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New Shape Milling Bodies for Ball Mills

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1. Introduction

Two patents are known in this field, in which milling bodies of a similar shape are offered.

The first patent was issued in 1927 in Germany (DE 440198/1927). It includes a milling body with a tetrahedron shape, with flat walls and slightly rounded edges. This milling body is better than the spherical, because allows better filling of the working space. The disadvantage is its difficult production, since its shape is not technological, and probably for this reason no publications are known of research using this type of milling environment in drum mills. No attempts have been made for industrial implementation.

The second patent was issued in Russia in 1985 (RU 1388088/1985). It offers a milling body shape “of Ryolo tetrahedron”, with rounded edges and tops. That shape allowed higher milling bodies’ density in the operating space than in the one of sphere and tetrahedron with flat walls, but again the patent was not followed by practical implementation even in laboratory conditions, due to technological difficulties in producing tetrahedron bodies.

For decades spherical working bodies are used in drum mills with a diameter not greater than 130 mm. In cement production in milling the clinker, along with spherical shape working environment tsilpeps working environment has been used which consists of cylinders with rounded edges and length to diameter ratio as 2 to 1.

Most of the vibration mills with horizontal chambers have cylindrical shape. The normally used environment is composed of spherical elements or bars. Less frequently a working environment made of cylindrical springs, etc. is used. There are publications on testing other shapes of working bodies such as lenses, tablets (short cylinders), paraboloids, rifled bars, barrel shaped cylinders, etc. Working environment where contacts between the working environment are “areas”, are more suitable for vibration comminution. As a result of this process more fine particles are achieved and in laminar minerals as spekularit, kaolinit, etc., selective grinding is obtained by selectively grinding the formation of a predominantly particles in laminar or scale shape.

The proposed for experimentation shape of the milling environment grinding element, in the milling drum mills, close to the geometric shape “spheroidal tetrahedron”, is consistent with the technological requirements for mass production through hot volume stamping. There have been produced in total of about 1000 kg working elements with shape similar to the shape of spheroidal tetrahedron. Comparative studies have been done with them on milling of copper-porphyry ore of grain size at maximum 16 mm taken from the supply of the ball mills in the Asarel concentration plant. To compare the effectiveness and efficiency of milling in both working environments, equal technological and construction conditions were provided. To equalize the kinetic energy of impact in the waterfall running regime, masses of the working bodies of spherical shape and one similar to spheroidal tetrahedron have been equalized. Experiments were made with spherical bodies – balls with a diameter of 80 mm, and the working environment of elements with shape similar to that of a spheroidal tetrahedron.The mass of every element was equal to the mass of the sphere with a diameter of 80 mm. Balls with a diameter of 80 mm are used for milling in drum mills under industrial conditions. To conduct the survey, an industrial mill type 900/900 mm was used. It was found that the use of milling bodies with a shape similar to that of a spheroidal tetrahedron, the newly 0.08 mm fraction increases by few percent more than using the environment consisting of balls with a diameter of 80 mm. The use of milling bodies in the form, similar to that of a spheroidal tetrahedron, showed better results also in grinding of larger classes in the process of milling. The performed experiments were in an open cycle. The lesser average diameter of the larger classes obtained by milling in a work environment composed of working bodies in a form, similar to a spheroidal tetrahedron, compared to spherical environment within a closed loop, will increase the percentage of circulating load and will further increase the productivity in a new class. These studies were funded by Asarel-Medet AD.

The actuality of the problem stems from the fact that the new form of milling bodies in equivalent conditions provides a higher percentage of ready for next technological operation product, increasing the drum mills productivity, while maintaining the same amount of spent energy. Reduction of spent energy in such a high energy consumption milling process by a few percent will bring significant economic benefits, particularly having in mind that over 30 million tons of ore and dirt are milled every year just in Bulgaria.

2. Scientific tasks

In order to bring greater clarity to the following text, we believe it is necessary to introduce the shape “spheroidal tetrahedron” – from a geometric perspective, and to identify the differences with the shape “sphere”.

Definition: A figure of “equal width” is one, for which the distance between every two opposite tangents is the same.

Obviously, the circle and the sphere are figures of “equal width”. Another such figure is the triangle of Ryolo (Fig. 1). For this triangle a theorem has been proven (Blaschke-Lebesgue) [1], which reads: “Triangle of Ryolo has the least area of all curves with the same equal width”. This area is calculated by the formula [1]

(1) $$S = (1/2)\,(\pi - 3^{1/2})r^2.$$

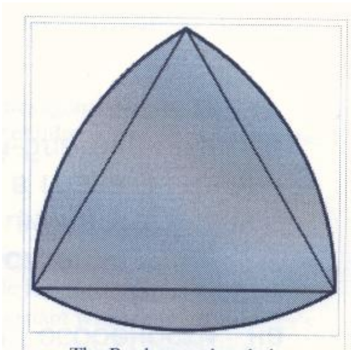


Fig. 1. Triangle of Ryolo

The relevant spatial figure by analogy is called “tetrahedron of Ryolo” (Fig. 2). It is characterized in that “it has the smallest volume of all volume figures which have the same equal width” [2]. This means that the sphere and tetrahedron of Ryolo with the same volume will have different radii, as

(2) $$R_{tetr} > R_{sph}.$$

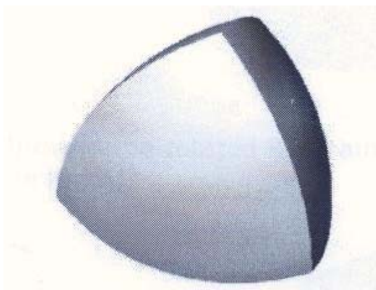


Fig. 2. Tetrahedron of Ryolo

The tetrahedron of Ryolo can be produced at very high cost. For that reason this shape of milling bodies did not get into production, although it was patented in Russia in 1985 [3].

The Bulgarian patent application [4] proposed a technological shape of a milling body similar to “Tetrahedron of Ryolo”, which is referred to as “spheroidal tetrahedron”. This shape of milling body has the following main differences from the milling body with spherical shape:

- Condition (2) is complied with. For example, in the spherical body where R_{sph} = 40 mm, a milling body with the same volume and shape of the “spheroidal tetrahedron” will be R_{tetr} = 56 mm. This means that the surface area of a “spheroidal tetrahedron” milling body will be greater than the surface of the body with spherical shape. In the example considered, this difference is 8.4%.
- The Tetrahedron of Ryolo is a geometric figure with sharp edges and peaks, while a “spheroidal tetrahedron” as a technological shape has rounded edges and three peaks, the fourth peak is cut to form a flat surface, on which the pushing element of the tool acts.
- The “spheroidal tetrahedron” milling bodies get denser, when powered in the mill, compared to grinding bodies with spherical shape. For example, if you pour in spherical bodies with R_{sph} = 40 mm, the volume that is occupied is ΣV_{sph}, the volume ΣV_{tetr} which the same number of “spheroidal tetrahedron” milling bodies occupy is less, i.e.

(3) $$\Sigma V_{tetr} < \Sigma V_{sph} .$$

The working group on the topic is to solve the following scientific problems.

1. Development of a mathematical model of the process of grinding in the drum mill using “spheroidal tetrahedron” milling bodies to form in the wet process and dry process, with:

- a sliding regime,
- a waterfall regime.

To get grinding in drum ball mill at a sliding regime, it is necessary to fulfill several conditions. The most common are:

- a part of the mill volume (usually 30-35%) to be filled with milling bodies;
- the speed of rotation of the mill to achieve the sliding regime of grinding bodies is below 70% of critical drum rotation speed.

Milling is the result mainly of comminution and to a lesser degree of particle crushing of the raw material particles. Comminution is the result of creeping between the surfaces of the elements of the working environment, and also to the fall of the working environment on the inner surface of the drum in its dragging in the direction of rotation of the drum. The crushing process is the result both of the impact of the elements on the particles of the milled material and the total mass of the working environment on the milled material.

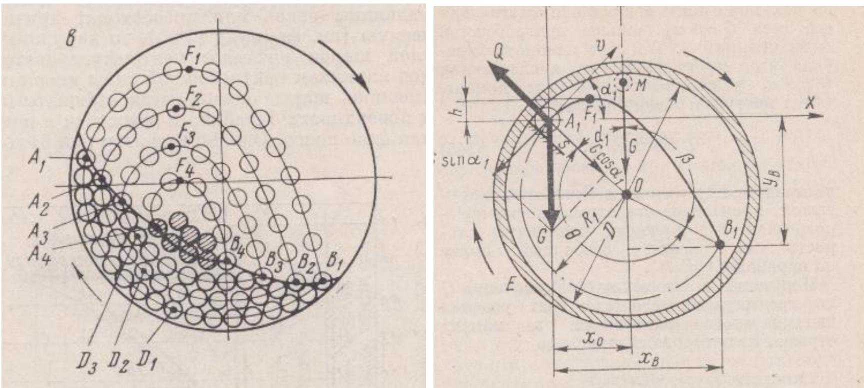
The regime of sliding is suitable for fine grinding, but due to low productivity has seen almost no application in industry.

To get grinding in a drum ball mill in waterfall regime one needs to have several conditions met. The most common are:

- a part of the mill volume (usually up to 45-48%) to be filled with milling bodies;
- the speed of rotation of the mill for implementation of the “waterfall” regime of grinding bodies is 70 to 100% of the critical speed of rotation of the drum.

Milling is mainly the result of impacts and to a lesser degree of comminution and crushing.

In [5, 6] the forces acting on a spherical ball in its motion in the case of the “waterfall mode” are described (Fig. 3). The sliding regime can be considered as a private case of “waterfalls mode”. Falling from a certain height (depending on drum’s diameter), the ball hits on a small area, assumed to be a point stroke, on the material being milled (ore, industrial minerals or other material). Each hit is random and therefore not always causes destruction. A great part of the strokes are empty, i.e., it hits on elements of the environment. Therefore, in wet milling control is exercised on the ratio between solid and liquid phase aimed at the saturation of the mill’s volume with material for grinding.



a b

Fig. 3. Movement of grinding bodies (a) and scheme of the forces separation of the ball in a spherical shape in waterfall mode (b)

In wet milling there is a practice the contents of the firm (raw material to be milled) to be maintained above 70%. During the rotation of the drum, a major part of the balls in the work environment just drag to some height performing a rotation around their axes and to other elements of the environment. When these movements are done, a comminution process takes place, in which particles are pulpified which are between the rubbing areas of items of the working environment, and between them and the inner surface of the drum. This process is supported by the mass of each of the working elements, which are most often made by steel and their density is about 2.5 times greater than the mass of the milled material.

This brief description of the movement of grinding bodies with a spherical shape in the volume of a drum mill in a waterfall regime gives the reason to suggest significant differences in the behavior of the “spheroidal tetrahedron” working bodies for waterfall regime. The more important are:

- In waterfall mode the “spheroidal tetrahedron” provides (with the same mass as a sphere), three different values of a hit, depending on hits contact: a top-hit, an edge-hit and an oval surface hit i.e., we have higher hitting intensity compared to that of spherical bodies grinding.
- In the process of turning the spheroidal tetrahedrons, greater contact areas are realized, in which comminution takes place. On the other hand the perimeter surface of the spheroidal tetrahedron is 8.5% greater than the sphere surface which directly affects the effectiveness of milling.
- The number and mutual disposition of the spheroidal tetrahedron grinding bodies will differ from that of spherical milling bodies. The per unit volume number of spheroidal tetrahedron working bodies is 12-15% higher.
- The shape of the spheroidal tetrahedron will have a positive effect on increasing the productivity of drum mills operating in sliding regime.

The existing mathematical models cover the movement of spherical milling bodies. The above mentioned features of the process, using spheroidal tetrahedron milling bodies, requires adjustment of these models or perhaps the creation of new ones.

2. Using the mathematical model, a software will be developed for computer simulation of the process of grinding, using the spheroidal tetrahedron milling bodies. Similar models have been developed for spherical working bodies.

3. Methods will be developed for comparative experimental study in specially designed ball mill of the process of grinding, using spheroidal tetrahedron milling bodies and spherical ones. Similar methods have been used until now primarily to study the impact of certain forms of milling bodies (paraboloids, lenses, tsilpebs, etc.) with small sizes in laboratory models drum mills [7, 8] and in cylindrical vibration mills. Milling bodies with production conditions dimensions will be applied in the project proposed during the survey.

4. The spheroidal tetrahedron grinding bodies will be improved so as to best meet the specific requirements of the process of grinding. Here, given that the pipe-shaped multichamber mills most often applied in cement production, in the first chamber “wholesale” grinding is realized of clinker, and in the second and third chambers – the fine grinding. Until now milling bodies of a spherical shape and different diameter were used in the first two chambers and tsilpeps – in the third chamber.

Using the spheroidal tetrahedron milling bodies can optimize the shape of the grinding bodies so that those used in the first chamber to have the shape of edges and peaks performing most efficient crushing, those used in the second camera to have perimeter surface with the highest efficiency in the process of grinding.

5. Based on experimental research a technology for production of steel spheroidal tetrahedron milling bodies will be developed to have a hardness on the surface and in the cross section adequate to the requirements (standards, plant rules) to spherical shape milling bodies.

3. Methodology

It is known that the milling of various raw materials requires a lot of energy, and also the quantity of the metal spent per unit of processed raw material is high. According to some publications comminution consumes about 20% of the total produced energy. Milling has the highest proportion – about 50 percent and above among the processes used in comminution (crushing, screening, grinding and classification).

A number of laboratory and industrial research works have been done on ball milling of ores to establish the amount of energy used and the useful work by estimating the newly formed surface per unit volume. This rate for actual work in milling is quite low and it is about 1%. Therefore reducing energy in the milling process is of great importance and has both economic and environmental aspects. Efforts are made to reduce the energy spent in several directions:

- implementation of autogenic and semi autogenic grinding;
- optimization of the total cost of comminution – crushing, sifting and milling;
- improving the indicators of the classification process;
- creation of new comminution machines: Grinding roll press, CIC (Conical Inertia Crusher) and others;
- automated management of mills, etc.

In drum milling mills in over 90% of the cases, spherical bodies (balls), made of different materials such as: steel, iron, alloys, porcelain, glass, basalt, and others are used. The dimensions of these spherical milling bodies vary from a diameter of several mm to 130 mm. The most widely used working bodies are steel balls made by the method of casting and stamping. Reporting the effect of milling is by definition the differences in grain-metric characteristics of the milled material prior to milling and after the milling process. The newly formed surface can be determined, which is a direct result of the grinding process. In practice this control with some approximation, is performed most often by setting the quantity of a given class, e.g. class minus 0.071 mm (200 mesh), which means the content of that class in the milled material or more precisely the percentage of the class passed through a sifting surface with a mesh size of 0.071 mm. This size corresponds to each different material grain-metric feature. This control class is called estimated grade. It may also have other values such as 0.1 mm, 0.08 mm, 0.063 mm and more. When grinding in laboratory testing various shapes have been used other than spheres with convex walls, such as lenses, paraboloid, short cylinders, barrel-like, etc. The results in many cases were better than milling with spheres. The difficulties in production and the higher price, however, make their use in industrial-type mills unattractive. Ball milling is a stochastic process. There are many publications on the ball milling process. Analyses of different parameters affecting the process of milling and optimal intervals were determined in accordance with economic indicators of milling. Much of the theory is empirical, but gives satisfactory explanation of the process of milling. For the new working environment, provisionally called “spheroidal tetrahedrons”, no theory was developed and no proven optimal values, influencing the process of grinding parameters existed. To verify the capabilities of spheroidal tetrahedrons working environment when grinding in a drum mill, a comparative experiment was done, in which the mill design parameters were reserved, technological parameters in the optimal range of ball milling in the environment, qualitative and quantitative composition of the processing material and the mass of milling bodies on condition of balls and spheroidal tetrahedrons to be manufactured by stamping one mark steel.

After statistical processing of the technological results, the following facts were determined:

1) the spheroidal tetrahedrons working environment gives a higher percentage of the new class minus 0.08 mm in all experiments;

2) the extent of milling of large classes plus 0.2 mm is two units higher in the working environment of spheroidal tetrahedrons.

3) the obtained absolute values of the technological results are higher than the statistical error;

4) all technological results are unidirectional, i.e., in a spheroidal tetrahedrons grinding work the environment results are better than the results with similar work by balls.

Obviously, the above mentioned experimental facts obtained in the spheroidal tetrahedrons working environment warrants further study of the process of grinding with the new working environment in order to find the most appropriate optimal values of technological parameters, influencing the process of grinding, as well as certain adjustments related to the design parameters of drum mills.

The sequence of the study will go through the following stages:

- analysis of existing information on the impact of the shape of the milling environment on the process of grinding;
- establishment of mathematical and computer models for the movement of spheroidal tetrahedrons in a drum mill;
- computer simulation of the influence of some constructional and technological parameters on the grinding process with spheroidal tetrahedrons and comparison to existing computer programs showing the work of the working environment consisting of balls;
- computer modeling of waterfalls running and fall of the regime to work from spheroidal tetrahedrons;
- computer modeling of contacts between the working bodies of spheroidal tetrahedrons in the work environment composed of different-sized bodies;
- computer modeling of the right convexity, rounded edges and the tops of the spheroidal tetrahedrons and their influence on each other in the work environment;
- design and production of a prototype drum mill for visual monitoring and regulation and amendment of certain design parameters;

- verification of findings in computer modeling and simulation relationships with real material;
- study the influence of circulating load in a closed cycle in the wet milling;
- explore the opportunities to spheroidal tetrahedrons working environment for fine and selective grinding under the sliding regime;
- comparative study of two working environments, balls and spheroidal tetrahedrons at optimum levels of technological and design parameters;
- technical and economic assessment of the grinding cycle when using a work environment spheroidal tetrahedrons and environment balls.

Forecast:

1. Increasing the overall productivity of the mill by increasing the circulating load and performance in the new class.
2. Reduction of energy per unit of processed material.
3. Increasing of effectiveness of grinding in the fine grinding and selective grinding of some raw materials, etc.

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Мелющие тела новой формы в барабанных мельницах

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(Р е з ю м е)

Традиционные мелющие тела в барабанных мельницах с 19-ого века до сих пор имеют сферическую форму и известны как шарики. Их возможности по отношению производительности и эффективности дробления доказаны. В статье исследуется новая форма элементов, формирующих мелющую среду в барабанной мельнице, построена на основе сфероидального тетраедра.