

Sept. 13, 1966

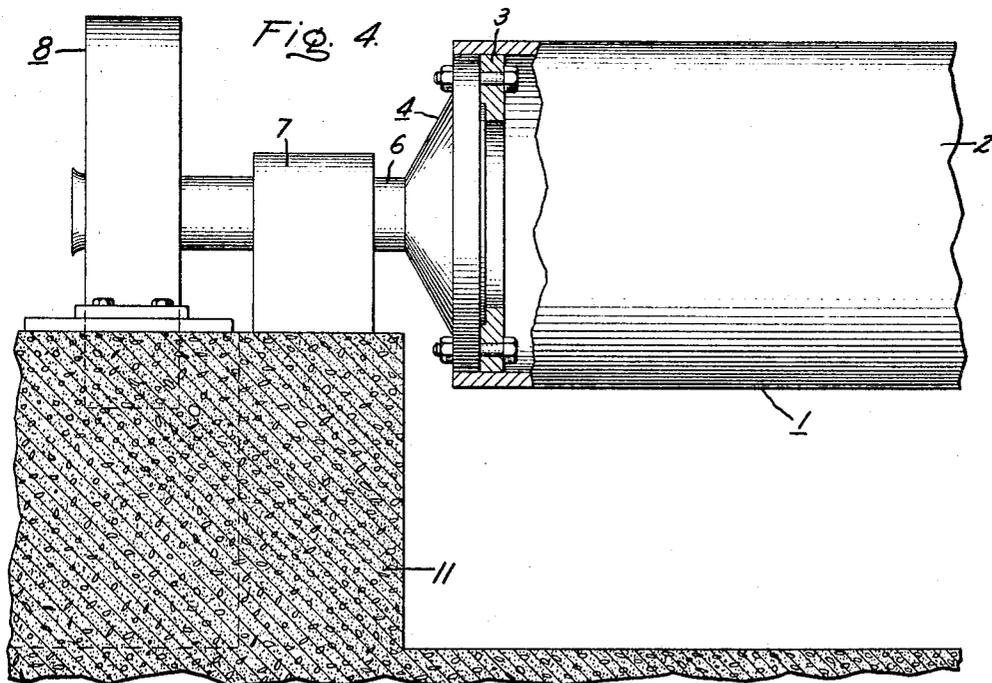
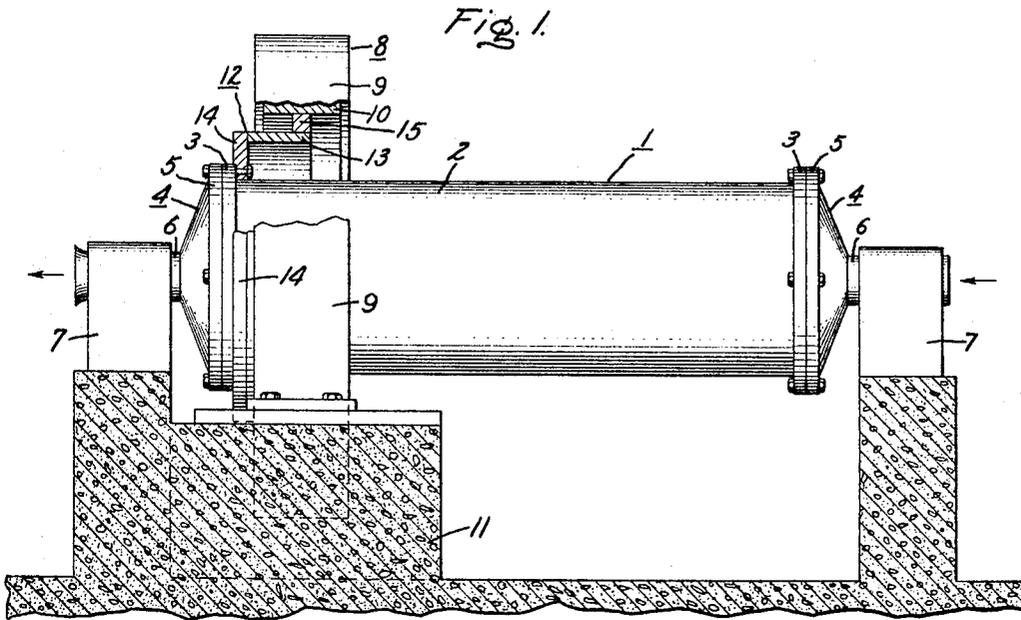
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3,272,444

GEARLESS ROTARY MILL

Filed Aug. 28, 1963

3 Sheets-Sheet 1



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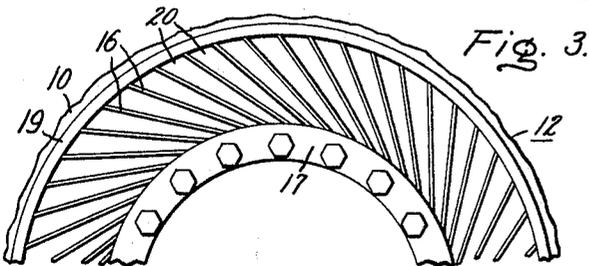
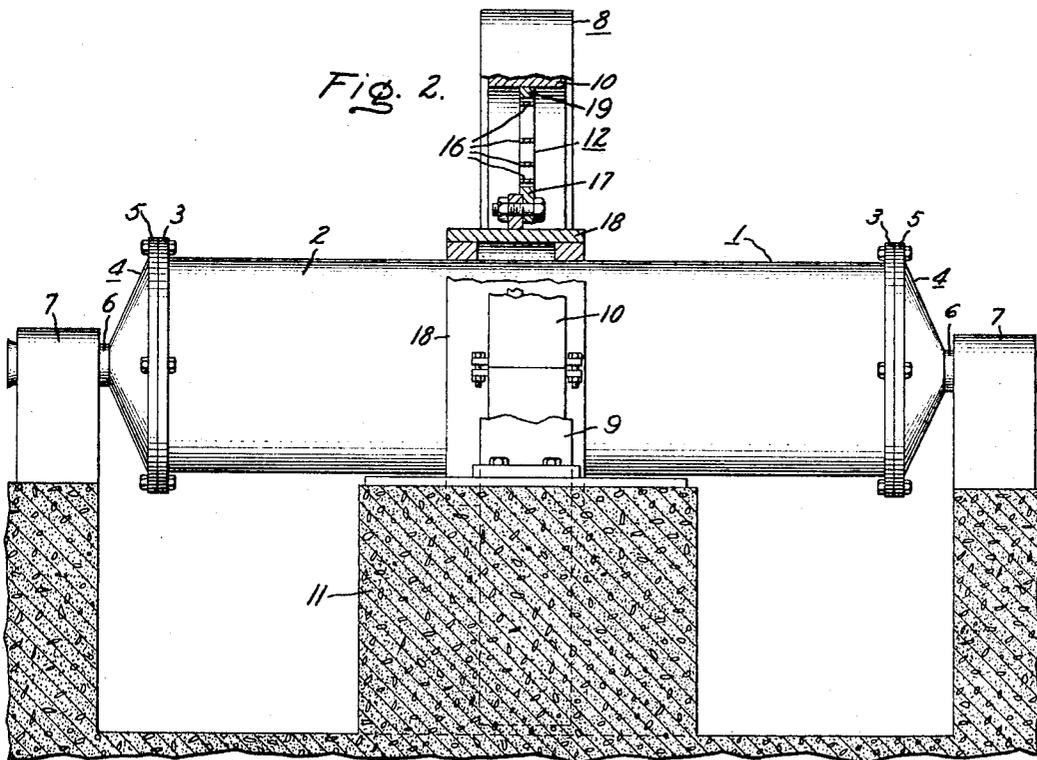
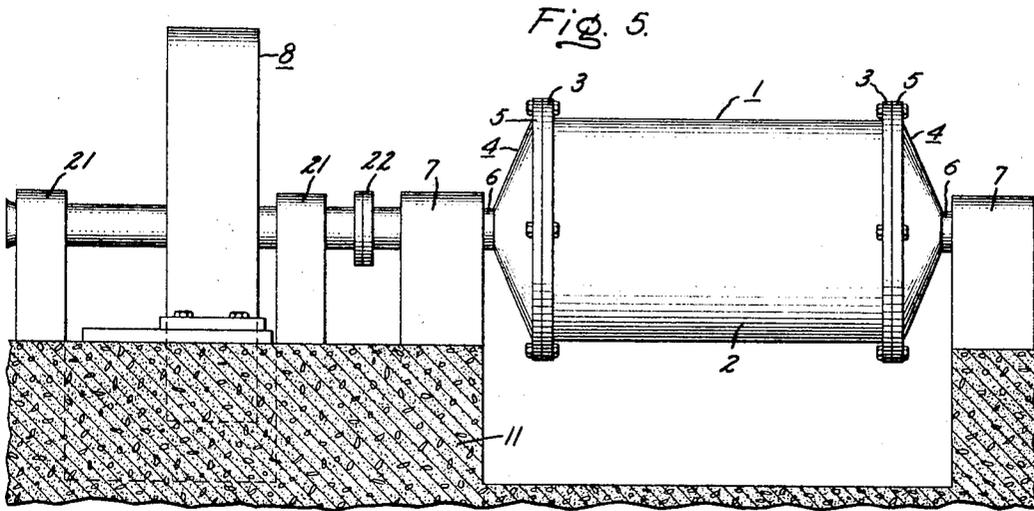
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5 Sheets-Sheet 2



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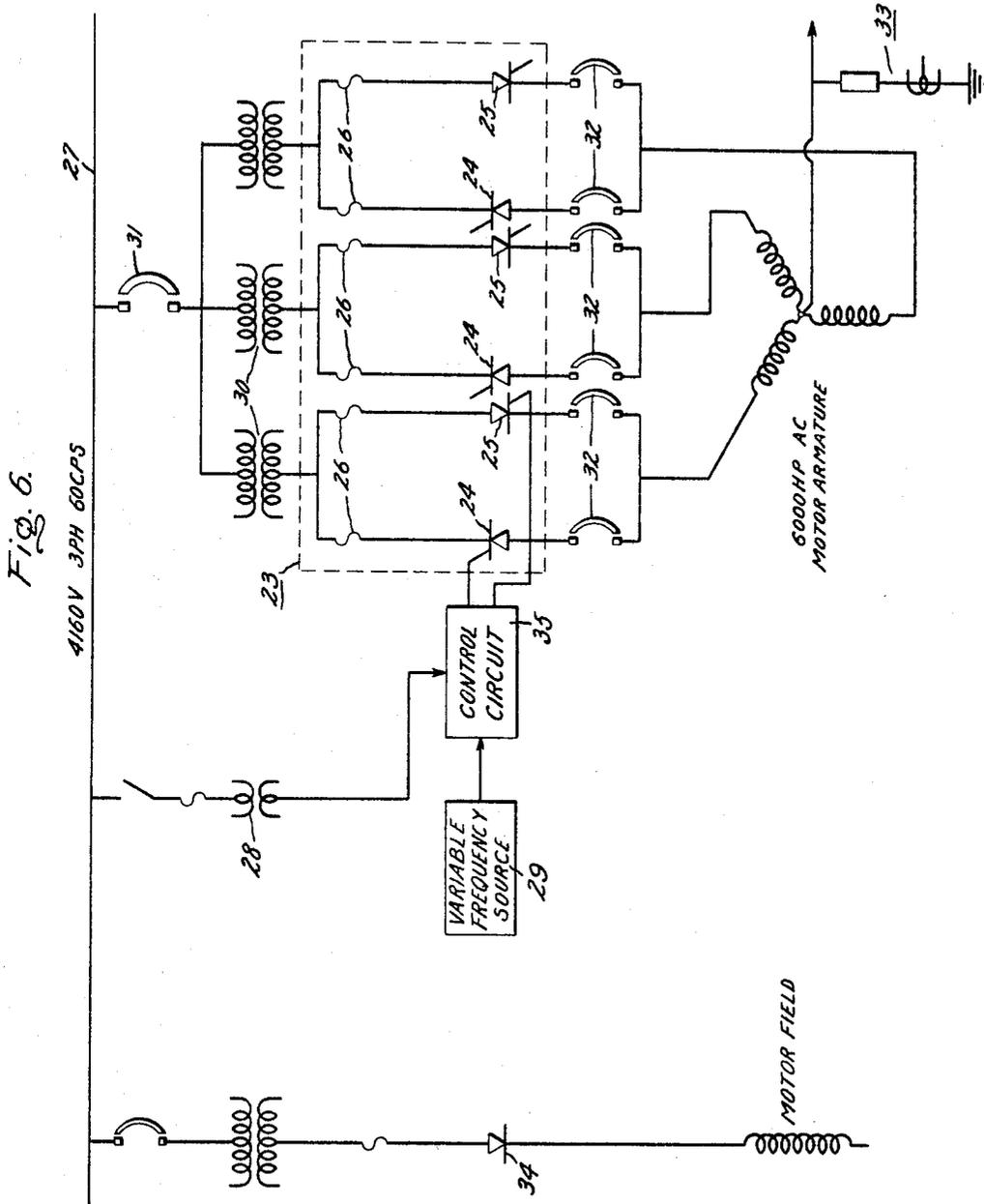
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3 Sheets-Sheet 3



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3,272,444

**GEARLESS ROTARY MILL**

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6 Claims. (Cl. 241—176)

Our invention relates to a direct driven rotary mill apparatus of the low speed, high torque type, and in particular, to the means for mechanically coupling the mill to the rotor of the driving motor and the means for providing a suitable electric power supply to the motor.

Rotary mills are a type of apparatus especially useful in applications where it is necessary that movement or agitation be imparted to the contents of a rotatable receptacle. The receptacle may have any of various forms depending upon the particular application. Such receptacles are often relatively large and comprise heavy metallic members having a weight of many tons. Rotary mills such as ball mills and rod mills find application in the grinding departments of cement industry and ore concentrating plants. Other applications of rotary mills are the cooling, heating, mixing, or chemically combining of contents within the receptacle.

The unbalanced movement of the material being ground within ball mills necessitates a low mill speed. The mill speed varies inversely with mill size (weight) and is typically in a range of 10 to 40 revolutions per minute (r.p.m.). The largest mills, as presently existing, weigh several hundred tons, and have maximum mill speeds of approximately 10–20 r.p.m. Such large mills require driving or mill motors having ratings of approximately 4500 horsepower. The conventional mill motors are of the synchronous type and are electrically energized from essentially fixed frequency alternating current power systems. Such energizing means are not economically suited to provide the large amounts of controllable low frequency power required for gearless drives. Thus, the armatures of conventional synchronous and squirrel cage induction rotary mill drive motors are energized with 60 cycle power and such mill motors in general have a speed rating in the range of 150–1200 r.p.m. The significant difference in speeds of the mill motor and mill requires a gear arrangement therebetween to obtain the necessary low mill speed. The gearing with its line-up problems—both initial and during operation—and attendant lubrication systems develop substantial maintenance problems. Further, a higher kilovolt-ampere consumption is required to start, accelerate, and pull into synchronous speed the conventional gear driven ball mill. Finally, the space requirements for the gear assembly extends the over-all length of the mill and driving arrangement. Thus, the elimination of the gears would provide many advantages over the rotary mills now in use and would also permit the maximum size of the mill to be increased greatly beyond present built limits of about 4500 horsepower.

Therefore, an object of our invention is to provide a gearless type rotary mill wherein suitable frequency conversion equipment permits low frequency energization of a low speed mill motor.

Although gearless rotary mills are known, their use has been very limited, and is unknown up to the present time in large size mills of the type employed in the cement industry, for example. In known gearless type rotary mills, the rotatable receptacle forms part of the rotor of the driving motor. The disadvantage of such gearless rotary mill becomes apparent during the initial period of operation of the mill at which time unequal temperatures and rates of temperature rise occur in the receptacle and rotor windings attached thereto. The

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differing temperatures may induce high mechanical stresses within the motor rotor and also vary the air gap between rotor and stator poles. The stresses may be so severe as to shear some of the retaining bolts of the rotor.

5 Further the induced high stresses in the rotor tend to produce an air gap at the rotor split in the case of split rotor motors. Such split rotor and stator configurations are generally employed in large size motors for ease in transportation and handling.

10 Therefore, another object of our invention is to provide a gearless type rotary mill apparatus wherein changes in the rotor-stator air gap and mechanical stresses within the motor rotor resulting from unequal temperature variation during mill operation are minimized.

15 Briefly stated, our invention provides a gearless type of rotary mill wherein the rotor of a low speed electric motor is spaced from a rotatable receptacle and is mechanically coupled thereto. In a first embodiment of our invention, the motor encircles the receptacle and the rotor is mechanically coupled to and supported from the receptacle by means of a plurality of resilient members. Such resilient members minimize mechanical stresses which would otherwise be developed within the rotor and rotor supporting members by nonuniform expansions and contractions produced as a result of unequal rates of temperature change within the respective structures and the receptacle. The rotor supporting members may be non-resilient in cases where the differential pressures and their effects are not large or where the temperature changes encountered are relatively small. A second embodiment of our invention comprises an arrangement of the rotary mill and motor wherein the motor does not envelop the mill but is aligned therewith and axially spaced therefrom.

25 The low speed synchronous motor which drives the rotary mill is energized by means of static type frequency converter power supply which converts power generally available at a frequency of 60 cycles to a substantially lower frequency.

30 The features of our invention which we desire to protect herein are pointed out with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings wherein like parts in each of the several figures are identified by the same reference character and wherein:

35 FIGURE 1 is a perspective view, partly in section, illustrating a first embodiment of our invention wherein the rotor of a driving motor is spaced from and mechanically coupled to an end portion of a rotatable receptacle;

40 FIGURE 2 is a perspective view, partly in section, of a second embodiment wherein the rotor is spaced from and coupled to an intermediate portion of the receptacle by means of resilient members;

45 FIGURE 3 is a detail side view of the resilient members shown in FIGURE 2;

50 FIGURE 4 is a third embodiment of a gearless rotary mill wherein the driving motor is axially spaced from the receptacle and is supported by a mill trunnion bearing; and

55 FIGURE 5 is a fourth embodiment wherein the driving motor is axially spaced from the receptacle and is supported entirely by its own bearings; and

60 FIGURE 6 is a one-line electrical diagram of the frequency converter power supply and motor circuit energized thereby.

65 Since our invention resides in the broad idea of employing an electric motor as a driving unit for the rotation of a rotary mill without the use of intervening transmission gearing, and since the selection of the prop-

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er type of motor is a matter of engineering design to one skilled in the art, we have not illustrated the same in detail. Furthermore, although our invention is useful in various types of rotary mills such as rod mills, tube mills, apparatus for roasting, cooling, or burning cement, and mixing cement, we have illustrated the rotary mill as a cylindrical ball mill in as simplified detail as possible.

In FIGURES 1, 2, 4, 5 there is shown a ball mill designated as a whole by numeral 1, and comprising a rotatable receptacle or mill shell 2 of cylindrical shape although other forms such as conical ended and hemispherical ended may be employed. Ball mill flanges 3 of the external type shown in FIGURES 1, 2, and 5 or the internal type shown in FIGURE 4 form the end portions of the ball mill. The ball mill is supported on either end by mill heads 4 which are aligned therewith. The large diameter end of each mill head is provided with a mill head flange 5 which is bolted to ball-mill flange 3. The small diameter end of each mill head is connected to a hollow mill trunnion shaft 6 which is rotatably supported by mill trunnion bearing 7. The material to be ground is introduced into the ball mill by being fed into hollow shaft 6 at one end thereof and is discharged therefrom by passing through the hollow shaft at the opposite end thereof, one example being indicated by the arrows in FIGURE 1. For the example illustrated in FIGURE 5, the hollow shafting for conveying of material in process can also terminate on the mill side of coupling 22.

Referring in particular to FIGURE 1, a low speed electric motor 8 of the alternating current synchronous type is shown disposed in concentric relationship with an end portion of ball mill 1. Motor 8 comprises a stator 9 and a rotor 10. Stator 9 is a conventional motor armature winding, and rotor 10 a conventional motor field winding, although it should be understood that such windings may readily be interchanged. Stator 9 is stationarily mounted on a foundation 11 which also supports the trunnion bearings 7. The disposition of rotor 10 relative to mill shell 2, and the means for mechanically coupling such members comprise a significant part of our invention. In the first embodiment of our invention as illustrated in FIGURE 1, rotor 10 is spaced from mill shell 2 and attached to an end portion of mill 1 by means of an offset rotor spider 12. Although spider 12 is shown as being connected to mill flange 3, it may alternatively be connected to head flange 5. Rotor spider 12 comprises a hollow cylindrical offset web member 13 which is concentric with mill 1, and radially extending members 14, 15 which are welded to web 13 at each end thereof. Member 15 extends radially outward of web 13 and is connected to the rim of rotor 10 in a suitable manner such as by welding. Member 14 may be of solid disk form or split. It may also have openings therethrough as required. Member 14 extends radially inward of web 13 and is attached to mill flange 3 by means of a rabbet fit and nut-bolt arrangement wherein the bolts pass through mill flange 3 and head flange 5. In like manner, web 13 may be offset in the opposite direction from that illustrated, that is, away from mill shell 2. Finally, there may be no offset at all, that is, a single radially extending web member may be employed as a rotor support member. This latter form has the least resiliency of the various arrangements described herein, and would be classed as essentially a non-resilient rotor spider.

A ball mill operates at temperatures which can have an extreme range of approximately 0° F. to 300° F., the lower temperature being that of the ambient atmosphere prior to mill operation. Mill operation over a substantial portion of such temperature range can develop a considerable mechanical stress in the rotor support members and rotor structure due to differential expansion or contraction of the various parts. Such changes in dimensions are occasioned by differential temperatures between motor rotor

and mill mounting parts arising from the unequal rates of temperature change sustained by such various parts. In particular, the temperature rise in the motor invariably occurs at a different ratio and stabilizes at a different operating temperature than in the mill. The unequal rates of temperature change are especially pronounced during the period of initial mill operation in a cold ambient atmosphere. In the absence of means for compensating for such thermal expansions and contractions, the driving motor may have poor operating characteristics, and in the extreme case, may be physically damaged. In particular, in the case of a split rotor-split stator motor, the bolts which join the two rotor halves can undergo a severe stress and result in an air gap formation at such rotor split. The air gap between the rotor and stator may also be adversely affected by such differential expansions and contractions. Spider 12 may provide a rigid support for the motor rotor or may be designed to compensate for differential expansion and contraction of the mill and motor rotor with varying temperature. A rigid rotor support is obtained by manufacturing radially extending member 15 in the form of a solid or split disk, or a disk with openings there-through for handling and other purposes. A resilient offset rotor support which is adapted to compensate for thermal expansion and contraction is provided by manufacturing member 13 in the form of a comparatively thin cylinder, with or without openings in it but welded to members 14 and 15. Another form of a resilient offset rotor spider construction includes member 15 in the form of spokes arranged somewhat tangentially as illustrated in FIGURE 3, or of the combination of a thin cylinder for member 13 and the spokes for member 15. As another example, member 15 may be a solid disk, and members 13, 14, 15 are manufactured from sufficiently thin steel to provide the desired resiliency.

A specific example of the apparatus illustrated in FIGURE 1 consists of components having the following approximate dimensions: ball mill 1 has a length of 36 feet, diameter of 17 feet and weighs 300 tons. Motor 8 is a 6000 horsepower, 12.8 r.p.m., 1080 volt, 3 phase, 7.7 cycles per second synchronous motor having a rotor inner diameter of 22 feet, a stator outer diameter of 30 feet and an axial length of six to seven feet. Member 15 consists of a three inch thick radial disk. Disk member 14 has an inner diameter of 17½ feet, outer diameter of 19½ feet, thickness of five inches and is constructed of low carbon or mild steel. For the resilient case, spider web member 13 is manufactured of two inch and is 45 inches in axial length. A relatively rigid connection between the rotor and mill is utilized in applications where differential pressures and their effects (forces), produced by unequal temperatures are of relatively small magnitudes, such as obtained from temperature differences as large as approximately 30° F. A rigid coupling of the rotor to the mill in the above example is obtained by constructing member 13 in the form of a four inch thick cylinder.

FIGURE 2 illustrates a second embodiment of our invention wherein the driving motor 8 encircles the mill shell 2 in a region intermediate the ends of the ball mill. Rotor 10 is illustrated as being of the split type, it being understood that the rotor and stator of all the illustrated motors may be of such manufacture, especially in the larger sizes. The rotor support member, spider 12, is illustrated as a resilient member comprising a plurality of metal bars 16 extending outward from a hub member 17 which is bolted to a mounting support 18 welded to mill shell 2. The outer ends of bars 16 are welded to a ring shaped member 19 which is connected to the rotor rim, or they may be attached directly to the rim. An end view of the rotor supporting member is shown in FIGURE 3. An alternative form of resilient spider 12 comprises recessed or cut out portions 20 in an originally solid disk rotor spider web as indicated in FIGURE 3. Resilient members 16 may also extend radially outward in the manner described for the FIGURE 1 embodiment. Also, rotor

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support member 12 may be solid or split disk, with or without openings, of sufficient thinness to provide the desired resiliency or of sufficient thickness to provide rigid support. Finally, rotor support member 12 may be a solid or split disk, with or without openings, but with member 18 being of resilient construction.

FIGURE 4 illustrates a third embodiment of our invention wherein motor 8 is aligned with ball mill 1 and axially spaced therefrom. An internally flanged mill is indicated in FIGURE 4, although it should be understood that such mill may be externally flanged as shown in FIGURES 1, 2, and 5. This third embodiment illustrates a direct driven ball mill wherein the over-all height is reduced by extending the over-all length. The rotor of driving motor 8 is connected to hollow mill trunnion shaft 6 or an extension thereof, and is supported entirely by mill trunnion bearing 7.

A fifth embodiment of our invention is illustrated in FIGURE 5, and is similar to the embodiment illustrated in FIGURE 4. The motor rotor is supported by one (not shown) or two bearings 21 and a solid or flexible type of shaft coupling 22 may be inserted between the motor and mill. The rotors in the FIGURES 4 and 5 embodiments may be directly connected to shaft 6 since the thermal variation problem is minimized in such configurations. In FIGURE 5, an alternative and substantially less costly arrangement results by inserting the mill feed or discharge between appropriate flanges (not shown) on the now solid motor shaft and hollow mill shaft 6 adjacent coupling 22.

Several embodiments of a gearless or direct driven rotary mill apparatus have been described and illustrated hereinabove. Over-all mill maintenance costs are reduced since gear wear and gear lubrication are eliminated. Further, the elimination of the gears reduces over-all (mill and drive) length. The electric current demand for starting, accelerating, and pulling of the mill into synchronism is also reduced due to the elimination of the inertia of the gears, and more importantly, due to the particular over-all characteristics which the system of the combined drive motor and its power supply provide. Mill feed and discharge are simplified since the path for the material comprises hollow mill trunnion shaft 6 and includes passage through the motor rotor in all but one of the described embodiments. Thus, the maximum size of ball mills can be increased almost indefinitely beyond the limits presently imposed by gear driven mills.

Synchronous drive motor 8 must of necessity be a low speed, high torque motor in order to obtain a direct drive between the motor and ball mill. However, a low speed (10-20 r.p.m.), high torque synchronous motor which is designed to be energized by conventionally available 60 cycle power may comprise a structure having hundreds of poles, small air gap, and low efficiency. Thus, of necessity, motor 8 must be energized from a low frequency (0-15 cycles per second) power source. Conventional adjustable frequency motor-generator sets cannot economically provide such low frequency power. We avoid such disadvantages by utilizing a system of electric valves, such as mercury arc tubes or silicon controlled rectifiers, suitably arranged and controlled to form a high power, high voltage, frequency converter power supply. While the desired result can be obtained by connecting a 3-phase power rectifier and inverter in series between a source of 3-phase 60 cycle electric power and the armature windings of the motor 8, with the inverter being designed in a known manner to have an adjustable frequency output of the proper range (such as 0-15 cycles per second), we prefer to use the arrangement shown schematically in FIGURE 6.

FIGURE 6 is a one-line electrical diagram of the preferred frequency converter power supply and the motor circuit energized thereby. Frequency and power control is accomplished by phase retardation of 3-electrode electric valves (silicon controlled rectifiers) located in individual power units of a static frequency divider circuit 23.

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The circuit 23 comprises three separate pairs of reversely-poled parallel power units, represented symbolically at 24 and 25, respectively. Each individual unit actually comprises a plurality of silicon controlled rectifiers interconnected to form a three-phase bridge circuit, with the D.-C. terminals of the paired circuits 24 and 25 being paralleled to supply bidirectional current to the connected phase of the armature windings of the motor. The number of serially connected rectifiers within each unit is determined by the voltage rating of motor 8. The number of units employed in parallel is determined by the current rating of the motor and the duty cycle of the load. The circuit 23 also contains protective fuses 26, surge suppression resistors and capacitors, indicating lamps and current limiting reactors (not shown).

The respective periods of conduction of the silicon controlled rectifiers which comprise the reversely-poled power units 24 and 25 are suitably varied and controlled, by means of the control circuit 35 shown in block form in FIGURE 6, so that these units supply the motor windings with electric current having the desired frequency and having a wave form approximating that of a sine wave. Each pair of units is provided with its own control circuit 35, although only one block has been shown. Techniques for designing the control circuits are known in the art.

The circuit 35 is provided with a 3-phase 60 cycle signal derived from the power bus 27 by way of transforming means 28, and a 3-phase variable frequency control signal is also applied. The latter signal is derived from a suitable source 29 representing for example, a small, variable frequency three-phase alternator, although other variable frequency alternating voltage sources may alternatively be employed. The variable frequency signal controls the voltage and frequency of the three separate reversing electrical energy supplies, one for each phase of the motor windings, to obtain balanced three phase variable frequency motor terminal voltage. The motor armature power supply is thus adapted to provide three phase adjustable voltage which has been converted from 60 cycles to a frequency range of 0 to 25 cycles per second. Since the particular details of the control circuit 35 are not being claimed as our invention, they need not be further disclosed herein. Power transformers 30 for reducing the voltage of the main bus 27 to the voltage rating of the motor, main bus switchgear 31, rectifier isolating circuit breakers 32, and suitable means 33 for detecting and limiting ground faults in the motor comprise the remainder of the major components in the adjustable frequency synchronous motor armature power supply. A typical main power bus 27, which distributes three phase, 60 cycle power at 4160 volts is shown by way of example.

A motor field energizing circuit, including rectifying means 34, provides field excitation for the motor rotor. The field circuit is shown connected to the main power bus through transforming and switching means.

The power supply described hereinabove permits the use of a synchronous motor 8 having such desirable characteristics as, a practical number of field poles having reasonably sized pole pitches (and thus a motor of moderate physical size), high efficiency (approximately 95%), and a relatively large rotor-stator air gap (approximately 0.4 inch) which readily permits mounting of the rotor on support members as described hereinabove.

From the foregoing description, it can be appreciated that our invention makes available a direct-driven or gearless rotary mill which is especially adapted for high torque, low speed applications. Gearless type drives have not previously been utilized for such applications, and this is especially true in ball mills. The means employed for resiliently or rigidly mechanically coupling the motor rotor to the mill and the use of a static frequency conversion power supply permits the practical use of low speed, low frequency motors and thereby achieves our invention.

Having described a new gearless rotary mill, it is believed obvious that modifications and variations of our

invention are possible in the light of the above teachings. Thus, the motor rotor may be supported from the mill in spaced apart relationship by members having a variety of configurations other than disclosed hereinabove. In particular, the rotor may be directly connected to an extension of mill flange 3 or head flange 5. Further, the power supply for the motor armature may utilize other rectifying means such as ignitron (mercury arc) tubes. Finally the driving motor need not be limited to the synchronous type and may be an alternating current wound rotor induction motor or a direct current motor. These latter type motors are not preferred, however, for the following reasons. In the direct current motor, the size and cost is large and presents the problem of splitting the commutator. In the induction type motor, the inherently small air gap creates problems in mounting the rotor around the mill shell, it is also difficult to split the rotor, and still maintain good efficiency and power factor. It is therefore, to be understood that changes may be made in the particular embodiments of our invention described which are within the full intended scope of the invention as defined by the following claims.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. A relatively low speed gearless rotary mill adapted to minimize mechanical stresses which are induced within the rotor of a driving motor due to unequal thermal expansions and contractions within the rotor and mill members, comprising
  - a rotary mill comprising a rotatable receptacle for treating material in said receptacle while said receptacle is being rotated, and
  - an electric motor having a rotor and stator, said stator being stationarily mounted, said rotor being spaced from said receptacle and resiliently supported therefrom whereby said receptacle is rotated by said motor through a resilient gearless driving arrangement which minimizes mechanical stresses that tend to be developed within the motor rotor due to unequal temperature conditions resulting from mill and motor operation.
2. A direct-driven ball mill comprising
  - a ball mill comprising a rotatable receptacle for treating material in said receptacle while said receptacle is being rotated, means for feeding the material to and discharging the material from said receptacle, said receptacle having a ball mill flange at each end thereof,
  - a mill head at each end of said ball mill and aligned therewith, each said mill head comprising a large diameter end and a small diameter end, said large diameter end having a mill head flange connected to said ball mill flange,
  - an electric motor having a rotor and stator disposed in encircling concentric relationship to said ball mill, said stator being stationarily mounted, said rotor being spaced from said receptacle, and
  - means for resiliently connecting the rotor of said motor to one of said ball mill flanges whereby said ball mill is rotated by said motor through a resilient gearless driving arrangement.
3. A direct-driven ball mill comprising
  - a ball mill comprising a rotatable receptacle for treating material in said receptacle while said receptacle is being rotated, means for feeding the material to and discharging the material from said receptacle, said receptacle having a ball mill flange at each end thereof,

- a mill head at each end of said ball mill and aligned therewith, each said mill head comprising a large diameter end and a small diameter end, said large diameter end having a mill head flange connected to said ball mill flange,
  - an electric motor having a rotor and stator disposed in encircling concentric relationship to said ball mill, said stator being stationarily mounted, said rotor being spaced from said receptacle, and
  - a rotor spider member for supporting said rotor from said receptacle in spaced apart relation, said spider member comprising an inner disk member attached to said receptacle, an intermediate offset web member, and an outer member attached to the motor rotor.
4. The apparatus set forth in claim 3 wherein said outer member comprises a plurality of outwardly extending steel bars having cross sections sufficiently small whereby said rotor is resiliently supported on said receptacle.
  5. The apparatus set forth in claim 3 wherein said outer member comprises a solid disk having a cross section sufficiently thick whereby said rotor is rigidly supported on said receptacle.
  6. A direct-driven ball mill comprising
    - a ball mill comprising a rotatable receptacle for treating material in said receptacle while said receptacle is being rotated, means for feeding the material to and discharging the material from said receptacle, said receptacle having a ball mill flange at each end thereof,
    - a mill head at each end of said ball mill and aligned therewith, each said mill head comprising a large diameter end and a small diameter end, said large diameter end having a mill head flange connected to said ball mill flange,
    - a synchronous motor having a speed rating in the range 0 to 40 revolutions per minute and a frequency rating in the range 0 to 15 cycles per second, said motor having a rotor and stator, said stator being stationarily mounted, said rotor being spaced from said receptacle in encircling concentric relationship and mechanically coupled thereto whereby said motor is connected to said ball mill through a gearless driving arrangement, and
    - static frequency conversion means for supplying alternating current electrical energy of frequency adjustable in the range of at least 0 to 15 cycles per second to said motor stator.

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