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[54] **BALL MILLS WITH SUPERELLIPSOIDAL BALLS**

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[51] **Int. Cl.**..... **B02c 17/10,** B02c 17/20

[58] **Field of Search**.....241/170–178, 184; 51/164.5

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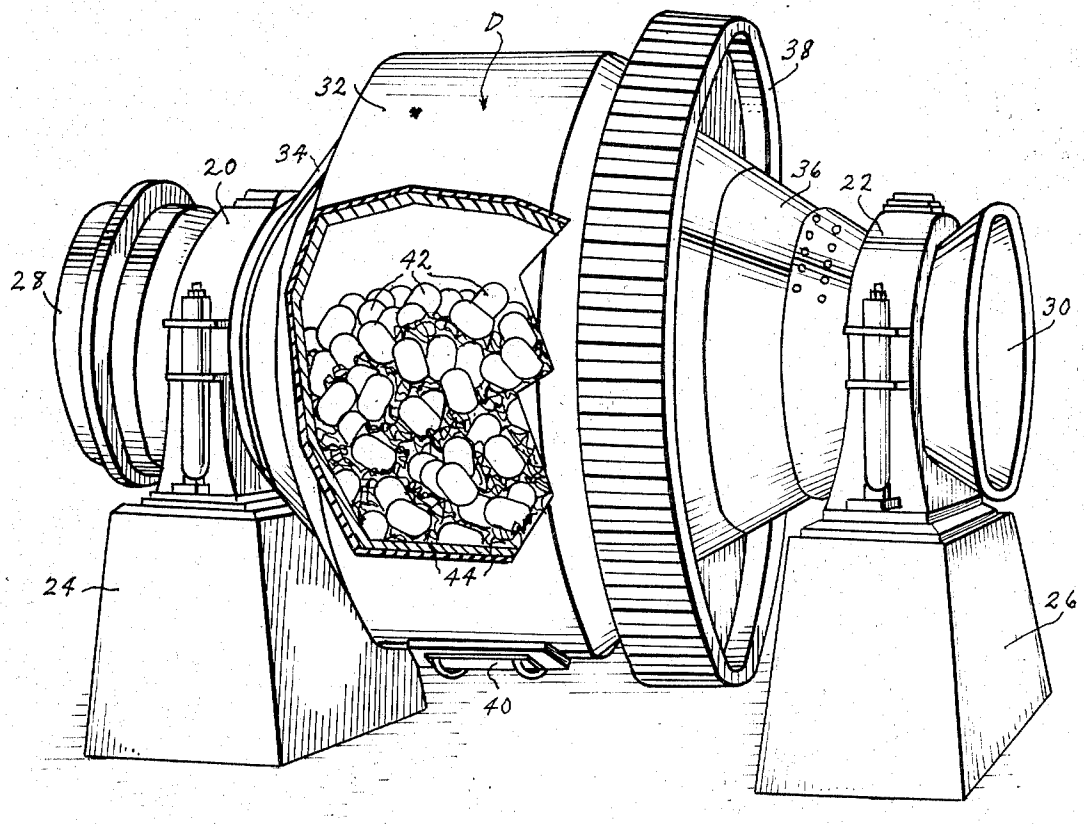
[57] **ABSTRACT**

A ball type grinding mill, in which the balls are superellipsoids of such a shape that the surface of the ball in each octant of a Cartesian coordinate system has x, y and z axes which are defined by the formula -

$$(|x/a|)^{n_1}+(|y/b|)^{n_2}+(|z/c|)^{n_3}=1,$$

wherein a, b, c, n_1, n_2 and n_3 are constants, a is unequal to b, and n_1, n_2 and n_3 each have a minimum value greater than 2. Preferably n_1, n_2 and n_3 each have a maximum value of 4 and most preferably in the range 2.1–4.0. It is also preferable that the ratio between at least two of the constants a, b and c be greater than 1 and less than 2, and more particularly the ratio between a and b may advantageously equal 4 to 3 when b equals c.

6 Claims, 3 Drawing Figures



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SHEET 1 OF 2

Fig. 1.

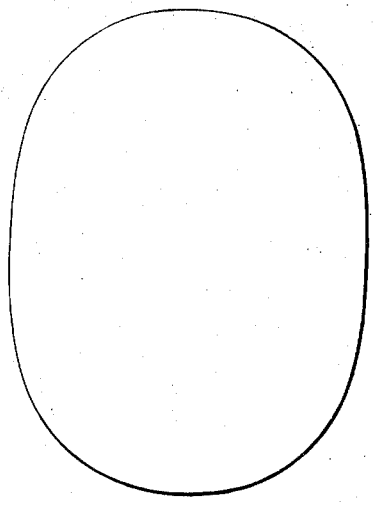
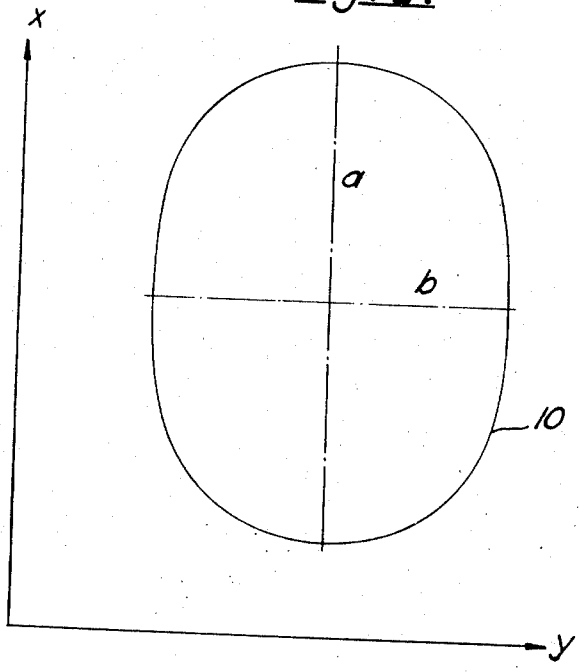


Fig. 2.



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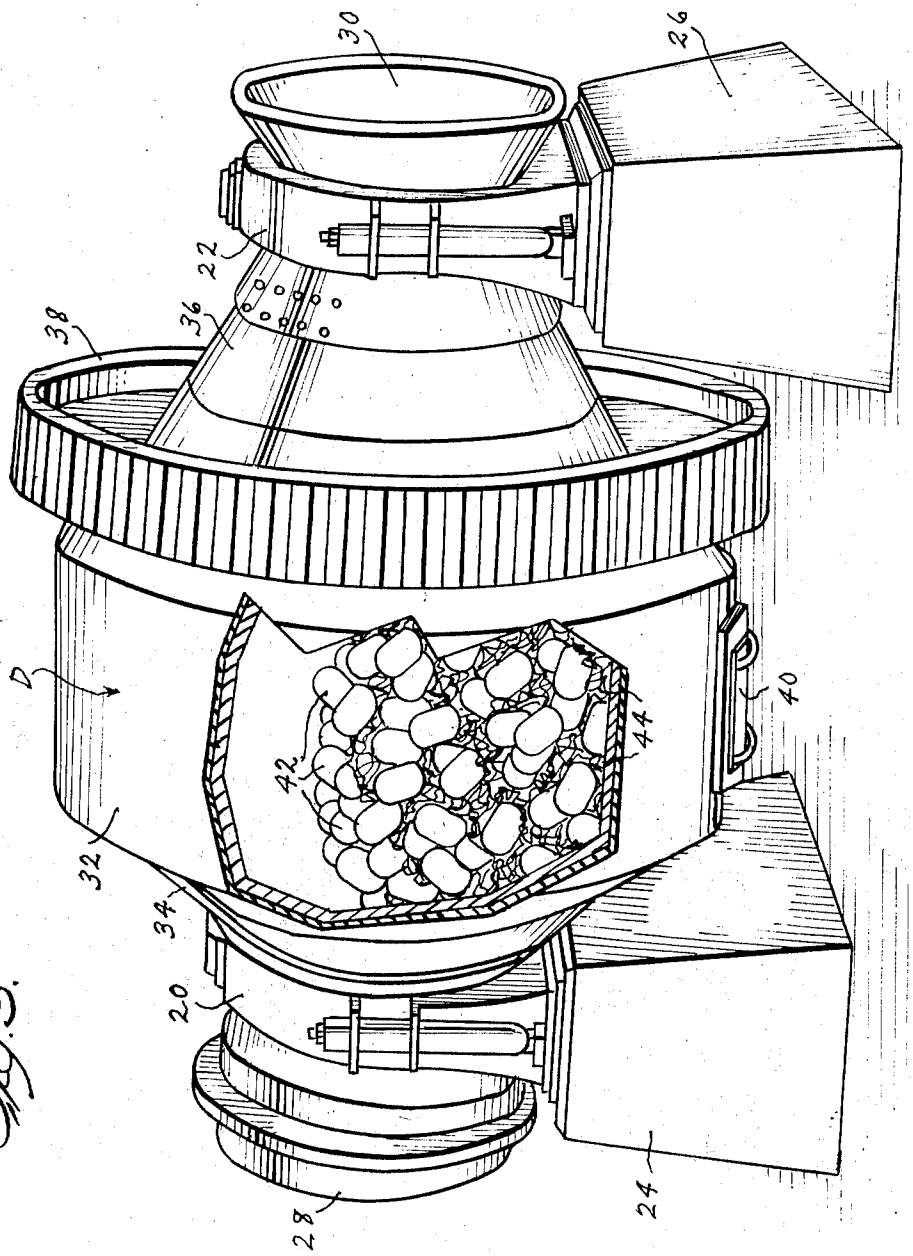

Fig. 3.

BALL MILLS WITH SUPERELLIPSOIDAL BALLS

This application is a continuation-in-part of our co-pending application Ser. No. 789,719, filed Jan. 8, 1969, now abandoned.

The invention relates to ball type grinding mills for the grinding of materials in either wet or dry state. The term "ball" is used as denoting the loose objects, also known as grinding media, within the rotating or otherwise moving part of the mill which perform the grinding operation. Such "balls" have heretofore been used in a variety of shapes.

Such balls may be made in various manners, including forging, upsetting or molding, and the materials used to make such objects may be steel, flint, ceramic, etc.

The balls have to be replaced from time to time because they wear away mechanically and are also subject to chemical corrosion, and this replacement is a considerable item of expense.

The object of the present invention is to provide balls of a ball mill with improved shape which are more economical to manufacture and more efficient in operation.

A circle when modified in shape by partial symmetrical deformation from four equally spaced directions (whilst retaining an approximately or totally convex form) is known and herein referred to as a "super-circle". Similarly, a symmetrically deformed ellipse is known and referred to as a "super-ellipse", the super-circle being a special form of super-ellipse. Correspondingly shaped solid bodies are known and herein referred to as "super-spheres" and "super-ellipsoids".

Mathematically the general formula for deriving a (three-dimensional) super-ellipsoid is as follows:

$$(x/a)^{n_1}+(y/b)^{n_2}+(z/c)^{n_3}=1.$$

In this formula x, y and z are rectangular Cartesian co-ordinates, a, b and c denote the lengths of the corresponding semi-axes of the super-ellipsoid, and n_1, n_2 and n_3 each represents a number greater than 2.

In a true geometrical ellipsoid or super-ellipsoid the semi-axes a, b and c would not be equal one to another. However, the expression "super-ellipsoid" is to be understood in the present context as including a solid body in accordance with the above general formula where a does not equal b but where b may equal c. This may be regarded as a special form of the more general super-ellipsoid. Also, as in the derivation of any ellipsoid or super-ellipsoid, the powers n_1, n_2 and n_3 need not be equal one to another.

For the purposes of the present invention a super-ellipsoid may therefore be defined as a derivative of the above general formula for all conditions other than where

$$a=b=c \text{ and}$$

n_1, n_2 and n_3 each have a value equal to or less than 2.

The above stated general formula is valid, in such cases where n is not equal to a multiple of 2, if the formula is employed to derive a super-ellipsoid octant by octant. That is, a complete super-ellipsoid may be derived to occupy a complete Cartesian space by constructing one octant of the super-ellipsoid and reflecting same into the remaining seven octants of the Cartesian space. Super-ellipsoids as hereinafter referred to in

conjunction with the general formula should be understood as so constructed.

For the purpose of this invention, the value of n is greater than 2 but preferably not greater than 4; the shape of a super-ellipsoid for values of n greater than 4 approaching that of a cylinder.

The present invention therefore provides a ball type grinding mill in which the balls are of such a shape that the surface thereof in each octant of a Cartesian co-ordinate system having x, y and z axes can be expressed by the formula -

$$(|x/a|)^{n_1}+(|y/b|)^{n_2}+(|z/c|)^{n_3}=1,$$

wherein a, b, c, n_1, n_2 and n_3 are all constants with a never equal to b, and wherein each of the constants n_1, n_2 and n_3 is greater than 2.

The foregoing definitions will be more readily comprehended by consideration of the accompanying drawings, in which

FIG. 1 is an exemplary outline of a ball for use in a grinding mill according to the invention, and which has the shape of a super-ellipsoid,

FIG. 2 is a mathematical diagram embodying the outline of FIG. 1, and

FIG. 3 is a perspective view of an embodiment of a ball mill according to the invention, with parts cut away.

FIG. 1 may be regarded as a super-ellipse per se or as an elevation of a super-ellipsoid generated by rotating the super-ellipse about its major axis. Also of course, it is a section on any plane passing through such major axis.

It is also possible to have the cross-section of the super-ellipsoid along any plane at right angles to the longest axis as itself a super-circle or a super-ellipse, although this may be more difficult to manufacture.

Referring now to FIG. 2, a pair of Cartesian axes are depicted having two co-ordinates x and y, and a super-ellipse curve is depicted at **10**.

In such curve **10**, a and b are half axes of the curve, a being half of the major axis and b being half of the (minor) axis at right angles thereto.

The remaining Cartesian co-ordinate z and the remaining half axis c are not visible in FIG. 2, being at right angles to the plane of the drawing sheet.

It has now been found in accordance with the invention that super-ellipsoids as hereinbefore defined are particularly efficient in the grinding of materials in ball mills. An example of a ball mill suitable for the purpose is shown in general outline in FIG. 3 and comprises a drum D which is mounted in alined bearings **20, 22** for rotation on a horizontal axis. The bearings are supported on base posts **24** and **26**, respectively.

The drum D has an inlet or feed end portion **28** and an outlet or discharge end portion **30**, and the portion of the drum between the bearings **20, 22** comprises a middle cylindrical section **32** and two conical end sections **34, 36** which converge from said middle section **32** towards the inlet end portion **28** and the outlet end portion **30**, respectively. A gear wheel **38** is secured to the drum D and is concentrical therewith. Said gear wheel **38** is adapted for mashing engagement with a pinion (not shown) connected to be driven by a motor (not shown).

In the embodiment shown the cylindrical drum section **32** is provided with an opening covered by a removable cover member **40**. The drum D is pre-charged

with a multiplicity of grinding mill balls **42** of the kind described above which may have been introduced through the feed end portion **28** or through the opening having the cover member **40** upon removal of said cover member.

In operation continuous rotary motion is imparted to the drum D by the motor (not shown) through the intermediary of the pinion (not shown) and the gear wheel **38.** Material **44** to be treated in the ball mill, for example ore, is fed into the drum D through the feed end portion **28,** usually continuously and with or without moistening liquid as required by the treatment process. Ordinarily the feed velocity is so adjusted that the combined volume of the grinding balls **42,** the material **44** and any liquid that may be present is constantly less than approximately 45 percent of the interior volume of the drum D, whereby it is achieved that only smaller and lighter fractions of the material **44** escape through the discharge end portion **30** of the drum D, while heavier fractions gravitate toward the lower portion of the drum and are subjected to further grinding action.

It may be mentioned that the actual grinding action caused by frictional surface engagement between the balls **42** and pieces of the material **44** — and partially also between said pieces themselves — is usually augmented by a crushing impact action caused by balls **42** which are entrained by the interior walls of the rotating drum to a higher level and then drop down onto the main mass in the drum.

During the rotation of the ball mill the balls of the inventive shape tend to align themselves end to end and side by side which serves to delay wear and to preserve the shape even under wear. Also, the balls have a smaller peripheral dimension than spherical balls of the same weight and they thereby impart a greater amount of energy per unit area on impact with the material in the drum than spherical or avoid balls, as generally employed in the art. Furthermore, the individual balls are readily subjected to rotational movements in the drum, particularly about their longer axes.

For practical purposes the invention is restricted to the use of balls in the shape of super-ellipsoids in which n_1, n_2 and n_3 each has a value of 2.1 to 4.0, and the ratio between the larger and smaller of at least one pair of semi-axes (a, b, c) lies between 1 and 2. A very desirable set of ratios is $b/c =$ and $a/b = 4/3$.

We claim:

1. A ball type grinding mill, in which the balls are superellipsoids of such a shape that the surface of the ball in each octant of a Cartesian coordinate system has x, y and z axes which are defined by the formula -

$$(|x/a|)^{n_1} + (|y/b|)^{n_2} + (|z/c|)^{n_3} = 1,$$

wherein a, b, c, n_1, n_2 and n_3 are constants, a is unequal to b, and 1, n_2 and n_3 each have a value greater than 2.

2. A ball type grinding mill as set forth in claim **1,** wherein n_1, n_2 and n_3 each have a maximum value of **4.**

3. A ball type grinding mill as set forth in claim **1,** in which b equals c.

4. A ball type grinding mill as set forth in claim **1,** in which $n_1 = n_2 = n_3$.

5. A ball type grinding mill as set forth claim **1,** in which n_1, n_2 and n_3 each have a value in the range 2.1–4.0 and the ratio between at least two of the constants a, b and c is greater than 1 and less than 2.

6. A ball type grinding mill as set forth in claim **3,** in which $a/b = 4/3$.

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