May 5, 1970 R. EDWARDS ET AL 3,510,074

VIBRATING BALL MILL

Filed July 27, 1967 5 Sheets-Sheet 1

FIG.1.

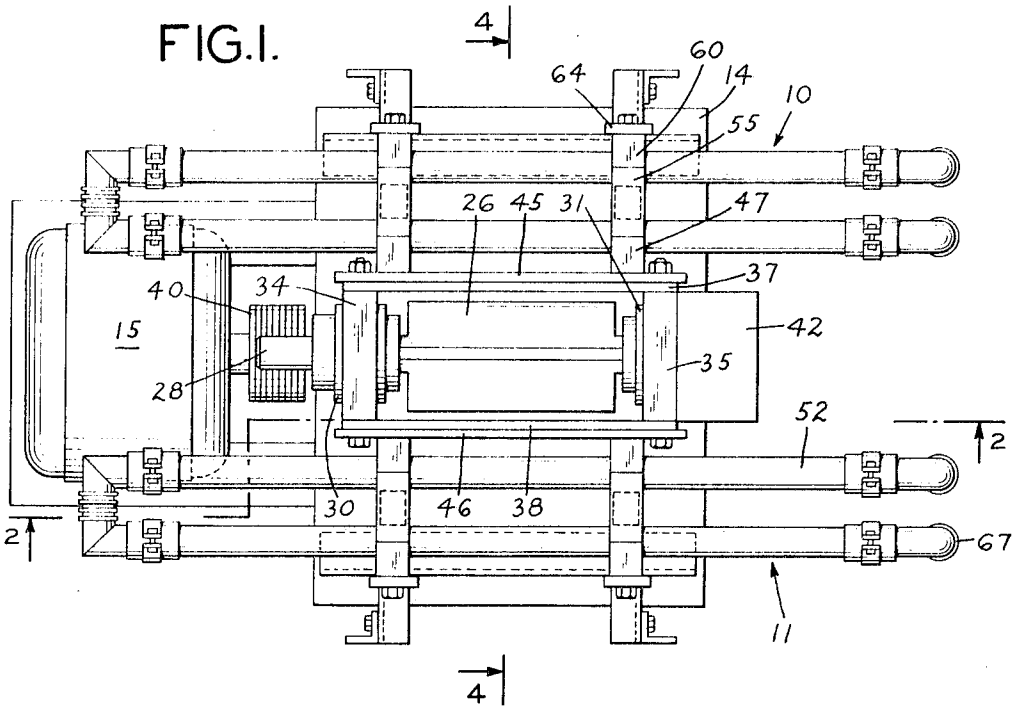
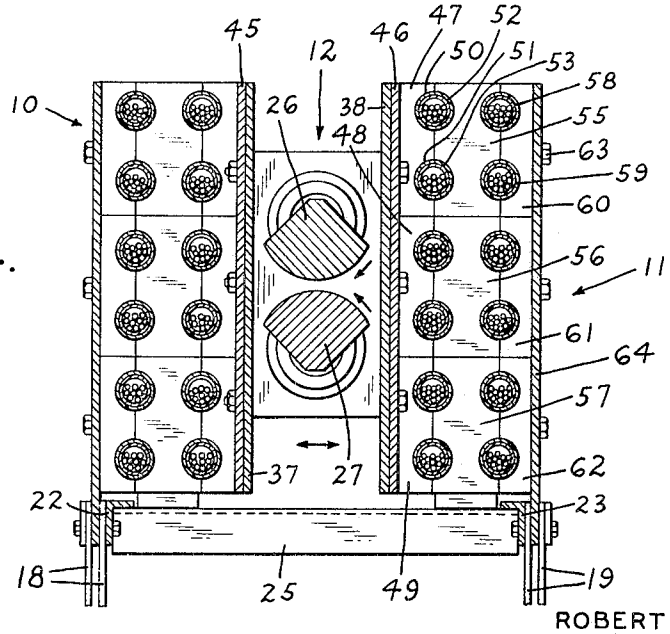


FIG.4.



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VIBRATING BALL MILL

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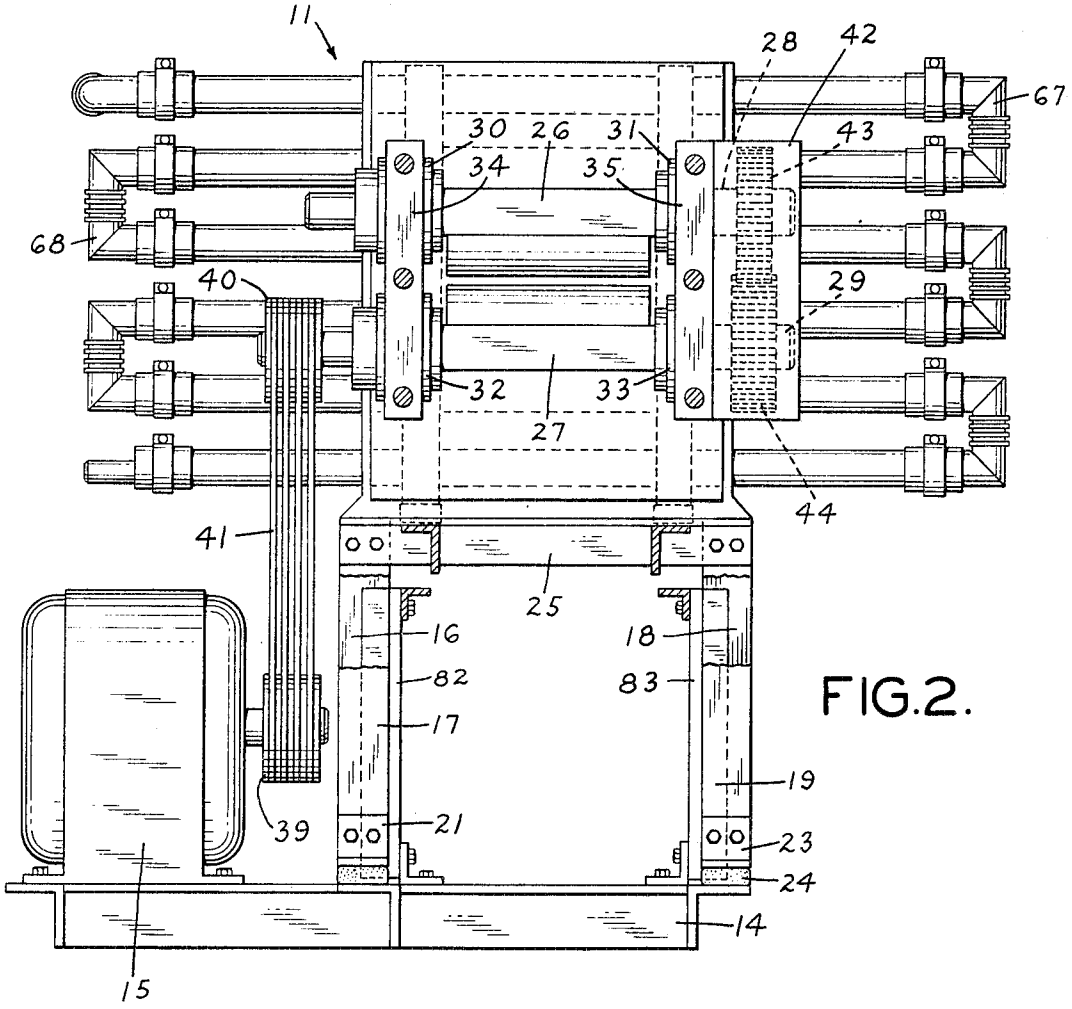
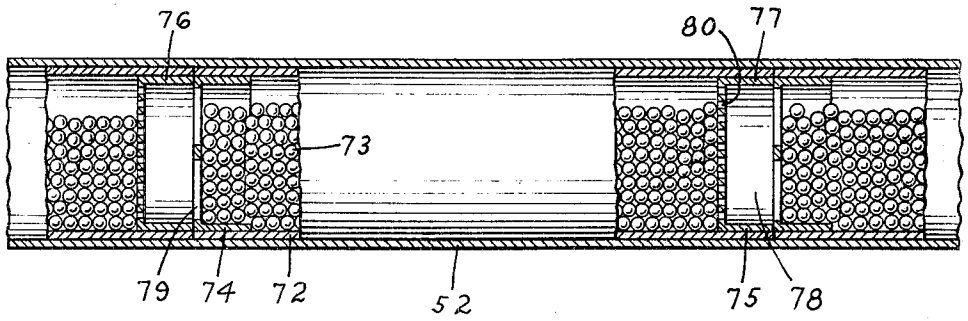


FIG.2.

FIG.5.



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VIBRATING BALL MILL

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FIG.3.

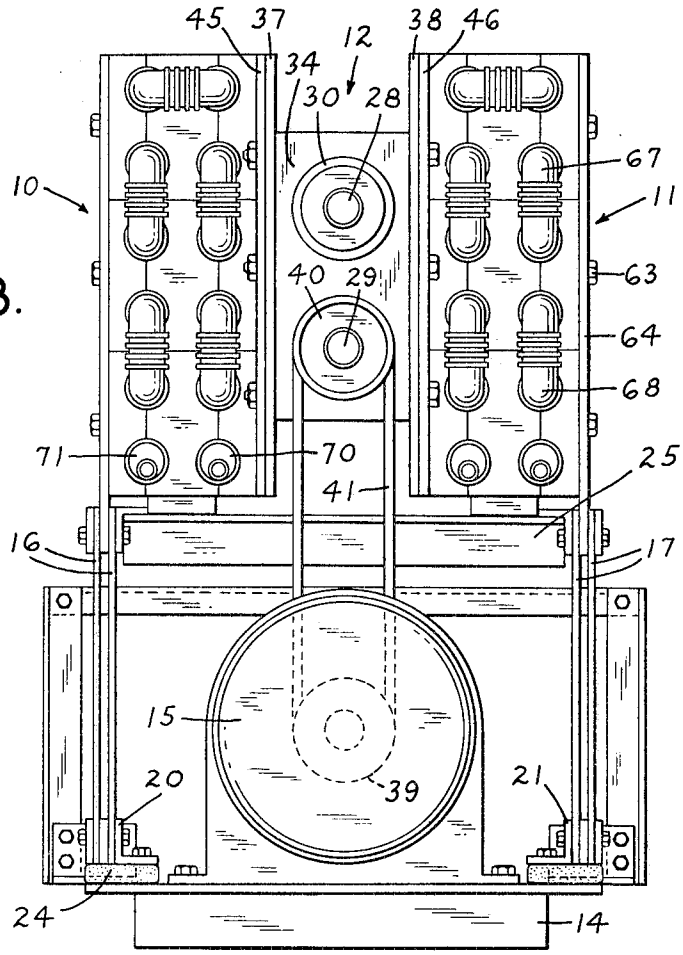


FIG.6.

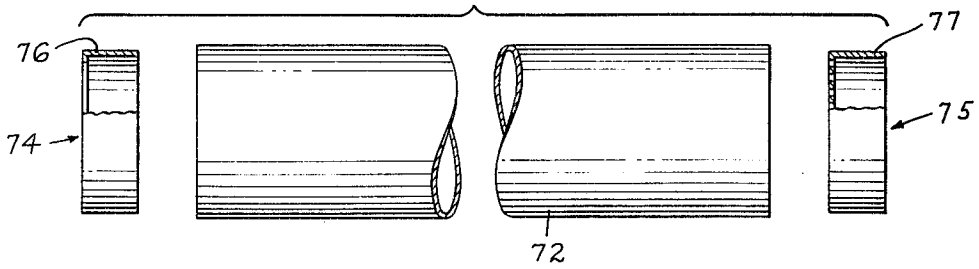
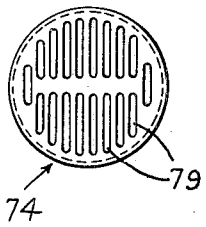


FIG.7.



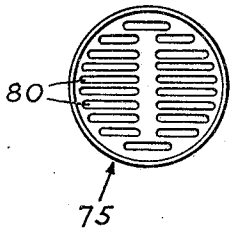


FIG.8.

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VIBRATING BALL MILL

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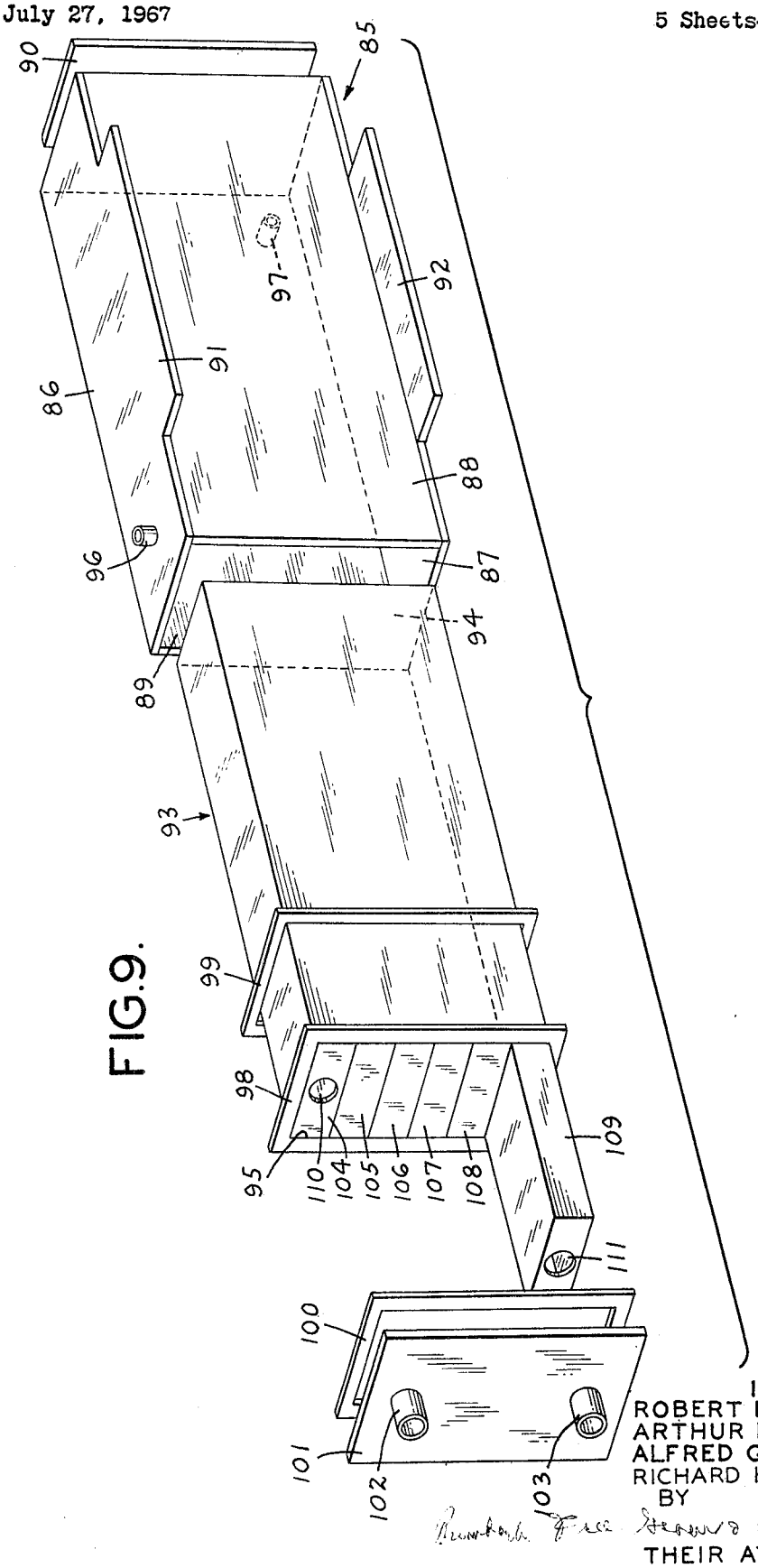


FIG.9.

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VIBRATING BALL MILL

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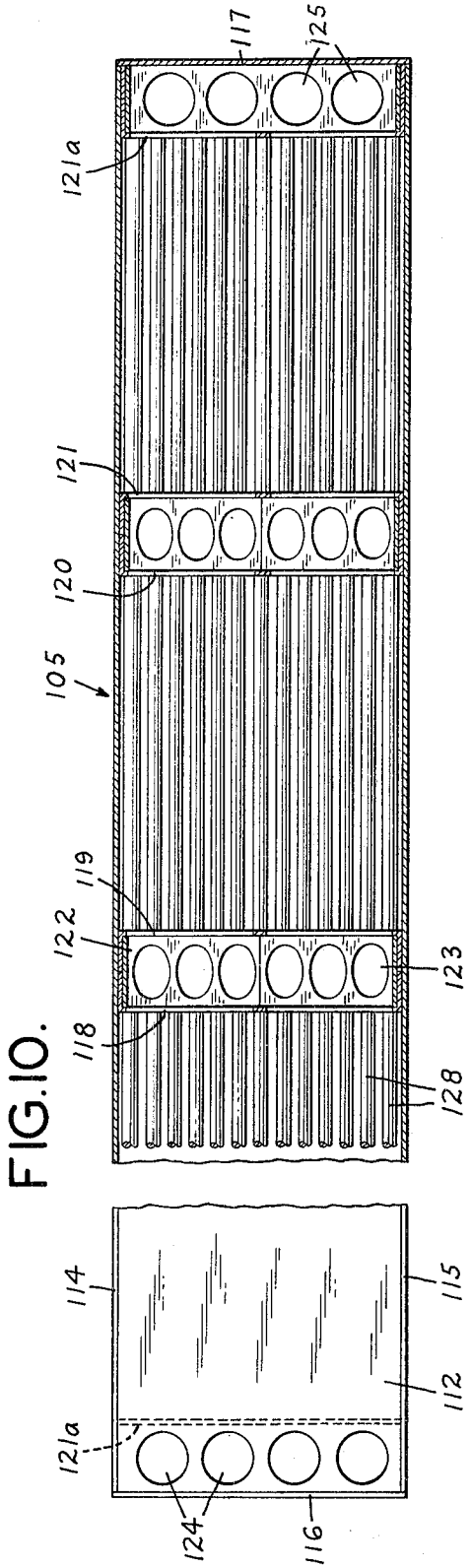


FIG. 10.

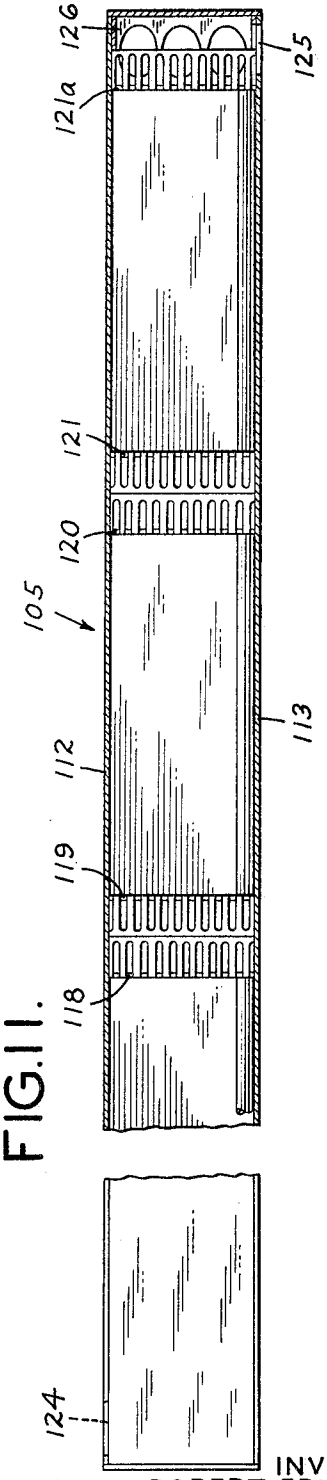


FIG. 11.

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United States Patent Office

3,510,074
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3,510,074

VIBRATING BALL MILL

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Int. Cl. B02c 17/06, 17/14
U.S. Cl. 241—153 19 Claims

ABSTRACT OF THE DISCLOSURE

This invention relates to a vibrating ball mill capable of grinding solids suspended in fluid or viscous liquid media and is characterized by conduits containing grinding balls vibrated by an unbalanced weight drive mechanism capable of providing an optium frequency and displacement of the conduits to enable fine grinding and high throughput, the grinding balls being segregated into groups with free zones therebetween to assure uniform distribution of the solids throughout the suspending medium and to reduce resistance to flow of the solids and suspending medium through the conduits.

This invention relates to improvements in mills for grinding solids, such as, for example, paint pigments and the like, to extremely fine particle size, and more particularly to improvements in grinding mills of the vibrating ball type.

Heretofore four general classes of mills have been provided to grind solid materials to a particle size of a few microns for use in paints, powders, and the like, in which a uniform product of very small particle size is required.

One type of apparatus which is commonly used for such grinding operations is a ball mill including a rotary drum partially filled with ball-like grinding elements. Such mills are effective in producing finely divided materials but are relatively inefficient in operation for the reason that grinding is produced by cascading of the ball elements so that at any given time only a relatively small proportion of the material being ground is subjected to shear and abrading action. Such ball mills become less effective when the liquid medium in which the solid is suspended is viscous due to the fact that the shear action and impact is reduced by the intervention of the viscous liquid.

Paint pigments are commonly ground in sand mills which include sand-like particles and impellers which are driven at relatively high velocity in order to produce high shear stresses in the material undergoing grinding. However, these shear stresses are produced only in the immediate vicinity of the impeller blades so that particles farther removed from the impeller blades may not be subjected to the desired grinding action and a less than uniform product results. Moreover, the power input required in such mills is very high and accordingly the grinding operation is neither economical nor efficient.

Roll mills are also used for grinding pigments or grinding materials to a fine particle size but due to the fact that the rolls have very limited areas of contact, the volume of material actually being subjected to shear and disintegration at any instant is very small as compared with the total charge of pigment and vehicle or suspending agent in the machine. Accordingly, the grinding efficiency is relatively poor on a per unit volume basis. In addition, an increasing viscosity of the suspending medium for the solid adversely affects the grinding action, both in sand mills and roll mills for the reasons pointed out above.

It has been pointed out before also that vibrating ball mills are more efficient than rotary ball mills and can, with many types of materials, produce a product of more uniform particle size than the rotary ball mill and handle more efficiently larger volumes of material per horsepower input than sand mills and roller mills. However, the vibrating ball mill has the same difficulty as the other types of mills in handling highly viscous media for the reason that the motion of the balls is markedly reduced by the viscosity of the media, and moreover, the balls which are usually loosely filled into the conduits making up the mill are caused by the viscous medium to pack together and thereby reduce the shear action in the mill and the rate of flow through the mill.

In accordance with the present invention, vibrating ball mills are provided which overcome the disadvantage of prior ball mills and have been found equally effective in the handling of either materials or media of low viscosity and media of high viscosity without the expenditure of as much power to drive the mill or power for developing pressure for forcing the media undergoing grinding through the mill.

More particularly, in accordance with the present invention, it has been found that a drive mechanism which is capable of imparting a predetermined amplitude of vibration at a predetermined optimum frequency, produces a more efficient and uniform grinding in high viscosity media, provided opportunity is afforded for changes in pressure and a remixing of the materials during passage through the grinding section of the mill and the shearing movement of the grinding balls in the mill is increased.

In a preferred and optimum form of the invention, the mill may take the form of one or more series-connected tubes each containing a plurality of capsules or cartridges arranged in end-to-end relationship and partially filled with grinding balls, the groups of grinding balls being spaced apart to provide free zones therebetween to produce a turbulent mixing of the medium and solids suspended therein and a change of pressure relationship which prevents the grinding balls from being immobilized within the capsules or cartridges. By vibrating the conduits containing the grinding media at an amplitude of about one-half inch and at a frequency at about forty cycles per second, it is possible to produce a uniform grinding operation without the need for the application of an excessive pressure to force the fluid medium through the grinding conduits or mill. Vibration of the conduits can be accomplished efficiently and effectively by means of pairs of unbalanced weights which are rotated in such a fashion to cause a straight line or essentially straight line vibration transversely of the tubes and the direction of flow of the material therethrough to develop the required shearing action between the grinding balls.

In a preferred embodiment of the mill, the shearing action between the layers of balls in the mill units is increased by forming the conduits of relatively shallow rectangular cross-section provided with longitudinally extending corrugations which thereby cause the lowermost layer of balls to remain substantially in fixed position during vibration of the mill while the vibration causes the overlying layers of balls to move relatively and thus create shear in the viscous fluid which results in a much more rapid and effective grinding and more efficient utilization of the power input to the mill.

For a better understanding of the present invention, reference may be had to the accompanying drawings, in which

FIG. 1 is a top plan view of a typical form of mill embodying the present invention;

FIG. 2 is a sectional view taken on line 2—2 of FIG. 1;

FIG. 3 is a side elevational view thereof;

FIG. 4 is a view in section taken on line 4—4 of FIG. 1;

FIG. 5 is a view of a portion of the conduit containing grinding capsules shown partly in section and partly broken away;

FIG. 6 is an exploded side elevational view of a grinding cartridge for the mill;

FIG. 7 is an end elevational view looking toward one end of the grinding cartridge;

FIG. 8 is an end elevational view looking toward the other end of the cartridge;

FIG. 9 is an exploded perspective view of a modified form of mill unit embodying the present invention;

FIG. 10 is a plan view partially broken away of one of the conduits of the mill unit shown in FIG. 9; and

FIG. 11 is a side elevational and partially broken away view of the conduit.

A typical mill chosen for purposes of illustration is a two-unit mill having two grinding units **10** and **11** which are essentially the same and mounted on opposite sides of a drive unit **12** for vibrating the grinding units in a substantially horizontal path. As shown in FIGS. 2 and 3, the mill includes a base **14** formed of angle iron or other structurally strong material which supports a drive motor **15** for the mill adjacent one end thereof and is also provided with vertically extending flat leaf springs **16**, **17**, **18** and **19** which are mounted by means of clamping blocks **20**, **21**, **22** and **23** on the frame. The leaf springs may consist of one or more spaced apart leaves and, as illustrated, include two leaves. The clamping blocks may be mounted on vibration-absorbing cushions **24** to minimize transmission of vibration to the floor of a building on which the frame **14** is supported.

The four pairs of springs **16**, **17**, **18** and **19** support at their upper ends in a manner described hereinafter a generally rectangular frame **25** formed of angle iron or the like on which the drive unit **12** is mounted so that it is free to vibrate generally in a direction perpendicular to the length and width of the springs **16** to **19**.

As best shown in FIGS. 2, 3 and 4, the drive unit includes a pair of eccentric weights **26** and **27** fixed to or integral with shafts **28** and **29** mounted in bearings **30** and **31** and bearings **32** and **33**, respectively, in heavy bearing blocks **34** and **35** at opposite ends of the weights. A pair of parallel spacing plates **37** and **38** are bolted to the bearing blocks **34** and **35** or secured to them in any suitable way to support the shafts and the bearings rigidly as the weights **26** and **27** are rotated. As shown in FIG. 4, the weights are positioned so that they are opposed to each other or opposite from each other in a vertical plane and upon rotation will cause vibration in a generally horizontal plane. In order to rotate the weights, the motor **15** is provided with a multi-grooved pulley **39** for driving a similar pulley **40** on the shaft **29** by means of multiple belts **41**.

Mounted on the bearing block **35** is a closed casing **42** which houses a pair of meshing gears **43** and **44** mounted, respectively, on the shafts **28** and **29**. The housing **42** receives lubricant to lubricate the gears.

As shown in FIGS. 1, 3 and 4, a pair of plates **45** and **46** are attached to the plates **37** and **38** by means of bolts or the like and each plate **45** or **46** is provided with a series of removable clamping plates **47**, **48** and **49** having arcuate recesses **50** and **51** in their outer faces for receiving conduits **52** and **53** etc., which make up the grinding section of the mill and through which the material being ground and a suspending medium therefor flows. Other clamping blocks **55**, **56** and **57** having notches on their inner and outer edges are provided to clamp the conduits **52** and **53** and to receive a second series of conduits **58** and **59**. A third group of clamping blocks **60**, **61** and **62** also having notched edges are clamped in a retaining relation to the other blocks by means of suitable bolts **63** and to clamping plate **64** which extends along the length of each row of clamping elements and has its lower end secured between the upper ends of the pairs of leaf springs **16** to **19** which thereby support the drive unit **12** and the mill units **10** and **11** for vibration in a generally horizontal plane.

As shown in FIGS. 1 and 2, two sets of the clamping plates are provided for gripping the conduits **52**, **53**, **58**, **59**, etc., at spaced-apart points generally in alignment with the bearing blocks **34** and **35** to provide a two-zone support for each conduit. The reason for mounting the conduits between separate clamping blocks is that by providing blocks having arcuate recesses **50**, **51**, etc., of appropriate radius, conduits of different diameters can be mounted on the mills for handling different volumes and types of materials. Thus the conduits **52**, **53**, etc., may be an inch, one and one-half inches, three inches or more in diameter, depending upon the desired throughput of machine and the type of material being handled.

As shown in FIGS. 2 and 3, the conduits **52** and **53** and the other corresponding conduits making up the mill units are connected by means of detachable resilient elbows **67**, **68** etc., so that the several conduits making up each mill unit **10** and **11** are connected in series, and the material introduced, for example as shown in FIG. 3, in the lowermost, inner conduit **70**, will flow back and forth and upwardly through one series of connected conduits, horizontally between the uppermost conduits, and then back and forth through the outer row of conduits being discharged through the outer, lowermost conduit **71** in a continuous flow path.

The material to undergo grinding is introduced into conduits and flows through under pressure supplied by a pump, not shown, at a pressure which is appropriate to the material undergoing treatment. If the conduits of each mill unit are partially filled with balls throughout their lengths with appropriate screening to prevent movement of the balls from one conduit to another, highly fluid media could be passed through the conduits under a relatively low pressure at a relatively low power input and with a satisfactory throughput (volume flow rate), and satisfactory grinding would be accomplished by the vibration of the balls in the conduits. However, with highly viscous materials, only very low flow rates and relatively unsatisfactory grinding can be achieved, even when the medium is supplied to the mill units under high pressure and the mills are vibrated at high frequency.

In accordance with the present invention, the need for high pressures to cause the flow of viscous materials through the conduits is overcome and greatly enhanced grinding efficiency is achieved by inserting in each of the conduits **52**, **53** etc., a plurality of capsules or cartridges of the type disclosed in FIGS. 5 to 8. As shown therein, each capsule includes a cylindrical shell **72** of a size to fit snugly in the conduits of the mill units, the cartridges being insertable into and removable from the conduits by removal of the detachable elbows **67**, **68**, etc., which connect the ends of the conduits. The shells of the cartridges may be of appropriate diameter and may be of any suitable length, for example, from one and one-half to eight inches long, and are about 75 to 80% filled with grinding balls, such as steel balls **73** or other metallic or ceramic balls. The balls are retained in the shell by means of cup-shaped end caps **74** and **75**. As shown in FIG. 5, the rims **76** and **77** of the end caps **75** extend in the same direction and are spot-welded or otherwise secured within the ends of the shell so that the bottom of the cap **74** is substantially flush with the left hand end of the shell **72** as viewed in FIGS. 5 and 6, while the end of the rim **77** is substantially flush with the end of the shell **72**, thereby leaving a space **78** equal to the depth of the flange **77** at the end of the shell **72**.

As shown in FIGS. 7 and 8, the end caps **74** and **75** are provided with slots **79** and **80** or other openings to

enable passage of liquid therethrough but at the same time retain the balls 73 within the shell.

As indicated in FIG. 5, a series of such cartridges are arranged in end-to-end relation in each of the conduits with a space 78 between each of the groups of balls in the cartridges. It has been found that the space serves two functions in the grinding operation which promote grinding efficiency, prevent clogging and also assure a more uniformly ground product. As the material being ground suspended in a liquid medium flows through the conduits, it is subjected to shear and impact by vibration of the balls in the cartridges. The viscosity of the liquid medium tends to displace the balls in the direction of flow of the medium so that a few layers of the balls will pack against the end cup 75 and only a slight rolling of these balls will occur despite violent vibration of the mill. Nevertheless, the remainder of the balls are free to move and to exert a shearing and impacting action on the solids undergoing grinding. Some resistance to flow of the viscous medium and solid particles results because of the packed relation of a few layers of the balls adjacent the ends of the cartridge but this pressure is reduced when the liquid flows into the space 78 between the cartridges. A space of about three-eighths of an inch to an inch and a quarter in length between the capsules has been found satisfactory. The pressure reduction and free flow of the medium causes turbulent flow in the space which mixes the material passing adjacent the interior wall of the shell and the material passing through the zone spaced from the shell and maintains uniform distribution of the solid material in the suspending medium. As a result, more uniform grinding is produced, the throughput of the mill is increased and the expenditure for power for developing pressure for flow of the suspending medium and solid particles through the mill can be reduced on the order of 50 to 75%.

It was thought heretofore that the power required for driving a vibrating ball mill could be reduced and grinding efficiency improved by operating the mill at the resonance frequency of the system, that is, at the frequency of a system composed of a pair of opposing masses with interposed springs between the masses. In accordance with the present invention, it has been found that maintenance of a resonance frequency of a system is not essential to efficient grinding or reduction of power input. On the contrary, the most efficient grinding is obtained by maintenance of a high amplitude (stroke) and as high a frequency of vibration as possible. An amplitude of substantial magnitude is required for most efficient grinding. Thus, an amplitude of about three-eighths to one-half inch appears to be far more effective in grinding than an amplitude of a quarter of an inch. A frequency of about 40 c.p.s. is about as high as can be obtained with an amplitude of the magnitude of about three-eighths to one-half inch. Accordingly, by providing counter rotating weights 26 and 27 of suitable weight and eccentricity and driving them at approximately 40 r.p.s. to produce an amplitude of about one-half inch provides a grinding action which is suitable for treating solids suspended in fluid or in highly viscous media flowing regardless of the cross-sectional dimensions of the conduits and overall mass of mill units.

With mills of the type described, even the most difficult paint pigments can be ground to acceptable particle size with efficient utilization of power input and satisfactory throughput of material.

It will be understood that the above-described mill is susceptible to considerable modification as, for example, by omitting one of the mill units or including more or fewer series connected parallel conduits in each mill unit or by connecting the units 10 and 11 in series. Other changes may be made in the mill, for example, the provision of stiffening U-shaped frames 82 and 83 affixed to the base 14 which also serve to support the mills and the drive unit in the event that one or more of the spring elements should be broken as a result of prolonged use of the mill or to facilitate assembly and maintenance or repairs.

Mills of the type described above utilizing conduits of circular cross-section grind by a combination of a bodily movement of the balls and relative rotation between the balls and also by some shear between the balls. It has been determined that if the shear in the viscous fluid can be increased, grinding efficiency likewise is greatly increased and the power input to the mill is utilized better.

A preferred form of grinding unit providing greatly increased shear is shown in FIGS. 9 to 11. As shown in the exploded view in FIG. 9, the mill unit includes a casing or house 85 of rectangular cross-section which may be suitably composed of steel plates welded together to form a top 86, bottom 87, opposite sides 88 and 89 and an end cover plate 90 which closes one end of the casing. Flanges 91 and 92 extend laterally from the top and bottom of the casing to enable the casing to be welded or otherwise secured to a drive unit like the drive unit 12 described above. Mounted within the casing 85 is a container 93 formed of sheet metal having a closed end 94 and an open end 95. The container 93 is of smaller cross-sectional dimensions than the internal cross-sectional dimensions of the casing 85 to leave a space for flow of water therearound for cooling purposes, the water being passed through an inlet coupling 96 in the top 86 of the casing and an outlet 97 at the rear end of the side wall 89. A flange 98 around the open end 95 of the container is adapted to be sealed to the open end of the casing by means of an interposed gasket 99, a gasket 100 and a cover plate 101 which can be bolted, clamped or otherwise secured to close the open end of the casing 85. The cover plate 101 is provided with an inlet coupling 102 and an outlet coupling 103 through which the material to be ground suspended in a liquid is introduced and through which the ground material is discharged, respectively.

Within the casing are mountetd a series of conduits 104, 105, 106, 107, 108 and 109, the number of conduits varying as may be required for grinding a particular type of material. The uppermost conduit 104 has an inlet opening 110 at its outer end which is aligned with the inlet coupling 102, and the lower conduit 109 also has an outlet 111 which is aligned with the coupling 103. The intermediate conduits are of slightly different construction so far as the inlets and outlets are concerned and are illustrated in FIGS. 10 and 11. As shown therein, each conduit is a relatively shallow box-like member of rectangular cross-section having a top 112, a bottom 113, sides 114 and 115 and ends 116 and 117. Within each conduit, for example conduit 105, are pairs of spaced-apart slotted of otherwise perforated ball-retaining plates 118 and 119, 120 and 121 etc., which are retained in spaced relation by means of flat strip material 122 which may be imperforate or, as illustrated, provided with cutouts 123 to lighten them. The compartments between the left-hand end of the conduit and the plate 118, the compartment between the plates 119 and 120 and the compartment between the plate 121 and the right-hand end of the conduit are partially filled with grinding balls, not shown. The spaces between the plates 118 and 119 and between the plates 120 and 121 do not contain grinding balls. At the left-hand end of the conduit 105 are four inlet openings 124 which open through the top 112 of the conduit. At the right-hand end are four openings 125 which open downwardly through the bottom 113 of the conduit. The ends of the conduits may be reinforced by means of the perforatetd strip material 126 also serving to retain ball-retaining screens or plates 121*a* near the opposite ends of the conduits but inwardly with respect to the inlet and outlet openings. It will be seen that conduits of the type described can be in-

serted in the container **93** with the outlet openings of a higher conduit aligned with the inlet openings of the next lower conduit. The upper and lower conduits **104** and **109** differ from the conduits **105** to **108** solely in that the inlet of the conduit **104** is in the end wall **116** of the conduit rather than in the top wall and the outlet **111** also is in the end wall of the conduit **109** instead of the bottom wall thereof. In this way, the conduits are connected in series for flow of the suspension therethrough to be ground therein. In order to increase the amount of shear occurring in the suspension and correspondingly improve the efficiency of grinding, the bottom of each conduit is corrugated as, for example, by a plurality of rods **128** welded to the bottom **113** with the rods extending lengthwise on the conduit. The rods terminate in each ball-containing compartment of the conduit adjacent the separating screen **118**, **119**, **120**, **121** or **121***a*.

When a suspension of solids in liquid is passed through the mill unit, the balls adjacent the corrugated bottom of the compartments are retained relatively stationary because of engagement with the corrugations or rods while the upper layers of balls are vibrated back and forth relative to the lower layers and to each other so that the shear in the liquid suspension is increased throughout substantially its cross-section and movement of the balls as a single body is greatly diminished. Moreover, by positioning the sidewalls of the conduits substantially perpendicular or sloping somewhat relative to the top and bottom thereof, the tendency of the balls to roll as a group in an oscillatory fashion is substantially diminished and in this way the action of the movement of the balls in shear is increased so that the energy input to the mill is largely converted into shear which, as indicated above, produces a much more effective grinding than the rolling and sliding between the balls which characterized the prior vibrating ball mills. The enhanced shear action, together with the provision of the spaces between the individual grinding compartments or capsules in the conduits accordingly enables a much more effective utilization of power in the grinding action and a much decreased expenditure of power in pumping the liquid suspension through the mill unit, thereby enabling an efficient grinding, of materials suspended in very viscous fluids with a relatively reduced power input to the mill.

It will be understood that the conduits disclosed in the drawings are susceptible to modification and that different types of ball-retaining screens, spacers therebetween, and connections between the inlet and outlet ends of the conduits may be provided. Moreover, conduits of different internal dimensions and correspondingly dimensioned ball-receiving compartments or capsules of suitable lengths may be used in the mill units depending upon requirements.

Accordingly, the mills described above should be considered as illustrative and not as limiting the scope of the following claims.

We claim:

1. In a vibrating ball mill having an elongated conduit for flow of a suspension of solids therethrough, and means for vibrating said conduit substantially transversely to its axis, the improvement comprising a plurality of separate groups of grinding balls spaced apart lengthwise of said conduit and means confining said groups of balls in spaced-apart zones in said conduit while affording passage of the suspension of solids from one zone to another, said groups of balls partially filling said zones for vibration relative to said conduit and the spaces between said zones being free of balls.

2. The ball mill set forth in claim **1** in which said conduit comprises a plurality of substantially parallel sections of conduit connected in series for flow of said suspension therethrough.

3. The ball mill set forth in claim **1** in which said means confining said balls comprises a plurality of compartments in said conduit in end-to-end relation, each compartment being partially filled with a group of said grinding balls, apertured end plates fixed to said compartments for retaining said balls in said compartments and means in said conduit spacing an end plate for each compartment from an end plate of an adjacent compartment to provide mixing and pressure reducing spaces between said groups of balls.

4. The ball mill set forth in claim **1** in which said means confining said balls comprises a cylindrical tube, an apertured ball-retaining member at one end of said tube, another apertured ball-retaining member spaced inwardly from the other end of said tube, and group of grinding balls partially filling said tube between said retaining members.

5. The ball mill set forth in claim **1** in which said conduit is of rectangular cross-section and said means for confining said balls comprises at least one pair of perforated ball-retaining plates spaced apart lengthwise of said conduit and comprising corrugations in the bottom of said conduit extending lengthwise of said zones on opposite sides of said pair of ball-retaining plates.

6. The ball mill set forth in claim **5** in which said corrugations comprise a plurality of substantially parallel rods fixed to the bottom of said conduit.

7. The ball mill set forth in claim **1** in which the means for vibrating said conduit comprises a pair or pairs of eccentric weights, means supporting said weights for rotation around parallel axes and means for rotating said weights in opposite directions to develop a vibrating motion substantially transversely of the axis of said conduit.

8. The ball mill set forth in claim **7** in which said means for rotating said weights develops a vibrating motion having a frequency of about 40 cycles per second and an amplitude of about one-half inch.

9. The ball mill set forth in claim **7** comprising means resiliently supporting said conduit and said means for supporting said weights for movement in a substantially horizontal plane and means rigidly connecting said conduit and said means supporting said weights to transmit said vibrating motion to said conduit.

10. A grinding capsule for a vibrating ball mill comprising a tubular member, a first retainer at one end of said tubular member, a second retainer spaced inwardly from the other end of said tubular member and from said first retainer, said retainers being cup-shaped members each having a bottom and a peripheral flange fixed to said tubular member and the bottom of one of said retainers being substantially flush with one end of said tubular member and the outer edge of the peripheral flange of the other retainer being substantially flush with the other end of said tubular member, and grinding balls partially filling said tubular member between said retainers, the bottoms of said retainers having apertures therein for flow therethrough of a suspension of solids to be ground.

11. A grinding mill unit comprising a casing, a plurality of conduits of rectangular cross-section in superimposed relation in said casing, each of said conduits having a top, a bottom, sides and ends and an inlet and an outlet adjacent to the opposite ends thereof connecting said conduits in series for flow of a suspension of solids therethrough, a plurality of perforated ball-retaining plates spaced apart lengthwise of each conduit between the inlet and the outlet thereof and separating said conduit into a plurality of spaced-apart ball-receiving zones, and a ball-free zone therebetween, and said bottoms of said conduits having corrugations extending lengthwise of said conduits in said ball-receiving zones.

12. The grinding mill unit set forth in claim **11** in which the uppermost conduit has an inlet in one end, and an outlet in its bottom, said lowermost conduit has an inlet in its top and an outlet in one end any any intermediate conduits have inlets in their tops and outlets in their bottoms.

13. In a vibrating ball mill having an elongated conduit for flow of a suspension of solids therethrough, and means for vibrating said conduit substantially transversely to its axis, the improvement comprising a multiplicity of spaced-apart members dividing the conduit into at least two longitudinally spaced apart grinding zones and adapted to confine a group of grinding balls in each of said zones while affording passage of the suspension of solids from one zone to another and leaving a space free of balls intermediate adjacent grinding zones.

14. The ball mill set forth in claim 13 comprising in each grinding zone for impeding vibratory movement of a portion of the group of grinding balls in said zone thereby to promote a shearing action between said portion of the group of balls and at least another portion of the balls in said zone.

15. The ball mill set forth in claim 14 in which each grinding zone is substantially rectangular in cross section transverse to the longitudinal axis of the conduit.

16. The ball mill set forth in claim 15 wherein the means for impeding movement of said portion of the group of grinding balls includes means in the base of each zone defining alternating relatively raised and relatively depressed surfaces, the depressed surfaces being of a size and depth sufficient to at least partly capture balls in at least one layer of said group of grinding balls.

17. A vibrating ball mill comprising at least one elongated conduit mounted with its lengthwise axis disposed substantially horizontal and arranged for flow of a suspension of solids therethrough, means for vibrating the conduit transversely of its axis in a substantially horizontal plane, a group of grinding balls confined in a zone of the conduit, and means in said zone for impeding vibratory movement of a portion of said group of balls thereby to promote a shearing action between said portion and at least another portion of said group of grinding balls.

18. The ball mill set forth in claim 17 wherein the zone in which said group of balls is confined is substantially longitudinal in cross section transverse to the axis of the conduit and has in such cross section a width substantially greater than the height.

19. The ball mill set forth in claim 18 in which the base of the zone includes means defining alternating raised and depressed surfaces, said means constituting said means for impeding vibratory movement of a portion of the group of grinding balls.

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