement is useful where a large radius of curvature of the crushing surfaces is required without a corresponding increase in the dimensions of the mill.

FIGS. 7 and 8 illustrate a preferred embodiment of a roller comminuting mill, operating according to the principles shown diagrammatically in FIG. 5, which will produce the desired self-classifying action of the present invention to a higher degree than that possible with mills operating according to the principle shown diagrammatically in FIG. 1, and which affords a higher rate of comminution for a given size of mill than that previously described and illustrated by FIGS. 3 and 4.

In this construction, the spinner 100 comprises an upper portion 101 having an integral hollow shaft 102 journaled in the fixed housing 103 by means of bearings 104, and a lower portion 105 devoid of a shaft and secured in spaced relationship to the upper portion of the spinner 101 by means of shouldered bolts 106. The upper and lower spinner portions 101 and 105 afford radially directed slideways 107 in which are slidably mounted the bearing housings 108 for the three crushing chamber assemblies 109. Each crushing chamber assembly 109 comprises an elongated cylindrical sleeve 110 closed at top and bottom by a spigot end portion 111 and affording a cylindrical internal crushing surface 112. The chamber sleeves 110 cooperate with a pair of stationary rings 113 mounted in the fixed housing 103, the sleeves 110 being urged into frictional engagement with the stationary rings 113

by centrifugal force when the spinner impels them into an orbital path around the central axis of the mill by being rotated by its shaft **102**. The shaft **102** is formed with a central duct **114** from which extend three branch pipes or ducts **115** leading into the top spigot portions **111** of the three crushing chamber assemblies **109** for the purpose of introducing the stream of carrier fluid bearing the particulate matter to be comminuted into each of the crushing chambers for comminution therein. The roller crushing masses in each crushing chamber comprise stacks of coaxial circulate discs **118** (in this particular example twelve identical discs per stack are depicted). In this particular example, each disc has a convex part-spherical edge **119**, urged into point contact with the cylindrical crushing surface **112** by centrifugal forces as the spinner rotates (and the crushing chambers with the stacks of roller crushing masses **118** within them advance in an orbital path around the central axis of the mill), so that, in this case, the crushing process in each crushing chamber takes place at twelve regions of point contact. The stacks of discs **118** are rotated about their own centers by frictional engagement with the internal surfaces of the sleeves **110** (or, more properly, by frictional engagement with particulate matter lining the internal surfaces of said sleeves) so that the discs roll around the interiors of the rotating sleeves **110** of each chamber assembly, this rolling motion producing the desired cleaving and comminuting action at the twelve regions of point contact per chamber assembly under the crushing pressure afforded by centrifugal force acting on the stacks of discs **118**.

The particulate matter to be comminuted, carried by a stream of fluid is introduced into the mill through the central duct **114** in the spinner shaft **102**, and thence passes to the branch pipes **115**. In the particular example illustrated in FIG. 7, the proportions of the central duct **114** and the branch ducts **115** are appropriate to a mill designed to receive the particulate matter to be comminuted carried in a stream of liquid rather than a stream of air, gas or foam. With mills intended for operation where the particulate matter is carried in a stream of air, gas or foam, the proportions of the central duct **114** and the branch pipes **115** will be larger in relation to the overall dimensions of the mill than those illustrated in FIG. 7. Moreover, for such operation the top spigot portions **111** of the chamber assemblies **109** will not be formed with the bottle neck illustrated in FIG. 7, but will open out more directly to the cylindrical internal crushing surfaces **112** of the crushing chamber assemblies **110**. Whether the mill be designed to operate with a liquid carrier stream, or a carrier stream of air, gas or foam, the branch pipes or ducts **115**, in effect, form the channels of a centrifugal impeller which will fling the particulate matter to be comminuted against the internal crushing surfaces **112**, whereafter the particulate matter will be dragged around by frictional contact with these same surfaces, as they rotate. The particulate matter is self-classified as it is comminuted in the manner described earlier by the sweeping action of the carrier stream, and progresses axially through the crushing chambers **110** being separately comminuted at individual rolling paths of the stacked discs **118** as it does so and, eventually, passes out of the bottom spigot end portions **11** of the chambers **110** into a convergent exit portion **120** of the stationary mill body.

In this particular example, the stacked discs **118** forming the roller crushing masses are depicted as having part-spherical edge surfaces **119** and as having identical axial thickness. As described before, these discs may have their edge surfaces **119** of more essentially cylindrical form, as may be appropriate to the material being comminuted, and may be of different individual axial widths, their widths diminishing (or even increasing) in the axial direction along which the material being comminuted progresses, as appropriate to the nature of the material being comminuted, the desired degree of fineness of comminution, and the rate at which the comminution process is to take place.

With the design of mill illustrated in FIGS. **7** and **8**, the "angle of nip" between the cooperating crushing surfaces will be finer than is generally possible with the design of mill illustrated in FIGS. **3** and **4**. Further variation in the "angle of nip" may be effected by adopting the polyhedral form of cooperating crushing members which is illustrated, diagrammatically, in FIG. **6**.

A further variation is foreseen, where the edge surfaces **119** of the stacked coaxial discs **118** may be formed with grooves or slots spaced around their peripheries, the grooves being angled to the axis of rotation of the discs **118** (or to the axis of the cylindrical crushing chambers **110**) in such a way that they assist the passage of particulate matter from one path of interception of the cooperating crushing masses to the next path in the axial sense of movement of the particulate matter. This variation may be applied equally to mills working on the principle depicted diagrammatically in FIG. **1** (illustrated in FIGS. **3** and **4**) or to mills working on the principle depicted diagrammatically in FIG. **5** (illustrated in FIG. **7** and **8**).

Whichever principle, or variation, is adopted, at least two, and preferably three or more, stacks of roller crushing masses (or sets of roller crushing masses and associated cylindrical crushing chambers) will be provided symmetrically distributed circumferentially around the main axis of rotation of the mill in order to ensure good mechanical balance.

In the illustrations shown in FIGS. **5** or **7**, the central axis of the mill has been depicted vertical. It will be understood that mills constructed according to these (or any other) embodiments may equally be operated with their central axes in the horizontal or another direction.

The stream of carrier fluid (air, gas, liquid or foam) in its passage through the crushing chamber (or crushing chambers) of the mill makes a contribution to cooling the chamber (or chambers) and to cooling the roller crushing masses by carrying away the heat generated by the crushing or cleaving actions (and by sliding attritive frictional actions, although these are avoided as far as is possible in mills operating on the self-classifying principle of the present invention). Depending on the size of the mill and the properties, including the heat sensitivity of the material being comminuted, it may be desirable to provide additional cooling in any conventional manner.

It will be observed that mills constructed according to the embodiments illustrated in the foregoing drawings and descriptions are extremely versatile in that roller crushing masses or sets of roller crushing masses of different sizes, weights, numbers and/or shapes and edge profiles can be interchanged readily, as can the complete crusher chamber units to suit the circumstances and the nature of the material being comminuted. This scope, together with control of the nature of the carrier fluid, its axial velocity through the mill, and the ratio of the mass of carrier fluid to the mass of particulate matter which it carries per unit volume, enables the self-classifying principle of the present invention to be effected to varying degrees. The higher the degree of self-classification achieved, the more nearly will pure cleaving of the particulate matter result from the rolling action of the cooperating roller crushing members, the less will be the wear on these cooperating crushing members through unwanted sliding, attritive, frictional actions, and the greater will be the efficiency of the mill in terms of power consumption in relation to quantity of material comminuted to a desired degree of fineness.

I claim:

1. A method of comminuting particulate matter by a mill having a crushing chamber with a wall formed by a surface of revolution and a number of disclike roller crushing masses arranged in stacks extending lengthwise of the chamber for following circular paths around the inside of said wall, said masses having freedom of movement for a distance radially inwardly of said wall, wherein the improvement comprises providing a vortex of carrier fluid carrying the particulate matter into one end of said chamber and through to the other end of said chamber as a stream of particle-laden fluid following a helical path along the wall, orbiting the roller crushing masses to intercept the helical path of the stream of particle-laden fluid; proportioning the mass flow, the flow velocity and

instantaneous directions of flow of the vortex of carrier fluid in relation to the mass flow and initial mean size of the particulate matter so that the particles of material, as they are comminuted and made smaller by being crushed between the disclike roller crushing masses and the wall of the crushing chamber, are separated, with the more finely comminuted or smaller particles tending to move more rapidly in the component direction parallel to the axis of the crushing chamber than less finely comminuted or larger particles; and proportioning the relative velocities of the cooperating roller members with respect to each other and to the stream of particle-laden fluid to maintain separation of the particles as they are comminuted and to ensure that particles comminuted at individual rolling paths spaced in the direction parallel to the axis of the crushing chamber tend to be of similar means dimension.

2. A method as claimed in claim 1, wherein the disclike roller crushing masses are so stacked that their crushing surfaces are spaced apart in the axial direction of the chamber, positively driving the roller crushing masses to follow orbital paths around the wall of said chamber, whereby the disclike crushing masses roll freely and substantially without sliding along individual tracks while being rotated about their own centers solely by frictional torque due to contact with a layer of particulate material intervening between the wall of the crushing chamber and the disclike roller crushing masses.

3. A method as claimed in claim 1, wherein the stream of carrier fluid is air.

4. A method as claimed in claim 2, wherein the stream of carrier fluid is a gas.

5. A method as claimed in claim 1, wherein the stream of carrier fluid is a mixture of gases.

6. A method as claimed in claim 1, wherein the stream of carrier fluid is a liquid.

7. A method as claimed in claim 1, wherein the stream of carrier fluid is a mixture of liquids.

8. A method as claimed in claim 1, wherein the stream of carrier fluid is a foam of air dispersed in a liquid.

9. A method as claimed in claim 2, wherein the stream of carrier fluid is a foam of air dispersed in a mixture of liquids.

10. A method as claimed in claim 1, wherein the stream of carrier fluid is a foam of gas bubbles dispersed in a liquid.

11. A method as claimed in claim 1, wherein the stream of carrier fluid is a foam of gas bubbles dispersed in a mixture of liquids.

12. A method as claimed in claim 1, the step of using roller crushing masses comprising stacks of separate discs whose peripheral edges are provided with grooves or recesses at intervals.

13. A method as claimed in claim 1, the step of employing roller crushing masses comprising roller masses of polyhedral form having a circumferential crushing surface made up of a series of convex part-spherical arcuate crushing faces all of equal radius of curvature greater than the mean curvature of the roller crushing mass itself, in combination with an associated crushing chamber having a cooperating internal surface made up of a series of identical concave part-cylindrical arcuate sections whose circumferential widths are equal to those of the convex crushing faces of the roller crushing masses and whose radius of curvature is greater than the mean internal radius of the associated crushing chamber and greater than the radius of curvature of the convex faces of the roller masses.

14. A method as claimed in claim 2, the step of using roller crushing masses comprising roller masses of polyhedral form having a circumferential crushing surface made up of a series of convex part-cylindrical arcuate crushing faces all of equal radius of curvature greater than the mean curvature of the roller crushing mass itself, in combination with an associated crushing chamber having a cooperating internal surface made up of a series of identical concave part-cylindrical arcuate sections whose circumferential widths are equal to those of the convex crushing faces of the roller crushing masses and whose radius of curvature is greater than the mean internal radius of the associated crushing chamber and greater than the radius of curvature of the convex faces of the roller masses.

15. A method as claimed in claim 1, the step of using roller crushing masses comprising stacks of coaxial discs whose axial thicknesses are alike.

16. A method as claimed in claim 1, wherein the roller crushing masses employed comprise stacks of polyhedral forms whose axial thicknesses are alike.

17. A method as claimed in claim 2, wherein the roller crushing masses employed comprise stacks of coaxial discs whose axial thicknesses vary progressively from one end to the other of the stacks.

18. A method as claimed in claim 1, the step of using roller crushing masses comprising stacks of polyhedral forms whose axial thicknesses vary progressively from one end to the other of the stacks.

19. A method as claimed in claim 1, the steps of using disclike roller crushing masses freely floating in relatively rotating crushing chambers, positively gyrating said chambers in an orbital path around a central axis of the mill and simultaneously rotating said chambers about their own axes of symmetry, thereby freely rolling the disclike crushing masses, stacked so that their crushing surfaces are spaced apart in the axial direction of the associated chamber, substantially without sliding along individual tracks while being rotated about their own axes of symmetry solely by frictional torque due to contact with a layer of particulate matter intervening between the walls of the relatively rotating and gyrating crushing chambers and the disclike roller crushing masses.

20. A method as claimed in claim 19, the step of using roller crushing masses comprising roller masses of polyhedral form having a circumferential crushing surface made up of a series of convex part-spherical arcuate crushing faces all of equal radius of curvature greater than the mean curvature of the roller crushing chamber having a cooperating internal surface made up of a series of identical concave part-cylindrical arcuate sections whose circumferential widths are equal to those of the convex crushing faces of the roller crushing masses and whose radius of curvature is greater than the mean internal radius of the associated crushing chamber and greater than the radius of curvature of the convex faces of the roller masses.

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