Oct. 7, 1952 R. S. ROBINSON 2,613,036

VIBRATORY AND ROTARY BALL MILL

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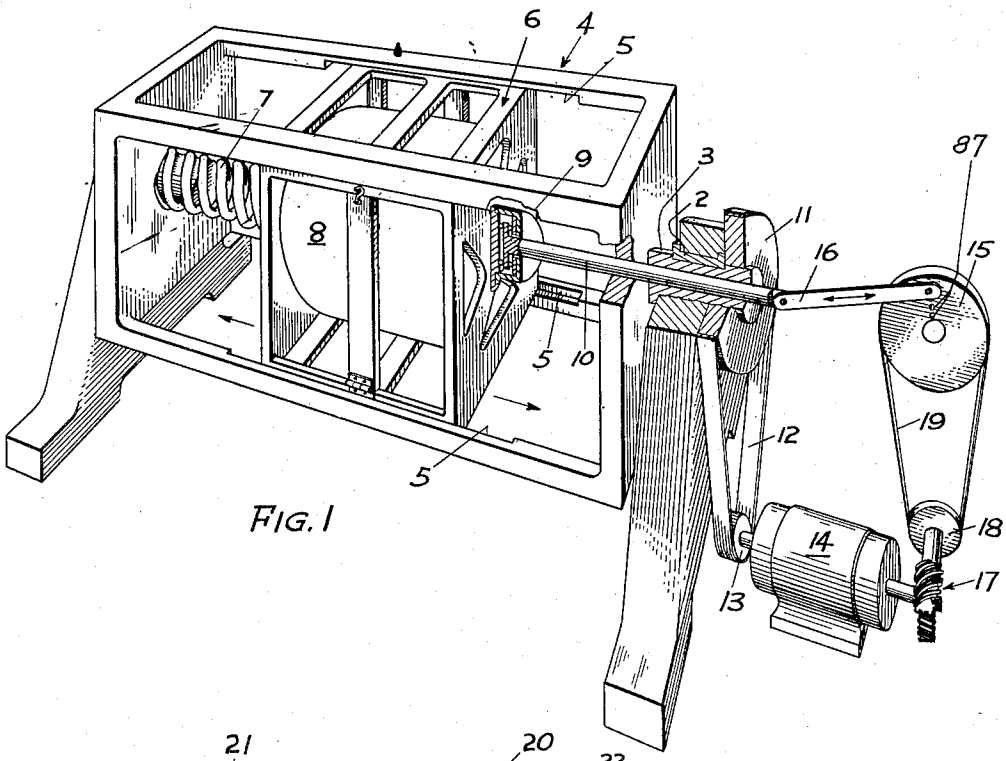


FIG. 1

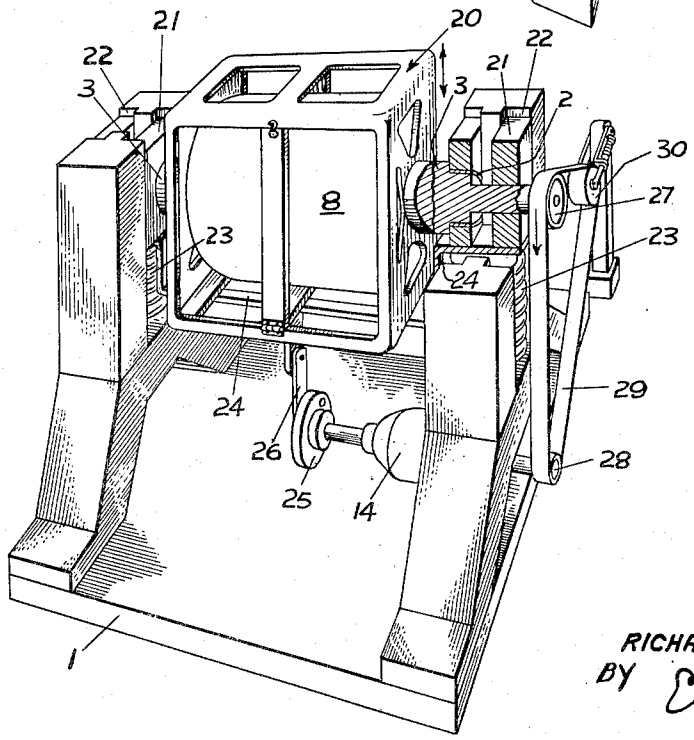


FIG. 2

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VIBRATORY AND ROTARY BALL MILL

Filed Jan. 11, 1947 5 Sheets-Sheet 2

FIG. 3

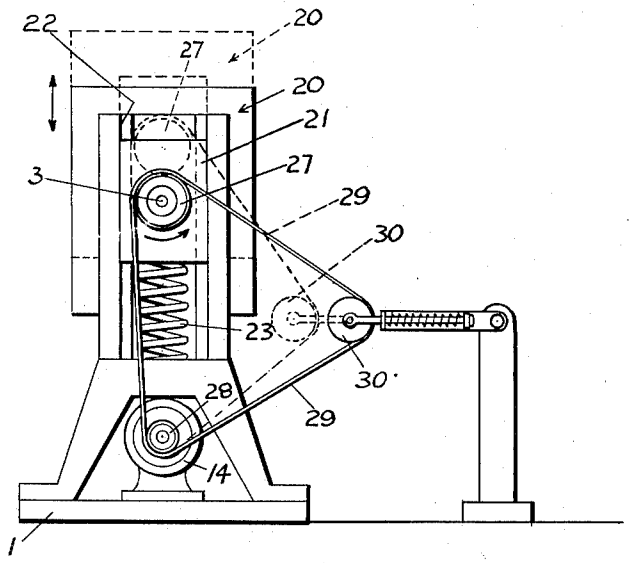


FIG. 6

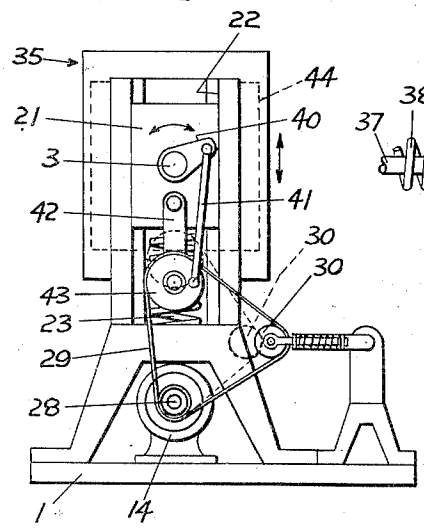
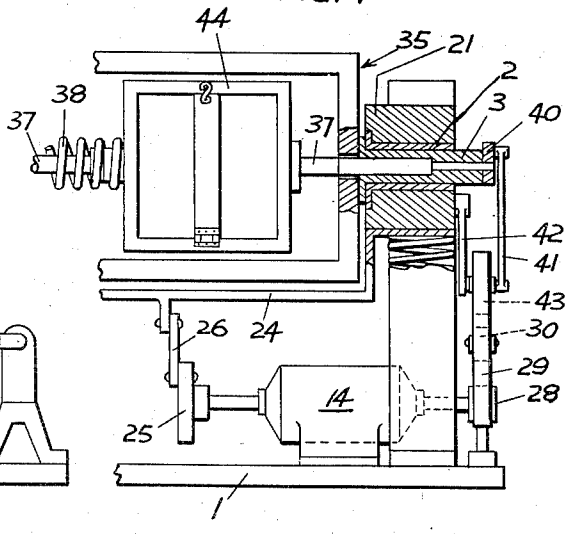


FIG. 7



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VIBRATORY AND ROTARY BALL MILL

Filed Jan. 11, 1947 5 Sheets-Sheet 3

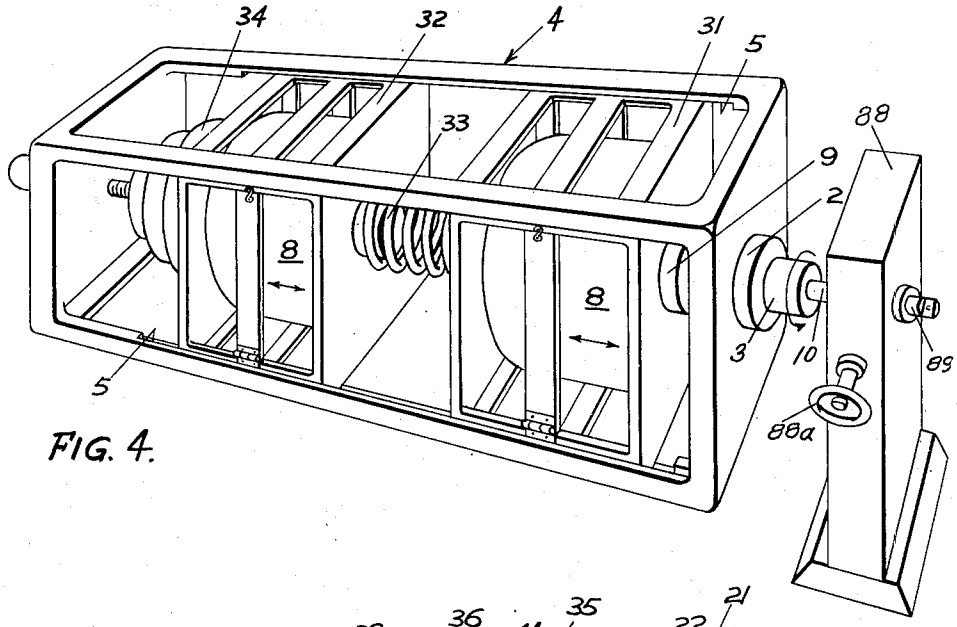


FIG. 4.

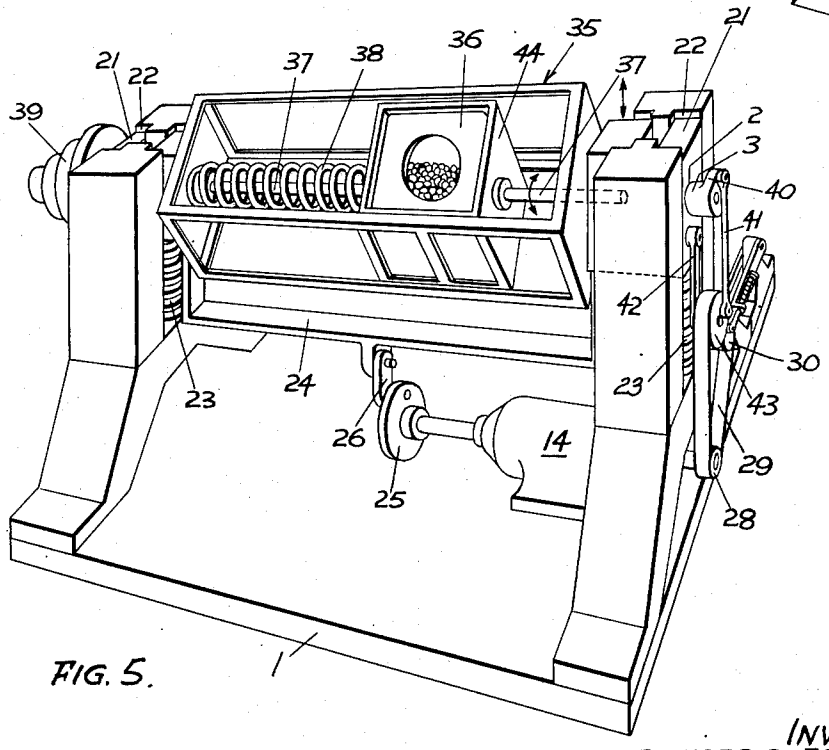


FIG. 5.

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VIBRATORY AND ROTARY BALL MILL

Filed Jan. 11, 1947 5 Sheets-Sheet 4

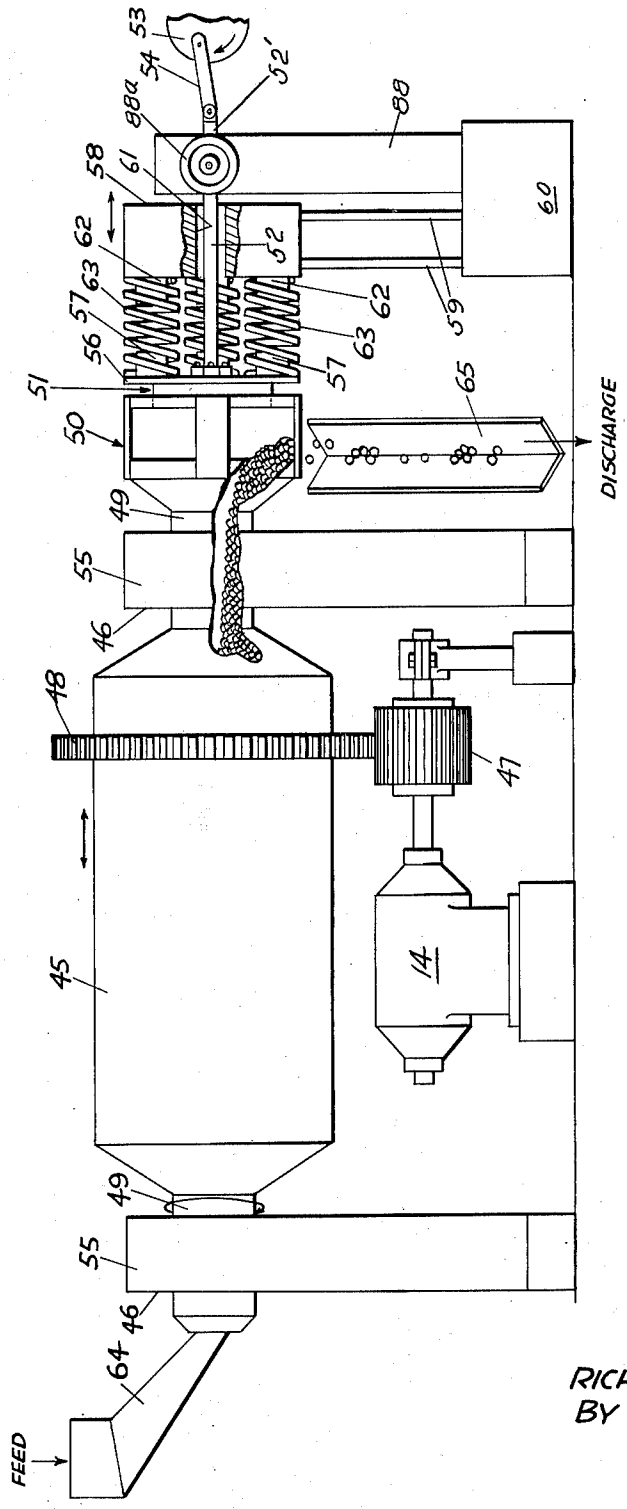


FIG. 8

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VIBRATORY AND ROTARY BALL MILL

Filed Jan. 11, 1947 5 Sheets-Sheet 5

FIG. 10.

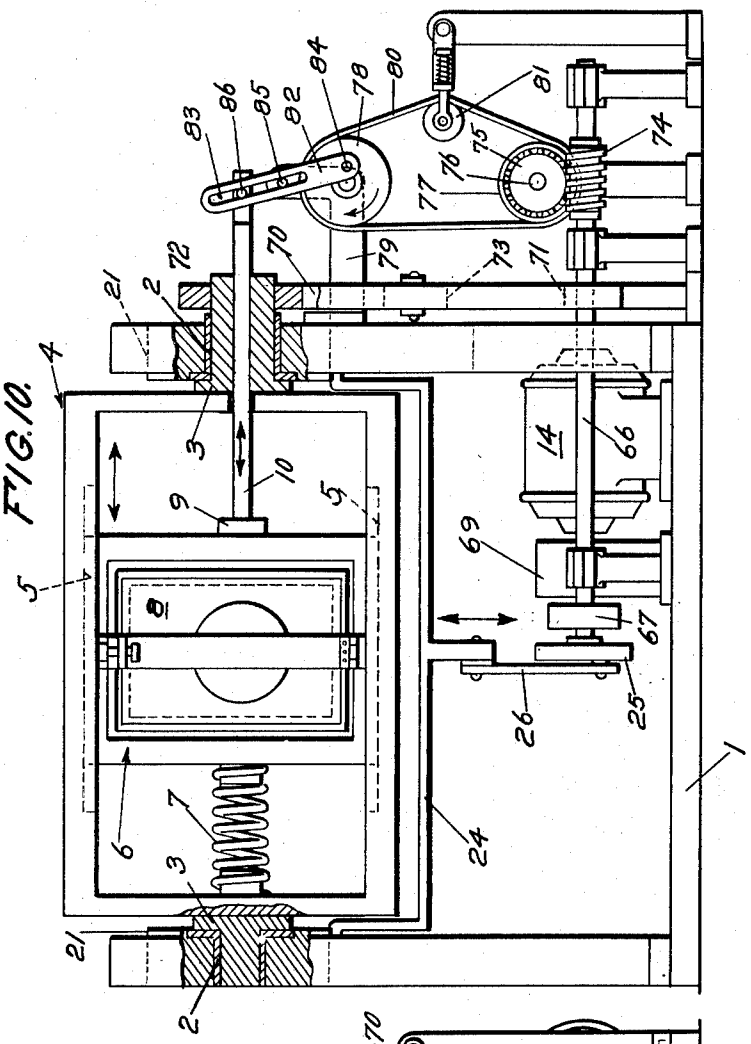
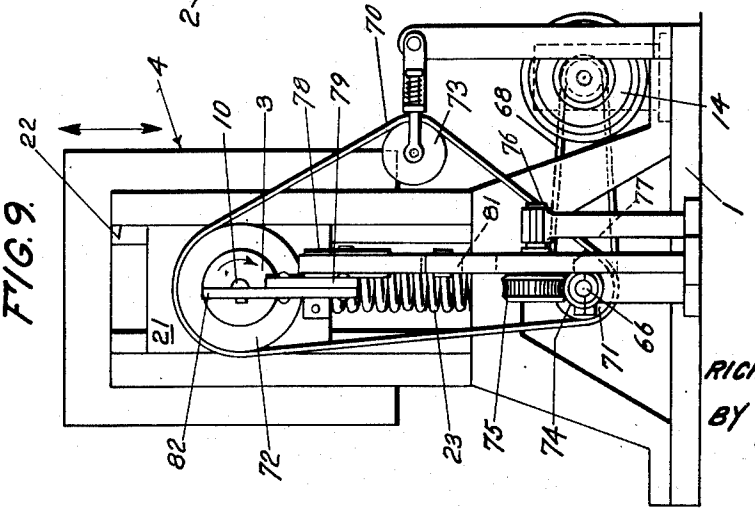


FIG. 9.



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Patented Oct. 7, 1952

2,613,036

UNITED STATES PATENT OFFICE

2,613,036

VIBRATORY AND ROTARY BALL MILL

Richard S. Robinson, Gloucester, Mass., assignor, by mesne assignments, to Vibro Dynamic Engineering, Inc., Boston, Mass., a corporation of Massachusetts

Application January 11, 1947, Serial No. 721,507

4 Claims. (Cl. 241—175)

1

This invention relates to comminuting or pulverizing machines, and more particularly to ball or rod mills for grinding solid materials into small particles.

In mills used for grinding materials, the speed with which the desired particle size may be obtained is largely dependent on the characteristics of the material being ground, but for a given material, mill, and ball size, there exists a critical speed of rotation for the maximum rate of grinding. If this speed of rotation is exceeded the balls and material tend to rotate with the container and the grinding efficiency is reduced.

An object of this invention is to increase the grinding efficiency of a ball or rod mill.

Another object is to raise the critical speed of a ball mill.

A further object is to effectively disperse the material in a ball mill, thereby preventing agglomeration of the material.

A still further object is to produce a greater grinding action in ball mills.

Still another object is to prevent the material being ground from coating the inside of the mill.

An additional object is to provide a novel mechanical movement for ball mills.

The foregoing and other objects of the invention will be best understood from the following description of some exemplifications thereof, reference being had to the accompanying drawings, wherein:

Fig. 1 is a perspective view of one type of apparatus embodying the invention;

Fig. 2 is a perspective view of another type of apparatus embodying the invention;

Fig. 3 is an end view of the apparatus of Fig. 2;

Fig. 4 is a schematic view of a modification of Fig. 1;

Fig. 5 is perspective view of still another type of apparatus embodying the invention;

Figs. 6 and 7 are side and front views, respectively, of the apparatus of Fig. 5;

Fig. 8 is a front view partly broken away of another apparatus embodying the invention; and

Figs. 9 and 10 are side and front views, respectively, of another apparatus embodying the invention.

It has been found that if a vibratory motion is imparted to a ball or rod mill, in addition to the rotation, an increase in grinding efficiency is obtained, in excess of that anticipated from the greater energy input. This is particularly true if the mill is made part of a resonant system and is operated at resonance, since the amount of

2

power required to maintain the vibrations is a minimum at resonance.

In regard to the comminuting or pulverizing action itself, a vibration along the horizontal axis of rotation not only produces a greater grinding action of itself, but by dispersing the material increases the rotary grinding action and even raises the critical speed, as defined above.

A vertical vibration normal to the axis of rotation provides an added impact of the balls against the material, and also tends to disperse the material.

Such dispersion of the material is particularly advantageous in dry milling or comminuting where agglomeration is sometimes severe. Also, the vibration tends to prevent the material being ground from coating the inside of the container. It is, therefore, the purpose of this invention to provide, in a pulverizing machine, vibratory or translatory motion simultaneously with the rotary motion. In the following specification and claims, the phrase "rotary motion" is used to refer to torsional or turning movements of less than 360°, in either direction, or in successive opposite directions in an oscillatory manner, as well as to repetitive 360° rotations in the same direction.

Now referring to the drawings, with particular reference to Fig. 1, a suitable fixed support includes a pair of spaced upright members 1 as shown. A bearing 2 is provided near the upper end of each of the upright members, these bearings being horizontally positioned and aligned. Journaled for rotation in bearings 2, about a horizontal axis, by means of a pair of stub shafts 3 fixed at opposite ends thereof, is an external framework 4 which may be four-sided and cage-like as shown. Each of the four horizontally-extending arms of the framework 4 has an elongated horizontal recess 5 cut therein, to thereby provide four horizontal guideways. Supported in these guideways for sliding or vibratory movement with respect to framework 4, and for rotary movement with framework 4, is a second cage-like frame 6, which is also four-sided. A helical or coiled spring 7 is horizontally positioned between framework 4 and one end of frame 6, by means of suitable abutments which extend into opposite ends of said spring, for a purpose which will be pointed out below; one end of this spring bears against framework 4 and the opposite end against frame 6.

The inner frame 6 is adapted to removably receive and support therein a container 8, said container being firmly mounted in this inner frame to follow the movements thereof. In container

8, which may be a porcelain jar of the type used in the conventional jar mill, are placed the material to be comminuted or pulverized and the relatively hard balls or rods. A thrust ball bearing 9 is fixed to the end of inner frame 6 opposite from spring 7, this bearing being coaxial with spring 7, shafts 3, and bearings 2. The outer raceway of bearing 9 is rigidly attached to frame 6. Attached to the inner raceway of bearing 9 is a horizontally-extending oscillatory shaft 10, this shaft being coaxial with stub shafts 3 and extending freely through one of said shafts 3 to a point external to the spaced upright support members, the corresponding shaft 3 being hollow for this purpose. Shafts 10 and 3 are free to rotate with respect to each other.

Stub shafts 3 and outer framework 4 (and thereby also inner frame 6 and container 8) are continuously rotated about a horizontal axis by any suitable means. For example, a pulley 11 may be rigidly attached to one of the shafts 3, this pulley being rotated in the direction indicated by the arrow by means of a belt 12 from a pulley 13 on the drive shaft of a motor 14. The relative diameters of pulleys 11 and 13 are made such that the number of revolutions per minute of container 8 is rather low.

In order to impart horizontal motion, or motion parallel to the axis of rotation, to container 8, the outer end of shaft 10 is attached eccentrically through a pivoted link 16 to a pulley 15, the axis of which is horizontal but is at right angles to the axis of rotation of the frameworks, this pulley being driven from motor 14 at a suitable angular velocity by means of worm-and-worm-wheel arrangement 17, through subsidiary pulley 18 and belt 19.

It is desirable, for different grinding actions or for grinding different materials, to be able to vary the amplitude of stroke, or the amplitude of vibration, of the mill from time to time. This adjustability of stroke may be effectuated in various ways. For example, a plurality of holes 87 may be provided in pulley 15, these holes being arranged radially of said pulley. By pinning link 16 to pulley 15 at any desired hole 87, it is possible to vary the stroke amplitude or the amplitude of vibration or horizontal motion of the container 8.

In the embodiment of Fig. 1, the container 8 is rotated about an axis passing therethrough, due to the rotation of both frameworks 4 and 6 about a horizontal axis by pulley 11. Since the inner framework 6 is capable of sliding movement on the surfaces or guideways 5 in a direction parallel to the axis of rotation, and since link 16 is reciprocated in the direction of the arrows by pulley 15, it will be seen that vibratory motion parallel to the axis of rotation, in the direction of the arrows, will be imparted to the container 8 simultaneously with the rotary motion thereof.

The mass of the vibrating system including the inner framework 6, the container 8 with its charge, the shaft 10 and the link 16, together with the stiffness of the spring 7, predetermine a resonant vibratory frequency for said system if the mass of frame 4 and its supports is large compared to that of jar 8 and frame 6. The mass of the material being ground in any ball mill is usually small compared to the mass of the balls, container, and frame so variations in the size or nature of the charge do not materially influence the predetermined resonance of the system. The type of apparatus shown in Fig. 1 is suitable for small mills such as bacilli mills, where the mass of the jar 8 and vibrating frame 6 is sufficiently small to consider the external frame 4 rigid. Here, then, we have a vibratory system, which has a predetermined resonant vibratory frequency, resiliently attached to a rigid support.

It has been found that, when such a vibratory system is vibrated at a frequency which is equal to its natural resonant vibratory frequency, the amount of power which must be expended to maintain the vibration is a minimum. In fact, the only input energy required is that necessary to overcome frictional losses and to supply the losses of the spring. By proper design, these can both be made extremely small. The losses are almost entirely in friction in the guides, there being almost no loss in the spring itself.

In this invention, the gear ratio at 17 and the ratio of diameters of pulleys 15 and 18 are made such that, in connection with the speed of rotation of motor 14, the vibratory system will be vibrated at its natural resonant vibratory frequency.

Now referring to Figs. 2 and 3, these figures show a means of vibrating a jar mill in a direction normal to the axis of rotation. In this case the fixed support 1 includes a pair of spaced upright members similar to those of Fig. 1. However, here the bearings 2 for the shafts 3 of the rotating frame 20 are mounted in opposite support members 21 which are slidably mounted in vertical guideways 22 provided in the upright members of support 1, so that said bearings are free to slide in a vertical direction. A coiled or helical spring 23 is positioned between each of the support members 21 and a corresponding abutment on the fixed support 1, in order to resiliently support the vertically movable parts. By means of these springs, the vertically-vibratile system is resiliently mounted in the fixed framework or rigid support 1.

The jar 8 is firmly but removably mounted in frame 20, so that it follows or partakes of the movements of said frame; as a result of the operation of the driving means to be described below, jar 8 with its charge has rotary motion imparted to it simultaneously with vertical vibratory motion.

The members 21 are attached to opposite ends of a horizontally-extending yoke 24 which in turn is attached to a means for vibrating the yoke in simple harmonic motion. This latter means comprises a disk 25 which is rotated by the drive shaft of motor 14, a pivoted link or arm 26 being fixed eccentrically to disk 25 at one end and to a downwardly-extending portion of yoke 24 at its opposite end. Thus, when disk 25 rotates, the yoke 24, members 21, frame 20, and jar 8 are reciprocated vertically. The eccentricity of link 26 with respect to disk 25 is made capable of being adjusted, as in the embodiment of Fig. 1, in order to vary the amplitude of the stroke or of the vertical reciprocation of frame 20. This adjustability feature is not shown, in order not to unduly complicate the drawing.

Frame 20 and jar 8 are also rotated about a horizontal axis simultaneously with this vertical vibration. A shaft 3, which extends through the bearing 2 in member 21, has fastened to the end thereof a pulley 27. A pulley 28, fastened to and driven by the output shaft of motor 14, drives pulley 27 by means of a belt 29, thus imparting rotary motion to the frame 20, jar 8 and its contents, about a horizontal axis through said jar, said axis being provided by shafts 3 and bearings 2. In order to allow for vertical motion of shaft 3 and thereby also pulley 27 during ro-

tation thereof, a resilient belt-tightening pulley **30**, which is pivotally mounted on a fixed support, may be used on belt **29**. Pulley **30** is spring-biased or weight-biased to maintain belt **29** tight at all times, and yet is resilient enough to permit vertical motion of pulley **27**. In this embodiment, as in that of Fig. 1, the mass of the vibratory system and the stiffness of springs **23** determine the natural resonant vibratory frequency of said system if the mass of support **1** is large compared to that of parts **8**, **20**, and **21**, and the oscillatory driving means **25**, **26**, etc. is designed to vibrate said system at a frequency equal to said resonant frequency. Therefore, the power needed to maintain the vibratory system in vibration is a minimum, while at the same time the grinding or pulverizing advantages of vibration along with rotary motion are obtained.

Now with reference to Fig. 4, this figure shows a system somewhat similar to Fig. 1, but utilizing a resonant vibratory system with two jars. The supporting frame **1** has been omitted from the drawing. The outer framework **4** is like that of Fig. 1 except that it is somewhat longer and has longer slots or guideways **5** therein. Mounted in these guideways for vibratory or sliding movement with respect to the outer framework, are a pair of spaced inner frames **31** and **32** which are substantially similar to each other and to the inner frame **6** of Fig. 1.

Firmly mounted in each of these frames is a jar or container **8** in which is placed the material to be comminuted or pulverized, these jars being mounted removably yet tightly in their respective frames so as to follow the respective movements thereof. Frame **31** resembles the frame **6** of Fig. 1 very closely, in that it has a bearing **9** fastened thereto at one end thereof, together with an oscillatory shaft **10** which extends through the stub shaft **3** to the exterior of the machine.

Shaft **10** is adapted to be horizontally reciprocated, through an adjustable clutch mechanism **88** to be described hereinafter, by a driving shaft **89** which is horizontally reciprocated, oscillated, or vibrated by means of an eccentric and link arrangement as in Fig. 1. As in Fig. 1, the eccentricity of the link is made capable of adjustment with respect to the rotating drive pulley, in order to vary the amplitude of horizontal vibration of the inner frames **31** and **32** and the containers.

Frame **32** is coupled to frame **31**, and thereby also to the vibratory driving means, only by means of a helical spring **33** the opposite ends of which contact, respectively, the adjacent ends of frames **31** and **32** and which forcefully surrounds and engages, near each end of said spring, projecting bosses integral with the adjacent ends of the respective frames; spring **33** engages frame **31** at the end thereof opposite from bearing **9**.

The natural resonant vibratory frequency of a vibratile system comprising two bodies connected together by a spring is

$$f=\frac{1}{2\pi}\sqrt{\mu\frac{m_1+m_2}{m_1m_2}} \qquad (1)$$

in which f is the frequency, μ is the stiffness of the spring, and m_1 and m_2 are the masses of the respective bodies. From the above equation, it can be seen that, for any certain fixed resonant frequency, the two masses need not necessarily be equal to each other, and actually can be quite dissimilar in magnitude. It is only necessary that the momenta (mass times velocity) on both sides of the nodal point be equal. If the masses are equal to each other, of course, the nodal point will be at the midpoint of the length of the spring.

The vibrating system of Fig. 4 is meant to be a resonant system, with the frame **32** and its jar acting as a compensating mass for the frame **31** and its jar. Each of the vibrating frames has a mass, which masses, together with the stiffness of the spring **33**, determine the natural resonant vibratory frequency of the vibratile system as a whole, and the vibratory driving means **10**, **88**, etc. is arranged to oscillate or vibrate the frame **31** at this frequency. Where less than a full-load charge is to be treated in the mill, the resonant frequency as defined in Equation 1 may vary, since the masses m_1 and m_2 will then have values different from their original ones. Since the driving motor has a substantially fixed speed, it may no longer be vibrating the masses at the resonant frequency of the system, which is an optimum condition. In this event, separate external masses may be added to both sides of the system to bring the resonant frequency of the system back to the proper value. One such external mass is shown at **34**, in the form of an adjustable counterbalancing means attached to the end of frame **32** opposite from spring **33**; a similar mass (not shown) may be attached to frame **31**. Such a mass could also be utilized on one side of the system when only a single jar is used in the system, to make up for the mass of the missing jar, or whenever, for any reason, there is inadequate mass on either side of the system.

It will be seen that the frames **31** and **32** constitute two vibratile masses connected by the spring **33**, frame **31** being adapted to be positively vibrated by the external vibrating means. When two masses are connected by a spring and one of the masses is set into vibration by an external means, it is well-known that the other mass will be set into vibration also by forces transmitted through the spring. Therefore, in the Fig. 4 embodiment, frame **32** will be vibrated by such forces, and, since the frames **31** and **32** are meant to be vibrated at their natural resonant vibratory frequencies, the vibrations of frame **32** will be always 180° out of phase with those of frame **31** (that is, when frame **31** moves to the left, frame **32** moves to the right, and vice versa).

In Fig. 4, the only power necessary to maintain the frames in vibration, at resonance, is that necessary to supply the elastic losses in the spring **33** and frictional losses, which losses can be made very small. As before, the power losses in the spring itself are very small, and most of the total loss is in the form of friction in the guides. It has been found, however, that substantially greater power is required to bring the vibrating system up to speed and the proper mode of vibration, from a standstill. On a small scale model, which the embodiments of Figs. 1 and 2 are intended to be, it is possible to throw the driving motor on the line, thereby bringing the vibrating system up to speed and the proper mode of vibration fairly easily. However, if such a procedure were attempted on a larger mill, such as that of Fig. 4, it would be impossible to get the mill started into proper vibrations without the use of an enormously oversized motor, which would be uneconomical because only a small motor is required to maintain the system in vibration at its resonant frequency. Therefore, synchronous starting is preferably resorted to.

An adjustable or variable clutch mechanism 88 is connected between driven shaft 10 and driving shaft 89. Mechanism 88 may be, for example, of the type described in Smith Patent 2,303,407, dated December 1, 1942, which is a mechanism for coupling a vibratory driving means to a vibratory system after the driving means has reached resonant speed. By operation of handwheel 88a, the vibrational amplitude transmitted from the source 89 to the vibratory system 10, etc. may be varied. In the procedure known as synchronous starting, the handwheel 88a is adjusted to the position corresponding to zero vibrational amplitude of the driven system 10, etc. Then the driving motor (not shown in Fig. 4) is thrown on the line and allowed to come up to resonant speed, thus rotating the outer framework 4. When the motor has reached resonant speed, handwheel 88a is operated to gradually increase the vibrational amplitude, of shaft 10 and the resonant vibratory system, from zero. In this way, the vibratory system is started into vibration at its resonant frequency; the driving motor does not have to pick up speed before reaching resonance, so that the load thereon remains small and a small motor may be utilized. Alternatively, the clutch mechanism may be a similar arrangement whereby the vibratory stroke can be varied while the drive motor is running.

In the two-vibrating-bodies machine of Fig. 4, there will be less vibration of the external fixed support means than in Fig. 1, due to the presence of the second vibrating system or compensating mass 32 which tends to exert a force on the support which is equal and opposite to that exerted by the system 31.

The pulverizing advantages of vibration of the mill along or parallel to the axis of rotation thereof are obtained with the Fig. 4 machine, as well as with the Fig. 1 machine, but in Fig. 4 twice as much material can be comminuted or pulverized as in Fig. 1, because there are two jars.

The machine of Fig. 4 could be coupled with the system of Fig. 2 to give both horizontal and vertical vibration, similarly to the combining of the apparatus of Fig. 1 with that of Fig. 2 to provide both vertical and horizontal vibration simultaneously with rotation, said combining being set out more fully hereinafter.

Now with reference to Figs. 5–7, this system illustrates a mill in which rotary motion is imparted to the mill back-and-forth through an angle of less than 360°, in the manner of torsional vibration, simultaneously with vertical vibration of the mill. As in Fig. 2, an outer frame 35 is journaled for rotary movement in bearings 2 which are mounted in opposite support members 21 which are slidably mounted in vertical guideways 22 provided in the upright members of fixed support 1. By means of springs 23, the vertically-vibratile system is resiliently mounted in the fixed framework or rigid support 1. The yoke 24 and means 14, 25, 26, etc. for vibrating the yoke 24 and frame 35 vertically are the same as described above in connection with Fig. 2. The eccentricity of link 26 with respect to disk 25 is made capable of adjustment, as in Fig. 2, for variation of the vertical stroke or of the vertical reciprocation of frame 35.

A trough or open-topped container 36 is positioned in frame 35 by firmly engaging an inner frame 44, frame 44 being journaled for free rotation with respect to frame 35, by means of pins 37 which are fixedly attached to opposite ends of the inner frame 44 and which are journaled in stub shafts 3 which are integral with frame 35. Frame 44 is sufficiently smaller in area than is frame 35, to provide proper clearances for unimpeded movement of the inner frame relative to the outer frame. Frame 44 is coupled to frame 35 mechanically by means of a helical spring 38 the opposite ends of which contact, respectively, one end of frame 44 and the adjacent end of frame 35, and which forcefully surrounds and engages, near each end of said spring, projecting bosses integral with said one end of frame 44 and said adjacent end of frame 35. The inner frame 44 is oscillated rotatively by the torsion applied through the spring 38 that is rigidly connected at its ends to the two frames 35 and 44.

There is a stub shaft similar to shaft 3 at the end of frame 35 adjacent spring 38, and this shaft extends outwardly beyond the space between the fixed upright members; at the end of this shaft there is attached an adjustable counterbalancing means 39 similar to that of Fig. 4.

Stub shaft 3 at the end of frame 35 opposite spring 38 also extends outwardly beyond the space between the fixed upright members, and at its outer end has fixed thereto a radially-extending plate 40. One end of a link or arm 41 is pivotally attached to the outer end of plate 40 (therefore, link 41 is eccentric with respect to shaft 3). A rigid bracket or support 42 is fixedly attached to the outer surface of the support member 21 which is remote from spring 38. Said bracket extending outwardly and downwardly from member 21 and carrying a bearing at its lower end in which is journaled for rotation a pulley 43.

The end of link 41 opposite from plate 40 is pivotally attached to pulley 43 eccentrically thereof; the eccentricity of link 41 with respect to shaft 3 is substantially greater than the eccentricity of said link with respect to pulley 43, so that continuous complete rotation of pulley 43 produces rotary motion of shaft 3 and frame 35 in an oscillatory, back-and-forth manner through an angle of less than 360°, which might be termed torsional vibration.

Pulley 43 is continuously rotated, by means of a belt 29, from a drive pulley 28 on the shaft of motor 14. In order to allow for vertical movement of yoke 24, members 21, frame 35, frame 44, trough 36, and the consequent vertical movement of pulley 43, by the vertical driving means 14, 25, 26, etc. aforesaid, while enabling torsional vibration or rotary motion of frame 35 to be simultaneously effectuated, a resilient belt-tightening pulley 30 is used on belt 29, similarly to Fig. 2.

By the operation of the above-described driving means, vertical motion (or vibratory motion normal to the axis of rotation) of frame 35 (and therefore also of frame 44 and trough 36, because of pins 37) is effectuated, simultaneously with rotary motion, or torsional vibration, of frame 35, about an axis through trough or container 36.

It will be noted that the external frame 35 plus whatever counterbalance 39 is necessary provides the resonant compensating mass for the mill. The rotary motion or torsional vibration is applied to this compensating mass and is transmitted, through torsional spring 38, to the inner frame 44 and trough 36, to cause said inner frame and trough to execute torsional vibrations along with its vertical movements, these torsional vibrations being in effect 180° out of phase with those of external frame 35. In this way,

the grinding or pulverizing advantages due to vibration of the mill simultaneously with rotary motion thereof are achieved.

It will be noted that two resonant vibratory systems are provided, one being the vertical system including springs **23** and the other being the torsional system including spring **38**. The masses of each of these systems, together with the stiffnesses of the respective springs, predetermine a natural resonant vibratory frequency for each system. The respective driving or vibrating means are designed to vibrate each of these systems at a frequency equal to its resonant vibratory frequency, the amplitude of the torsional vibration being substantially larger than the amplitude of the vertical vibration. Thus, the power required to maintain each of these systems in vibration is a minimum.

The modification shown in this figure is intended to be a small mill, so that a variable clutch mechanism for the vibratory system need not be used; motor **14** is thrown directly on the line to bring the vibrating system up to speed and the proper mode of vibration. "Synchronous starting" need not be utilized on this machine.

Due to the fact that the rotary motion of this mill is through an angle of less than 360°, the container **35** can be a trough, since a cover is not necessary. Also, the mill could be made continuous with either balls or rods. If desired, another container and balls could be used in this machine, making the apparatus analogous to that of Fig. 4. Such a modification could be made in a manner obvious to those skilled in the art.

Fig. 8 illustrates an apparatus in which a resonant mass is utilized in connection with a horizontally-vibrating continuous ball or rod mill. A cylindrical container **45**, which may be made of metal such as steel for example, is journaled for rotation about a horizontal axis passing through said container, by means of a pair of hollow shafts **49**, in and between a pair of fixed bearings **46** which are mounted near the respective upper ends of two spaced fixed upright members **55**. The outer raceway of each of these bearings **46** is mounted with some degree of looseness in its respective upright member, while rotation of said raceway with respect to said member is prevented by any suitable means, such as a key-and-keyway arrangement for example. Therefore, the container **45**, together with its bearings **46**, is free to move horizontally with respect to the fixed supports **55**, in addition to its being free to rotate about a horizontal axis.

Container **45** is rotated continuously about a horizontal axis by means of motor **14**, a driving gear **47** on the drive shaft of which engages a ring gear **48** fixed circumferentially to container **45**.

One of the shafts **49** is extended beyond or outside of the corresponding upright support member **55** for a substantial distance, and near its end is provided with an integral yoke structure **50** which joins said extended shaft to the outer (rotating) portion of a bearing **51**. The inner (nonrotating) portion of said bearing **51** is rigidly connected through a plate member **56** of substantial diameter to a shaft **52** concentric with said plate, said shaft being adapted to be horizontally oscillated, vibrated or reciprocated, through adjustable clutch mechanism **88**, by a driving means which may comprise a pulley **53** having a link or arm **54** pinned eccentrically thereto and which in turn is pivotally connected to the drive shaft **52'** of the clutch mechanism **88**. As in Fig. 1, the eccentricity of the link **54** is made capable of adjustment with respect to the pulley **53**, in order to vary the amplitude of horizontal vibration of container **45**.

Pulley **53** is adapted to be continuously rotated by any suitable driving means (not shown, but which may conveniently be motor **14**), to thereby cause horizontal vibration or reciprocation of shaft **52'**, shaft **52** (when handwheel **88***a* is properly adjusted), plate **56**, bearing **51**, yoke **50**, shafts **49**, bearings **46**, container **45**, and gear **48**, simultaneously with the rotation of container **45**, shafts **49**, and yoke structure **50**. In order to put the vibrating system into operation from a standstill, "synchronous starting" is used for the vibrating movements of the container, the handwheel **88***a* being operated accordingly. This "synchronous starting" procedure has been explained in detail above, in connection with Fig. 4, and briefly consists in bringing the driving motor up to a speed corresponding to resonance of the vibrating system before providing any amplitude of vibration, and then gradually increasing the amplitude of vibration from zero to the desired value, this being possible through clutch mechanism **88**.

A suitable weight or mass **58** is positioned concentrically with shaft **52** and is resiliently mounted, for example by means of a plurality of flat leaf springs **59**, on a fixed support **60**. Mass **58** has an aperture **61** extending therethrough, concentric with shaft **52**, of sufficient size to allow for free longitudinal movement of said shaft therein with respect to said mass. Mass **58**, for example, may be of the same diameter as plate **56**. Due to the above-described mounting, mass **58** is capable of executing horizontal vibrations.

A plurality of bosses **57** are fixed to plate **56**, having their centers arranged, for example, on the circumference of a circle concentric with said plate. A plurality of bosses **62** aligned with bosses **57** are fixed to the end surface of mass **58** which is adjacent plate **56**. A plurality of coil springs **63** are positioned between plate **56** and mass **58**, each of these springs having its axis horizontal and each spring firmly and tightly surrounding, at its opposite ends, a pair of aligned bosses **57**, **62**.

Mass **58** is arranged to act as a resonant or compensating mass for the mass comprising container **45** and its contents. When plate **56** is vibrated horizontally, by means of shaft **52**, at its resonant frequency determined by the mass of the container and the stiffness of spring **63**, mass **58** will be set into vibration at the same frequency, but 180° out of phase with the vibrations of said plate, by means of forces transmitted through said springs. Due to the provision of a resonant compensating mass, the amplitude of the vibrations transmitted to supports **55** is reduced, while at the same time the advantages of reduced input power for vibrating purposes are obtained.

The pulverizing advantages described in detail above are obtained with this apparatus, since in this mill vibratory motion is imparted to the container **45**, containing the balls or rods and the charge, simultaneously with the rotary motion thereof.

In order to make this mill continuous, shafts **49** at each end of container **45** are hollow, the container itself being provided with internal weirs and screens in the usual way, with balls of different sizes being placed in the separate chambers thus provided. A feed spout **64**, which connects

with the hole in the left-hand shaft 49, enables the charge of unpulverized material to be fed into container 45. The hole in right-hand shaft 49 connects with the yoke structure 50, which is an open framework, so that the pulverized material discharges through the openings in said yoke into discharge spout or trough 65 placed therebeneath.

Now referring to Figs. 9–10, an apparatus combining that of Fig. 1 with that of Fig. 2 is shown, whereby both vertical and horizontal vibration of the mill is provided, simultaneously with rotation thereof. These figures show a small mill, analogous to those of Figs. 1 and 2, which is capable of being started by throwing the driving motor on the line to bring the entire vibrating system up to speed and the proper mode of operation; "synchronous starting" is not necessary with such a mill.

An outer framework 4, similar to that of Fig. 1, is mounted for rotation about a horizontal axis by means of a pair of shafts 3 and a pair of horizontally-disposed aligned bearings 2 at opposite ends of said framework. Bearings 2 are fixed in corresponding vertically slidable members 21 which are adapted to slide in vertical guideways 22 provided in a pair of upstanding fixed spaced supporting members or standards fastened to a fixed support or base 1. Framework 4 is provided with horizontal guideways 5 similar to those of Fig. 1.

Mounted for sliding or reciprocating movement in guideways 5 is an inner frame 6, inside which is firmly fastened a jar or container 8 which contains the balls and the charge. Jar 8 partakes of the movements of frame 6. A helical spring 7 couples one end of frame 6 to framework 4. Frame 6 is mounted sufficiently rigidly in framework 4 to follow the rotary and vertically-reciprocating movements of said framework. A bearing 9, similar to that of Fig. 1, is fixed to the end of frame 6 opposite from spring 7 and permits rotation of frame 6 with respect to shaft 10, while at the same time coupling frame 6 to shaft 10 for horizontal vibration or reciprocation.

As in Fig. 2, a coil spring 23 is positioned between each of the sliding members 21 and a fixed abutment of support 1. In order to vibrate members 21, framework 4, and frame 6 vertically, a yoke 24 is provided, as in Fig. 2, the opposite ends of said yoke being attached to the respective members 21; yoke 24 is driven in simple harmonic motion by a linkage arrangement 25, 26 as in Fig. 2. The eccentricity of link 26 with respect to disk 25 is made capable of variation as in Fig. 2, in order to vary the amplitude of the stroke or vertical reciprocation of framework 4. In this case, pulley or disk 25 is fixed to a countershaft 66 which is horizontally positioned and is supported from support 1. Motor 14 drives shaft 66 at a suitable speed by means of a drive belt 68 which engages a pulley 67 attached to said shaft, a suitable speed-reducing mechanism 69 being interpositioned between motor 14 and belt 68.

Outer framework 4, and therefore also inner frame 6 and jar 8, are rotated about a horizontal axis by means of a drive belt 70, which drivingly connects a pulley 71 keyed to countershaft 66 with a pulley 72 keyed to shaft 3 which is integral with outer framework 4. In order to allow for vertical movement of members 21, and therefore also of shafts 3 and pulley 72, a belt-tightening pulley 73 is used on belt 70.

Innner frame 6 and jar 8 are horizontally vibrated or reciprocated by means of actuating shaft 10 which extends through a hollow shaft 3 and the inner end of which is attached to frame 6 by means of bearing 9. The shaft 10 is horizontally vibrated or reciprocated by a mechanism to be described below. A worm gear 74 is keyed to countershaft 66 near the outer end thereof, said worm engaging and driving a worm wheel 75 keyed to a suitably-supported and journaled stub shaft 76 whose axis is at right angles to that of shaft 66, shaft 76 also having keyed thereto a pulley 77. A pulley 78 is journaled in a bearing which is attached by a suitable bracket 79 to one of the sliding members 21. A belt 80 drives pulley 78 from pulley 77. In order to allow for vertical movement of pulley 78 as a result of vertical movement of member 21 to which said pulley is fixed, a belt-tightening pulley 81 is used on belt 80.

A rigid link or crank member 82 having an elongated longitudinal slot 83 therein is pivotally fastened eccentrically to pulley 78 by means of a pin 84. The eccentricity of pin 84 with respect to pulley 78 is made capable of variation, as in Fig. 1, in order to vary the amplitude of horizontal vibration of frame 6. A pin 85 is fastened to bracket 79 above and vertically aligned with the axis of rotation of pulley 78, said pin being engaged in slot 83. A pin 86 is fastened to the outer end of shaft 10, this pin also being engaged in slot 83. As will be apparent to those skilled in the art, the linkage mechanism 82—86 above described produces horizontal reciprocating motion of shaft 10 (and also of frame 6 and jar 8) when pulley 78 is rotated. It will be apparent, from the above description of the structure of Figs. 9–10, that horizontal reciprocatory, vertical reciprocatory, and rotary motions are simultaneously imparted to jar 8. By this apparatus, an extremely effective pulverizing action is produced, and the above-described advantages of simultaneous vibration and rotation of a ball mill are obtained to a greatly enhanced degree.

In the apparatus of Figs. 9–10, as in other figures, the mechanically vibrating systems are driven at their resonant frequencies, these frequencies being determined by the masses of the respective systems and the stiffnesses of their respective mountings, so that the desired minimum amount of power is all which must be utilized to maintain the vibrating systems in vibration.

Of course, it is to be understood that this invention is not limited to the particular details as described above, as many equivalents will suggest themselves to those skilled in the art. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of this invention within the art.

What is claimed is:

1. In a comminuting machine of the class described, a container for the material to be comminuted and loose pulverizing elements, said container being supported for rotary and vibratory movement, a vibratile body supported for compensatory vibratory movement with the container, resilient means mediate said container and said body, said means being disposed in the plane of the axis of rotation of the container and the axis of the body, means for rotating said container and means for inducing vibratory movement of said container and said body in said plane at natural resonant vibratory frequency.

2. In a comminuting machine of the class described, a pair of containers for the material to be comminuted and loose pulverizing elements, said containers being supported for rotary and vibratory movement, resilient means mediate the

containers and forming therewith a vibratory system, said means being disposed in the plane of the axes of rotation of the containers, means for rotating the containers and means for inducing vibratory movement thereof in said plane at natural resonant vibratory frequency.

3. In a comminuting machine of the class described, a container for material to be comminuted and loose pulverizing elements, said container being supported for rotary movement and for vibratory movement along the axis of the rotary movement, a body of a mass substantially corresponding to the total mass of the container and its contents supported for compensatory vibratory movement along the axis of rotation of the container, resilient means mediate said body and said container and forming therewith a vibratory system, means for rotating said container and means at one end of the system for inducing vibratory movement of said container and said body along their common axis at natural resonant vibratory frequency.

4. In a comminuting machine of the class described, a pair of containers for the material to be comminuted and loose pulverizing elements, said containers being supported for rotary movement along a common axis and for vibratory movement along said axis, resilient means mediate the containers and forming therewith a vibratory system, said resilient means being disposed on the line of said common axis, means for rotating the containers and means at one end of the system for inducing vibratory movement thereof along said axis at natural resonant vibratory frequency.

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