Oct. 7, 1969 F. O. WIENERT 3,471,093

METHOD FOR GRINDING

Filed June 16, 1965 2 Sheets-Sheet 1

Fig. 1.

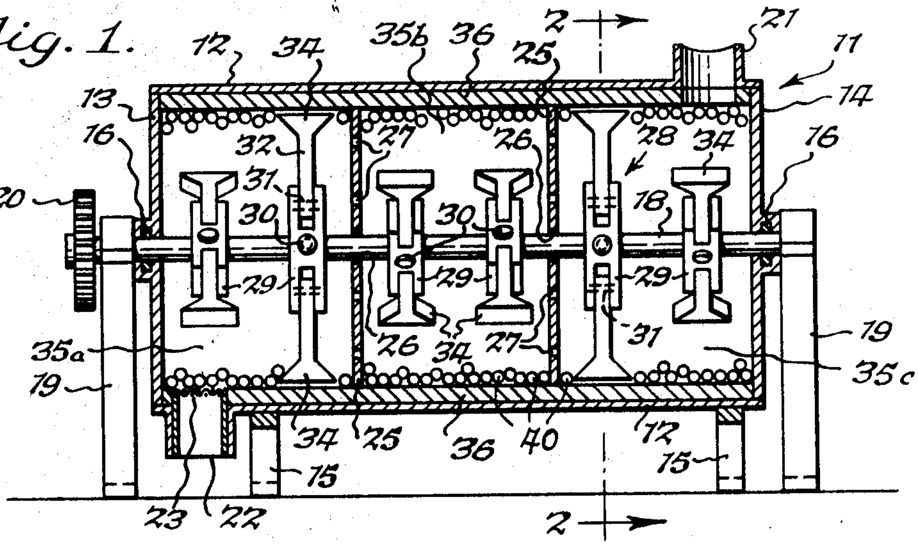


Fig. 2.

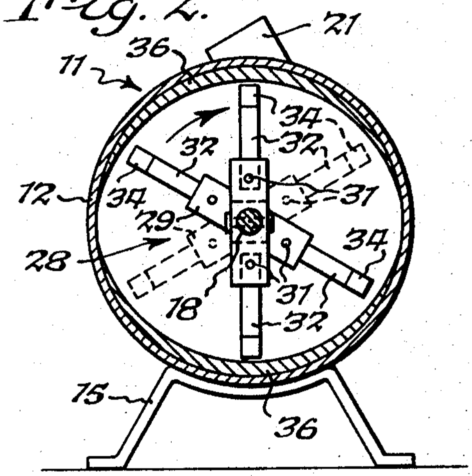
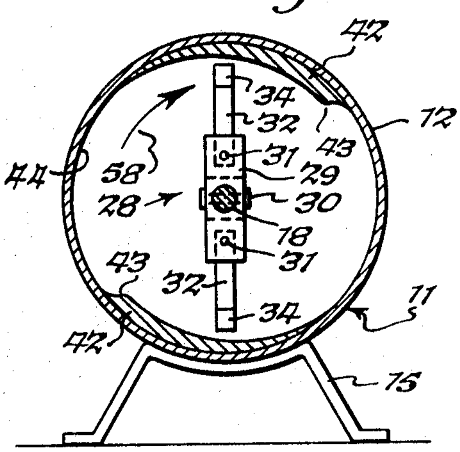


Fig. 3.



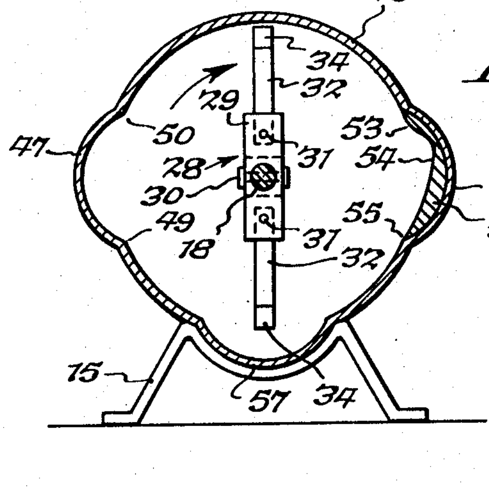


Fig. 4.

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Fig. 5.

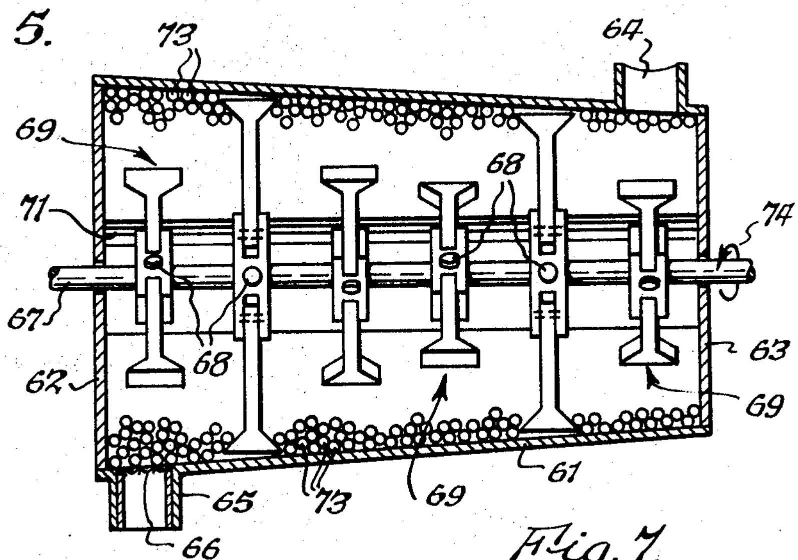
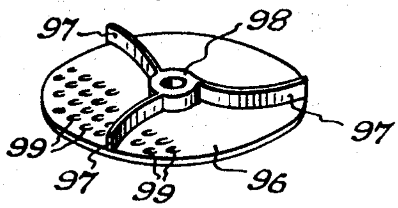


Fig. 7.



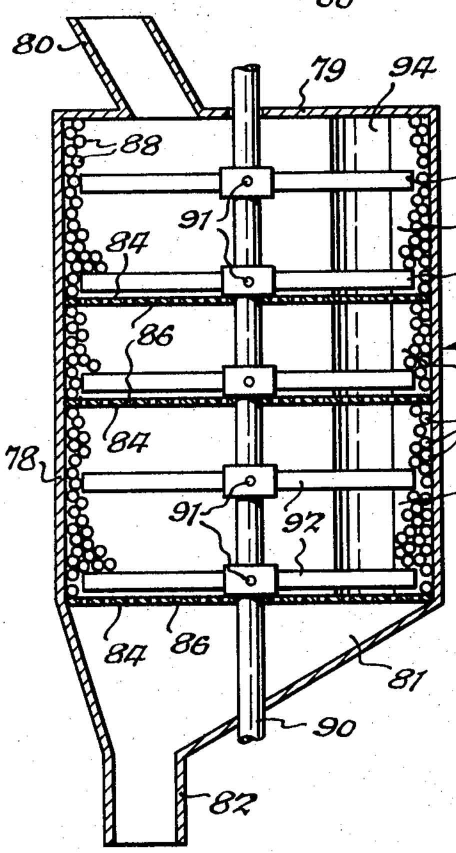
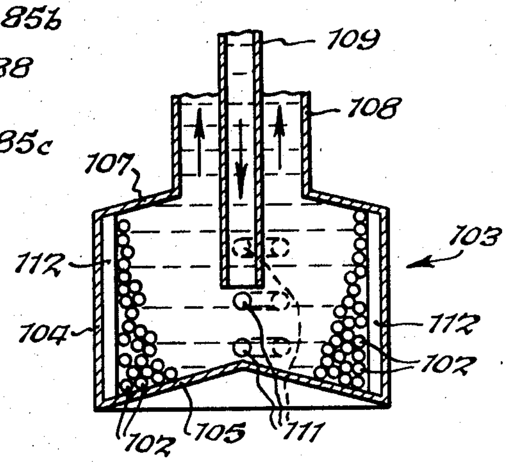


Fig. 6.

Fig. 8.



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3,471,093
METHOD FOR GRINDING

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Continuation-in-part of application Ser. No. 253,158, Jan. 22, 1963. This application June 16, 1965, Ser. No. 467,187
Int. Cl. B02c 4/06
U.S. Cl. 241—30 9 Claims

ABSTRACT OF THE DISCLOSURE

The method of grinding in which all of the grinding bodies of a mass of such bodies are moved, with speeds causing centrifugal force greater than gravity, in closed-curved paths along the inner wall of a casing and in which the radii of curvature of said paths are variable through at least minor portions of said paths.

This application is in part a continuation of application Ser. No. 253,158, filed Jan. 22, 1963, now abandoned.

This invention relates to the grinding of material by means of freely movable grinding bodies and more particularly to a novel method and apparatus for grinding by means of grinding bodies which perform their function while being subjected to centrifugal force.

In common practice grinding by means of grinding bodies is caused by gravitational force. For example, in ball mills the balls are continuously lifted by the mill and grind as they cascade downwardly by gravity. The general disadvantage of such mills is that they require a large amount of power for lifting the balls and that only a portion of the balls effectively provide grinding action at any one time.

It is also common practice to achieve grinding or comminuting by moving a definite number of balls or rolls along a prescribed, fixed circular path at such speeds that they exert pressure on this path as a result of centrifugal force. However, the grinding action thus obtained is small in relation to the size of the apparatus because it takes place only in the limited contact zone between the relatively few balls or rolls and the fixed path in the mill.

It is also known to achieve a grinding action with grinding bodies by subjecting to centrifugal force an indefinite number of such bodies freely movable in regard to each other within a vessel of circular cross section and to move the centrifuged grinding bodies mixed with interspersed material to be ground relatively to one another by means of agitators. This agitation within the mass of centrifuged grinding bodies causes high power consumption and heavy wear of the apparatus as it also the case in other agitator type mills of known design. It is further known to suspend material to be comminuted in a fast moving fluid and utilize the kinetic energy of the fluid for comminution. However, the power consumption in such fluid-energy mills is likewise high.

It has also been suggested to centrifuge grinding bodies with interspersed material against the inner peripheral wall of a rapidly rotating, circular container while simultaneously shifting the axis of rotation of the container in a circular orbit, thereby causing the grinding bodies and materials to vibrate against said wall and comminute the interspersed material.

It is, therefore, an object of the present invention to provide novel grinding apparatus which is highly efficient and has a relatively low power consumption for equivalent grinding results as compared to other types of grinding mills.

Another object of the invention is to provide a novel grinding mill in which the grinding is carried out by grinding bodies moving in closed-curve paths within a casing.

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Another object of the invention is to provide novel grinding apparatus which is simple to construct and inexpensive to maintain.

A further object of the invention is to provide a novel method of grinding in which all of the grinding bodies of a mass of such bodies are moved, with speeds causing centrifugal force greater than gravity, in closed-curve paths along the inner wall of a casing and in which the radii of curvature of said paths are variable through at least minor portions of said paths.

Still another object of the invention is to provide grinding apparatus which has a grinding capacity much greater in proportion to the mill size than mills previously used.

Other objects and advantages of the invention will be apparent from the following description thereof taken in conjunction with the accompanying drawings.

The present invention avoids the drawbacks of the above-mentioned previously known and suggested grinding methods and apparatus by repeatedly circulating at high speeds a mass of freely movable grinding bodies interspersed with material to be ground in continuous, curved, non-circular paths. More specifically, the grinding bodies and material are caused to move at high speeds, under the influence of centrifugal forces in closed-curve paths within a generally round (including elliptical) preferably stationary vessel, said paths being along the inner peripheral wall of said vessel and each of said paths having at least a portion thereof in which the radius of curvature varies.

This is achieved in an apparatus which comprises a preferably stationary vessel having a generally round circumferential or peripheral wall with a continuous, curved inner surface. The vessel contains a number of freely movable grinding bodies and means to impart centrifugal motion to said bodies and the material to be ground so that the bodies race around said curved inner surface. The cross section of the inner peripheral wall of the vessel in an orbital plane, i.e., a plane incorporating the path of a grinding body in such motion, deviates from a circle in at least one place so that the moving grinding bodies are forced to deviate from a circular path at least once during each orbit. Stated more generally, the radius of curvature of the continuous, curved path of each of the grinding bodies in its orbital motion varies at least once in each orbit.

In the accompanying drawings, which illustrate preferred embodiments of the invention and some of the possible modifications thereof:

FIGURE 1 is a longitudinal sectional view through one type of horizontal mill according to the invention;

FIGURE 2 is a cross-sectional view taken approximately on line 2—2 of FIGURE 1;

FIGURES 3 and 4 are cross-sectional views similar to FIGURE 2 illustrating modified forms of the apparatus illustrated in FIGURES 1 and 2.

FIGURE 5 is a longitudinal sectional view through another type of horizontal mill;

FIGURE 6 is a longitudinal sectional view through one type of vertical mill according to the invention;

FIGURE 7 is a perspective view of a modified type of impeller; and

FIGURE 8 is a sectional view of a vertical type mill according to the invention in which orbital movement of the grinding bodies is produced by fluid streams.

Referring to the embodiment illustrated in FIGURES 1 and 2, the mill casing, comprehensively designated as **11**, comprises a horizontal cylindrical body **12**. The body **12** is provided with ends **13** and **14** which may be joined to the body portion by welding or other suitable means. The casing **11** is supported on stands **15**. Extending axially through the casing **11** and the packing glands or seals **16** on the ends **13** and **14** of the body is an impeller shaft **18** which is rotatably supported exteriorly of the casing by pedestals **19** and which has secured on one end thereof a gear **20** that may be engaged by rotating means (not shown) for said shaft.

In the upper portion of the casing **11**, adjacent to the end **14** thereof, an inlet **21** is provided for introducing into the mill grinding bodies and material to be ground. The inlet **21** projects outwardly, preferably tangentially to the body **12**, and is so disposed that material or grinding bodies entering the mill therethrough are moving in the same direction as the material and grinding bodies therein. Adjacent to the other end of the casing **11**, in the bottom portion thereof, is an outlet **22** therefrom which is provided with a removable screen or grate **23**. Within the casing **11** and spaced longitudinally at intervals therein are a plurality of partitions **25** secured to the body **12** in suitable manner, such, for example, as by welding, and each is provided with a center hole **26** around the shaft **18** and a plurality of smaller perforations **27**. The latter are sufficiently numerous and of such size as to permit passage of material that is being ground but are not large enough to permit the passage of grinding bodies.

Along the portion of the shaft **18** within the casing **11** a plurality of impellers **28** is provided at spaced intervals. Each of the impellers comprises a double ended yoke **29** mounted on the shaft **18** and secured thereto by suitable means such as a pin **30** so that the bifurcated ends of the yoke extend radially on opposite sides of the shaft. A paddle **32** is pivotally mounted in each of the ends of the yoke **29** on a pin or shaft **31** which extends parallel to the shaft **18**. The paddles on each yoke are thus capable of swinging motion or oscillation in the same plane in which they are rotated but around centers radially removed from the axis of rotation. The outer, free ends of the paddles **32** are preferably enlarged, as at **34**, longitudinally of the mill casing to increase their striking areas. Adjacent yokes **29** are preferably secured to the shaft **18** at different angles as shown in FIGURES 1 and 2. Also, as will be seen, the interior of the casing **11** is divided into a plurality of longitudinally arrayed, communicating compartments **35***a*, **35***b*, **35***c*, by the partitions **25** and a plurality of impellers **28** is located within each of said compartments.

Within each of the compartments **35***a*, **35***b*, and **35***c* there are secured to the body **12**, at diametrically opposed positions, as best shown in FIGURE 2, a pair of crescent-shaped orbit deflectors **36** which extend longitudinally of the body **12** for substantially the full length thereof. The length of the paddles **32** is such that the impellers may revolve within the compartments at high speeds without direct interference from the deflectors. The deflectors may be secured to the wall of the casing by suitable means such as bolts or studs (not shown).

The numeral **40** in FIGURE 1 indicates grinding bodies, for example balls of any suitable hard material, which are used in grinding mills according to the invention. It is preferred to have the bodies of different sizes and/or weights. The number of grinding bodies employed may vary. It is desirable to have enough, as shown in FIGURE 1, to at least substantially cover the interior peripheral surface of the mill body **12** when the bodies are moving in orbital paths and enough may be used to provide a layer equivalent in thickness to about one-half the radius of the mill body when they are distributed uniformly around the interior surface of the body **12**. In some cases the numbers and/or sizes of grinding bodies in the several compartments **35***a*, **35***b*, **35***c*, may be different. The materials used for such bodies may also be different.

In the operation of the mill illustrated in FIGURES 1 and 2 a plurality of hard grinding bodies such as balls **40** are placed in the compartments of the mill and the impeller shaft **18** is rotated rapidly by suitable means (not shown) engaging the gear **20** thereon. The revolving paddles **32** of the impellers **28** impart centrifugal motion to all of the balls **40** and thereby cause them to race along the inner curved surface of the mill body and over the deflectors **36**. The material to be ground is introduced through the inlet **21** and is likewise thrown outwardly by the paddles **32** toward the inner surface of the mill body where it is interspersed in and moves with the balls **40**. Because of their different velocities and/or masses the balls **40** shift their relative positions as the radii of curvature of their orbital paths are changed in passing over the deflectors **36**. The shear friction between the balls **40** resulting from such changes in relative position comminutes the interspersed material. Obviously the impellers do not directly contact all of the grinding bodies at any one instant but it will be apparent that because of close contact and friction between the bodies all of them will be moved simultaneously rapidly and repeatedly in closed-curve paths.

In FIGURE 3 there is illustrated a modification of the mill shown in FIGURES 1 and 2. The modification consists in forming the orbit deflectors as curved wedges **42** that gradually increase in thickness in the direction of travel of the mill contents and have their trailing ends steeply inclined toward the inner face **44** of the mill body from the points **43** on the faces of the wedges.

The operation of the modified mill illustrated in FIGURE 3 is similar to that of the mill illustrated in FIGURE 1 except that the grinding balls adjacent the continuous, curved inner surface of the body **12** upon passing over the points **43** on the faces of the wedge deflectors **42** are caused to jump to the inner face **44** of the body. The distance travelled from the take-off points **43** before striking the face **44** will vary with the mass and the velocity of the balls but in any event the balls in the mass of grinding bodies will move relatively to each other thereby comminuting the interpersed material.

FIGURE 4 illustrates further possible modifications of the mill shown in FIGURES 1 and 2. Here the mill body **46** is constructed with diametrically disposed longitudinal troughs **47** and **48** and a third longitudinal trough **57** intermediate them, all of which project outwardly from the main cylindrical portion of the body. As the grinding balls in their orbital paths around the inner wall of the body **46** reach the edge **49** of trough **47** they will momentarily be out of contact with the wall, but centrifugal force will cause them to move outwardly so that they strike the inner face of the trough while continuing their orbital motions. Then, on reaching the other edge **50** of the trough **47**, the balls adjacent the curved inner surface of the body **46** will again be caused to jump before again contacting the inner wall of the cylindrical portion of the body **46**.

A liner or filler plate **52** is provided in the trough **48**. The plate, which may be secured to the body **46** by suitable means such as bolts or studs (not shown) is so shaped as to modify the deflecting action of the trough on the grinding balls in the mill in their orbital paths. As the outer balls reach the point **53** at the leading edge of the depression **54** formed in the liner **52**, they take off, i.e. jump, before striking the inner surface of the liner. However, the trailing edge **55** of the liner **52** has a smooth transition into the curve of the inner face of the cylindrical body portion and, accordingly, the balls are not caused to jump or shift positions abruptly when they leave the trough **48**. The trough **57** is similar in structure and action to the trough **47**. However, either of the troughs **47** and **57**, or both, may be provided with a liner like the liner **52** of trough **48**, if desired. The troughs **47**, **48**, and **57** in this embodiment constitute orbit deflectors for the grinding balls used therein.

In the operation of the modified form of mill illustrated in FIGURE 4, as in the embodiments previously described, the orbital paths of the grinding balls will vary in accordance with their velocities and masses, thus producing shifting of the relative positions of the balls. As previously pointed out, such shifting results in effective grinding of the interspersed material.

It will be understood that in the modified forms shown in FIGURES 3 and 4, as well as in the embodiment of the invention illustrated in FIGURES 1 and 2, partitions may be employed to divide the mill longitudinally into compartments. In the embodiment of FIGURE 4 it will usually be more convenient for the troughs to run for the full length of the mill body, but this is not essential. As in the mill illustrated in FIGURES 1 and 2, in use the mills of FIGURES 3 and 4 should contain at least enough grinding bodies to substantially cover the surface of the inner peripheral wall of the mill and may contain enough bodies to provide a layer equivalent in thickness to about one half the radius of the mill body when they are distributed uniformly around said wall.

It will be apparent that considering the possible variations in such factors as mill size, ball sizes and weights, percentage of loading, feed rate, etc., etc., and the fact that the movements in any grinding mill are inevitably quite complex, it is not feasible to specify a particular deflector shape and/or size as being most efficient. Since the efficiency in a particular case will depend on many variables, the best arrangements and operating conditions will necessarily be determined by practical use. It should be noted, however, that corners and sharp bends leading to violent impacts of the grinding bodies on the face of the mill body or on each other are preferably avoided since such impacts increase wear and produce indiscriminate impact grinding. For this reason, the mills illustrated in FIGURES 3 and 4 are only intended to be used with the impellers rotating in the direction indicated by the arrows, designated **58** in FIGURE 3. Orbital movement of the grinding balls in the opposite direction would result in violent impacts against the back faces of the wedges **42** in FIGURE 3 and against the front edge of the depression **54** in FIGURE 4.

Still another form of horizontal mill according to the present invention is illustrated in FIGURE 5. In this embodiment the mill comprises a casing having a body portion **61** and ends **62** and **63**. The casing is generally frustoconical in shape and is provided with an inlet **64** in its upper portion adjacent the smaller end **63** and an outlet **65** in its lower portion adjacent the larger end **62**. A removable grate or screen **66** is provided for the outlet **65**.

Extending longitudinally through the body portion **61** and projecting through the ends **62** and **63** is a rotatable impeller shaft **67** to which are secured, as by pins **68**, a plurality of impellers **69** spaced along the length of the shaft. The impellers **69** are substantially like the impellers **28** in FIGURES 1 and 2, except that, because of the shape of the casing **61**, they are graduated in length, the length increasing toward the large end of the casing. A longitudinal trough **71** similar to the trough **47** in FIGURE 4 is provided along the side of the body **61** to serve as an orbit deflector for the grinding balls **73**. The latter are shown distributed around the inner periphery of the body approximately as they would appear during operation at some instant.

In operating the mill illustrated in FIGURE 5, a sufficient number of grinding balls are placed in the mill so that the balls are thrown outwardly by the rotating impellers and travel in an orbital path around the inner curved face of the body **61**. The material to be ground is introduced through the inlet **64** and becomes interspersed in the mass of grinding balls where it is comminuted by the relative movement between the balls that results from the orbit deflector **71**.

As with the mills illustrated in FIGURES 1–4, it is preferred to have the grinding balls in the mill shown in FIGURE 5 vary in size and/or mass since the deviations,

produced by the deflecting trough, from the normal orbital path of such a mixture of balls will be such that greater grinding efficiency is obtained. Because of the frustoconical shape of the mill casing in FIGURE 5 there will, of course, be a tendency for a greater number of the grinding balls and the balls of greatest mass to collect in the portion of larger diameter near the outlet **65**. As a result, the grinding or comminuting effect is progressively greater as material to be ground moves from the inlet **64** to the outlet **65**. The inlet **64** is preferably arranged so that material enters the mill substantially tangentially, in the direction in which the balls **73** are travelling (see arrow **74**), thus preventing ejection of the balls or material.

In the use of apparatus of the type described above, the grinding or comminuting operation is preferably a continuous one with material being fed into the mill adjacent one end and being discharged adjacent the other end. Depending upon the size of the orifices in the discharge grate or screen, all of the feed material may be discharged as it reaches the outlet or only the finer particles may be discharged.

FIGURE 6 illustrates an embodiment of apparatus according to the invention in which the orbital paths of the grinding bodies tend to lie in horizontal planes and the general direction of travel of material through the mill is vertical. In this figure the mill casing **77** comprises the generally cylindrical mill body **78**, which is provided with a top **79** in which there is an inlet chute **80**, and is constructed at its lower end to form a discharge hopper **81** having an outlet **82**. A plurality of vertically spaced horizontal partitions **84** are provided within the body **78** to divide the mill into a plurality of compartments **85*a*, 85*b*, 85*c***. The partitions **84** are provided with holes or perforations **86** of such size that particles of material may pass through, but the grinding bodies **88** in the several compartments will not pass.

A rotatable impeller shaft **90** extends vertically through the casing **77** and the partitions **84** and carries, securely mounted thereon, as by pins **91**, within each of the compartments **85** at least one impeller **92** which may be, as shown, merely a straight bar or may be similar to those illustrated in FIGURE 1.

In operation, the impellers **92** when revolved rapidly by rotation of the shaft **90** engage the grinding balls **88** in each compartment and impart to them centrifugal motion that results in orbital movement around the inside face of the body **78**. As shown in FIGURE 6, the balls **88** are shown distributed approximately as they would be at some instant during their orbital movements. The balls are deflected at least once during each orbit by a deflector associated with the casing such as the vertical, longitudinally extending trough **94**. Trough **94** may be constructed substantially like the trough **47** in FIGURE 4 and functions in the same way. As in the previously described embodiments, the grinding balls **88** are preferably of different sizes and/or masses to increase the grinding effect. The holes **86** in one or all of the partitions **84** may be of such size that the material to be ground is retained in a compartment until it is reduced to a desired degree of fineness before it can pass to the next compartment or to the discharge hopper.

FIGURE 7 illustrates an alternative form of impeller which may be used in carrying out the invention. As shown, this comprises a plate **96** to which are secured a plurality of vertically extending vanes **97**. The vanes which may be spiral, as shown, or straight if desired, extend from the collar **98** provided for attachment to a shaft to the periphery of the plate and are adapted to engage the grinding balls and project them into orbital paths within a mill. The plate **96** is provided with a plurality of perforations **99** to permit passage of material particles and, when used in a mill like the one illustrated in FIGURE 6, may serve as a partition as well as an impeller. Also in such a mill impellers of this type facilitate starting. When employed in a horizontal mill, impellers of this type may be provided with vanes on both sides of the plate **96**.

FIGURE 8 illustrates, somewhat diagrammatically, a modified form of mill according to the present invention in which the grinding bodies such as the balls **102** have an orbital motion imparted thereto by fluid jets or streams. The mill in this embodiment comprises a stationary casing, generally designated by the numeral **103**, having a vertical, cylindrical body **104**, the bottom **105** of which is dished inwardly to cause grinding balls **102** resting thereon to roll toward the side of the mill. The top **107** of the body has an upwardly projecting discharge duct **108** and concentric therewith is an inwardly projecting inlet tube or chute **109**. A plurality of tangentially disposed nozzles **111** are provided around the side of the body **104** for admitting fluid, preferably compressed air or high pressure steam, to the interior of the mill.

The operation of the mill illustrated in FIGURE 8 is somewhat similar to that of a cyclone. The fluid jets entering through nozzles **111** impart centrifugal motion to the balls **102**, the latter being shown approximately as they would appear in operation at some instant, and to the material being ground which is introduced through the inlet tube **109** and interspersed with the balls. The relative movement of the balls in their orbital movement, increased by the orbital deflectors **112**, which extend longitudinally in the body **104** and may be constructed substantially like the deflectors **36** of FIGURE 1 or **42** of FIGURE 3, comminutes the interspersed material until it is fine enough to be swept out of the mill through the outlet duct **108** by the spent fluid. Thus the mill also acts as a classifier. If desired, a similar mill with the grinding bodies moved by fluid streams or jets in orbital paths in substantially vertical planes could be provided.

It will be understood that the mills shown in FIGURES 5, 6 and 8 will be provided with suitable supporting means and that in the two former mills suitable means will be provided for rotation of the shafts **67** and **90**. Also in FIGURE 8 the discharge duct **108** will be connected to a suitable hopper, classifier, or the like, and the inlet chute will be connected to a feed hopper or the like. It will be further understood that mills according to the present invention may be formed of any suitable material and may be provided with such conventional adjuncts (not shown) as inspection and/or filling holes, linings, packing glands, and the like. Also they may be of any desired and feasible size.

As has been indicated above, many modifications of and variations in the structures of mills according to the present invention are possible. For example, the number of orbital deflectors employed may vary as necessary or desirable and the type or types of deflector used may also be varied. Thus, if desired, a deflector such as that shown in FIGURES 1 and 2 might be used in the construction illustrated in FIGURE 4 instead of one or more of the troughs. The construction of and number of impellers used is also subject to change in accordance with circumstances, and such impellers may, as desired, be disposed at varying angles one from another, as suggested in FIGURES 1 and 5, or parallel, as shown in FIGURE 6. It may be noted here that pivoted impellers such as shown in FIGURE 1 are advantageous in starting with a loaded mill since they gradually exert more force as their speed increases and thus do not pick up the whole load at once.

In many cases the use of partitions to separate the mill into compartments is desirable since this permits the use of graduated ball sizes in the several compartments and thus increases efficiency. The number of partitions, their spacing, the number of impellers in each compartment, and the type and number of orbit deflectors used in such compartments is a matter of choice. However, under some conditions it may be desirable to have the mill

body comprise only a single compartment so that both the balls and material to be ground may be simultaneously introduced after the impellers are revolving. The starting load of the mill may thus be minimized. If desired in such cases, there may be recirculation of grinding bodies with continuous feed and discharge thereof.

The new method of grinding described herein offers the advantage of allowing preferential grinding, as for instance, when it is desired to liberate hard material from soft material by the least amount of comminution. Such preferential grinding may be achieved according to the new method by choice of rotational speed of the impellers, the extent of the diversion from the circular path, the frequency of diversion during one orbit, and the number, size, specific density, and distribution of the grinding bodies. The new method is suitable for preferential grinding because it does not involve indiscriminate heavy impact as in tumbling ball mills, or forceful shear under high pressure as in mills with a fixed path for a grinding element or with agitators stirring a bed of balls.

The grinding operation, according to the method of the invention, is preferably continuous and the finished ground material may be separated in the mill and discharged continuously, or the material may be discharged continuously, separated outside the mill into the desired fine material and coarser particles, the latter being returned to the mill for further grinding. It is understood that in preferential grinding the coarser particles may be the desired product so that the fines are discarded in such a case. The finely ground material may be separated in the mill and discharged from it by means of a current of air or other gas or fluid. The grinding may be either dry or wet.

I claim:

1. A process for grinding material which comprises placing said material in a vessel and interspersing said material in a mass of freely movable grinding bodies, and then while retaining said vessel stationary, simultaneously moving all of said grinding bodies, by imparting centrifugal motion thereto, rapidly and repeatedly in closed-curve paths, the radius of curvature of each of said paths being variable through at least a minor portion of said path.

2. A process as set forth in claim **1** in which said vessel has a continuous, curved inner surface and said grinding bodies are moved essentially along said inner surface.

3. A process as set forth in claim **2** in which the radii of curvature of the paths of grinding bodies adjacent said inner surface are essentially the same as that of said inner surface.

4. A process as set forth in claim **3** in which centrifugal motion is imparted, at substantially all points along said curved inner surface, to at least some of said grinding bodies.

5. A process as set forth in claim **4** in which said closed-curve paths are essentially elliptical and centrifugal motion is imparted to said grinding bodies mechanically.

6. A process as set forth in claim **1** in which said closed-curve paths are essentially round.

7. A process as set forth in claim **1** in which said closed-curve paths are essentially elliptical.

8. A process as set forth in claim **1** in which centrifugal motion is imparted to said grinding bodies mechanically.

9. A process as set forth in claim **1** in which centrifugal motion is imparted to said grinding bodies by fluid force.

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