July 4, 1961 R. T. HUKKI 2,991,017

GRINDING METHOD IN BALL, TUBE AND OTHER MILLS

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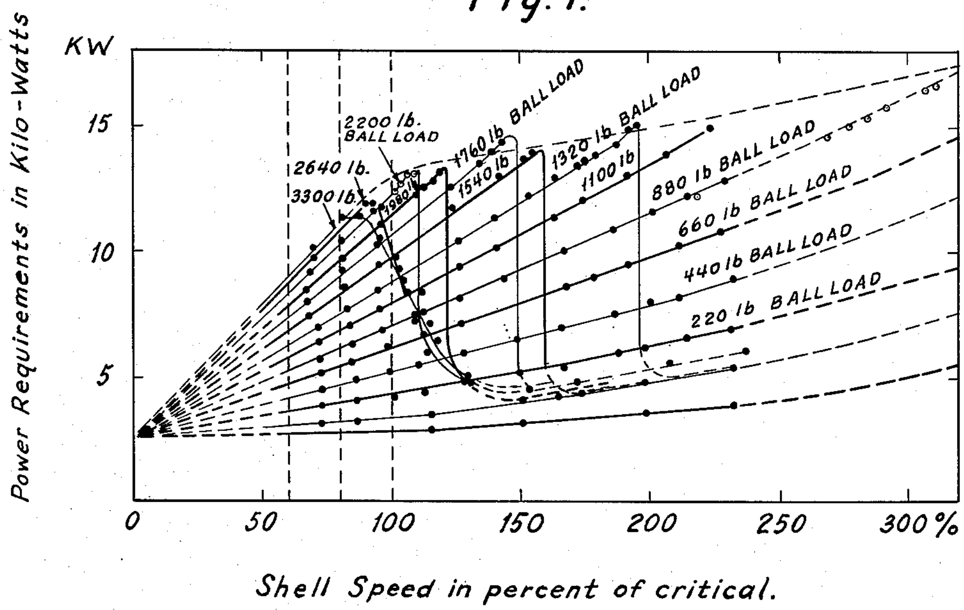
Fig. 1.



Power requirements at various speeds for indicated ball charges

Fig. 2.

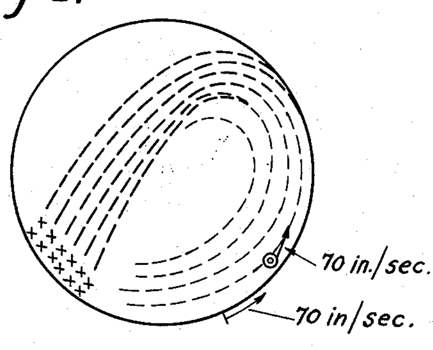
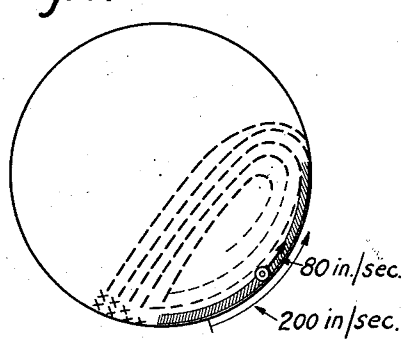


Fig. 3.



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GRINDING METHOD IN BALL, TUBE AND OTHER MILLS

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1 Claim. (Cl. 241—26)

This invention applies to an improvement in, or relating to a grinding method in ball, rod, tube and other mills by making use of supercritical speeds.

Grinding has been performed in such a way that the speed of the mill has been 60–90 percent of the critical speed, which can be evaluated from the following well known formula:

$$n_0 = \frac{76.6}{\sqrt{D-d}}$$

where

n_0=the numerical value of the critical speed in revolutions per minute,

D=the inside diameter of the mill in feet, and

d=the diameter of the grinding piece in feet.

A widely accepted opinion is that when the speed of the mill exceeds 100% of the critical, the grinding capacity of the mill is either substantially lower than in the speed range 60–90% of the critical, or even non-existing.

The purpose of this invention is to introduce grinding speeds thus far unknown, by means of which a novel grinding action can be brought about, which at supercritical speeds is concentrated to a zone, in the following called the zone of attrition grinding, and which grinding method results in a totally new grinding process in rod, ball and other mills.

The most characteristic feature of the invention is that when a mill is rotating at a supercritical speed, the peripheral speed of the mill and the tumbling load are selected in such a way that the subcritical speed of the tumbling media is obtained at a supercritical speed of the mill. The zone of attrition grinding is formed between the mill lining and the outer layer of grinding media in a mill provided with a comparatively smooth lining. By providing the mill with special holding bars, or with other obstacles preventing slippage, the mill will automatically form its own lining of the material used as grinding media when rotating at a supercritical speed. In this case the attrition grinding is based on the speed difference between the attached layer of media rotating with the mill shell and the second layer of media next to it.

The following observations show the validity of the invention.

On the drawings:

FIG. 1 shows a number of ball mill characteristics,

FIG. 2 shows the principle of the conventional method of grinding, and

FIG. 3 shows the principle of the method of grinding in mills operating according to the invention.

FIG. 1 shows a series of tests run in a ball mill of pilot plant scale. The mill was equipped with a rather smooth lining. It has been possible to regulate the speed of the mill within the range 50–310% of the critical. The speed is shown on the abscissa and the power draft on the ordinate. As shown by the diagrams, power peaks have not been obtained with ball loads of 220, 440, 660, 880 and 1100 lbs. within the speed range available. The formation of the power peak presupposes that either a part of the ball load or the entire load will centrifuge at still higher speeds. The power peak, on the other hand,

is observed with greater ball loads at the following speeds:

Ball load, lbs.:	Speed at the power peak, percent of the critical
1320	197
1540	160
1760	150
1980	122
2200	108
2640	93
3300	87

The curves for the two last-mentioned ball loads represent diagrams typical for the conventional grinding. The load of 2640 lbs. represents a ball charge of about 50% of mill volume which is usually considered to be the most advantageous charge in grinding.

Because the top of the 2640 lb. diagram, e.g., is close to the limiting value of 100%, at least the outer part of the ball load begins to centrifuge at the critical speed. This test shows that in a mill, in which the ball load is about 50% of its volume, the outer ball layer situated against a rather smooth lining proceeds also at a speed very close to the peripheral speed of the mill. If the lining is not smooth, the outer ball layer has no possibilities to slip in relation to the lining, and they must proceed at the same speed.

From the FIG. 1 showing it is clear that for each tumbling load there is a speed beyond which the mill should not be operated unless the load centrifuges without any grinding working being performed. The term "relative mill speed" appears to characterize the particular speed referred to here, it being the speed of the mill expressed as a percentage of the critical speed.

Considering again FIG. 1, it will be seen that as soon as peaks occur for the particular loads the power requirements for increased speed drop off abruptly. This is clearly indicative of the fact that the charge is centrifuging so grinding work is no longer being done, consequently the power employed for grinding is no longer needed. By plotting power consumption against speed for any selected tumbling load, as is done in FIG. 1, the relative mill speed just below that at which the power peak occurs can be readily determined and the mill can be operated accordingly. Then, grinding in accordance with the invention as illustrated in FIG. 3 is assured.

On the basis of what has been said, grinding is accomplished in the conventional mills either by cascading or cataracting media mainly at the toe of the ball charge as shown in FIG. 2, and to some extent within the tumbling mass itself. No grinding, not at least worth mentioning, takes place between the outer layer of media and the lining.

According to the tests related to this invention grinding is possible over a wide range of supercritical speeds in a mill equipped with a rather smooth lining in such a way that while the mill with liners rotates at a supercritical speed, the speed at which the ball load and especially its outer loose layer proceeds represents a subcritical speed. The top speed of the mill and the weight of the ball load are related in such a way that the smaller the ball load, the higher it is possible to increase the speed of the mill.

By so doing it is possible to accomplish a zone of attrition grinding, in the conventional practice unwanted and unknown, between the mill lining and the outer ball layer as shown in FIG. 3. The attrition zone is based on the speed difference between the lining and the outer ball layer. The higher the mill speed in the supercritical range, the higher is also the speed difference. Should the speed of the mill be only slightly over 100% of the critical, the share of attrition grinding is only a part of the entire grinding effect. At high speeds grinding takes place almost exclusively as attrition grinding.

The grinding process according to this invention has been illustrated in the preceeding by the use of balls of iron or iron alloys in a ball mill. It should be clear that this invention covers grinding in general within the supercritical speed range in ball, rod, tube and other mills as stated earlier. The process is not limited to any particular type of material to be ground. It is also applicable in the production of ground wood pulp or ground knot pulp in the wood industry.

It is well known that the autogenous method of grinding has found many applications in recent years. Autogenous method of grinding may be defined as a grinding process where the material to be ground and the grinding media consist essentially of the same solid substance. The autogenous method of grinding at supercritical speeds described in this invention includes not only the rocks and ores occurring in the nature, but also artificial industrial products such as cement clinker, etc. thus, e.g. in the fine grinding of cement, original cement clinker can be used as grinding media; crushed or coarsely ground clinker will then be the material to be ground.

Modifications between the autogenous methods and the non-autogenous methods of grinding are possible according to this invention at supercritical speeds. Thus, grinding media consisting of pieces of natural or artificial, metallic or non-metallic substances, or of their mixtures, can be used in wet or dry grinding of any substance that is or can be ground in the conventional grinding practice.

In the practice of this invention there exists a relationship between the speed of the mill on one hand, and the tumbling load, the friction between the charge and the mill lining, as well as the mass of the individual grinding pieces on the other hand in such a way that the mill speed can be raised by decreasing the tumbling load, by decreasing the said friction for example by pulping the material to be ground into a more and more dilute pulp, by decreasing the amount of material to be ground or by increasing its degree of fineness and/or by increasing the mass of individual grinding pieces within certain limits.

It has been verified in practice that because of the low specific gravity of grinding media, the capacity of autogenous mills operating within the conventional subcritical speed range is hardly ever ½ of that of the respective steel ball mills, but usually ⅓, and even less than that. Accordingly, the plants in which autogenous grinding has been practiced with the idea of replacing iron balls with crushed ore pebbles, have been forced to at least double the number of mills, to increase their size by increasing their diameter or length, or both.

It has now been discovered that the original capacity of a conventional iron ball mill used e.g. for fine grinding can be recovered to a desired extent, either partly, fully, even exceeding the original capacity, also in practical applications of autogenous methods of fine grinding by increasing the mill speed from the previous subcritical speed range to a desired value within the supercritical range. This desired value is the relative mill speed determined from plotting in accordance with FIG. 1 as pointed out above. In this way it is possible to achieve economically a very valuable result, because it is possible to obtain e.g. the same final result with the original mills without the expensive metallic media, by using screened or unscreened crushed ore pebbles produced at a low cost as grinding media. The mill capacity as well as the grinding result can be simultaneously affected by a change in the diameter or length of the mill.

The validity of this particular feature of the invention can be demonstrated by the following:

Experiment 1

Crushed limestone was ground at a rate of 2100 lbs./hour first in a pilot plant rod mill. Its product was investigated for fine grinding in a ball mill operating at 70% of the critical speed and with a 24% ball load in closed circuit with a mechanical classifier. After steady operation had been reached, the screen analyses of the feed (rod mill discharge) and product (classifier overflow) were:

	Feed, Percent	Product, Percent
−35 mesh	77.5	100.0
−48 mesh	64.8	99.6
−65 mesh	53.3	97.4
−100 mesh	45.5	91.3
−150 mesh	34.3	73.2
−200 mesh	27.7	58.8

Experiment 2

Limestone was ground in the same way as above except that the balls had been replaced by limestone pebbles amounting to 48% of the mill volume. The speed of the mill had been increased to 230% of the critical. The results were:

	Feed, Percent	Product, Percent
−35 mesh	79.4	99.9
−48 mesh	67.6	99.6
−65 mesh	55.7	96.2
−100 mesh	46.6	84.8
−150 mesh	36.2	67.8
−200 mesh	29.1	54.1

A comparison between the results obtained indicates that the amount of new −48 mesh material in Experiment 2 was 92% and that of new −65 mesh material 91.8% of the result obtained in Experiment 1.

From the comparison of the results obtained from Experiments 1 and 2 it is apparent that close to the same amount of raw material may be ground to approximately the same fineness per hour using pebbles of the limestone material itself as the grinding bodies while operating the mill at a speed substantially in excess of the critical, as is done using balls for the grinding bodies at a speed below the critical. The advantage of the grinding of the invention, pointed up by Experiment 2, is that with the power consumption being the same in each case, wear on the grinding bodies is saved. In Experiment 1 the metal balls will wear substantially and heavy expense is involved in replacing them. In Experiment 2, however, where autogenous grinding at supercritical speed is carried out, the wear of the grinding bodies is desirable and is utilized in the grinding process. Since all of the material in the mill is the same, the wear is the grinding process proper. Accordingly the use and expense of grinding bodies, or balls, of different materials is dispensed with.

As a general rule it can be stated that the capacity of a mill increases with increasing speed and with increasing effective specific gravity of the grinding media, up to a certain maximum. A certain desired capacity can be obtained at a lower speed in a grate type mill than in an overflow type mill, if other conditions are equivalent.

It is the additional object of this invention to introduce a novel modification of the autogenous method of grinding at supercritical speeds which is characterized by the use of a coarse product separated of mineral material occurring in the nature, as grinding media, the specific gravity of which is distinctly higher than the average specific gravity of the original material of which it has been separated.

The basic capacity of autogenous mills is relatively low due to the low specific gravity of grinding media. It has been discovered now that in many cases the mill capacity can be increased, except by increasing the speed, also by using a coarse concentrate of a desired size range as grinding media instead of ore pebbles representing the overall average composition of the ore. Such concentrate, the specific gravity of which is substantially higher than that of the ore, can be produced by hand picking, by wet or dry magnetic separation, by jigging, by sink-float process, or by some other means. This coarse concentrate can be advantageously used as grinding media e.g. in the fine grinding of the rest of the ore after it has been reduced to a suitable fineness in a rod mill, or by some other means.

As a modification of the process described above, a product separated from a particular ore or rock can be used for grinding another ore, rock, or product. Its grinding effect can be further improved by mixing it with another similar concentrate of higher specific gravity, or with metallic grinding media. As the mills are operated at supercritical speeds, the automatic method of lining may again be applied.

All that has been said before will be true in grinding at supercritical speeds in general. The novel grinding action within the attrition zone will constitute perhaps the most effective method of fine grinding that can be developed. As indicated before, the abrasive forces in the attrition zone will become tremendous at high supercritical speeds because of the great speed difference between the mill lining and the outer layer of grinding media. High speed operation will be especially suitable in fine grinding.

This invention includes also a special, very important modification which is related to grinding of coarse materials, especially of products obtained by crushing.

The first phase of grinding, so-called coarse grinding, is often performed in a rod mill operating in open circuit at a subcritical speed; the product is ground to the final degree of fineness in a separate fine grinding circuit.

In certain cases grinding of coarse crushed ore has been performed by using the autogenous method of grinding in such a way that in mills operating in the subcritical speed range the impact force necessary for breaking is obtained by providing the shell and the end walls of a large diameter but short mill with special lining, which together with the narrow gorge formed in between the mill walls, and with the help of large grinding pieces develops a sufficient lifting force to elevate the grinding pieces to the upper part of the mill while it rotates.

The additional purpose of this invention is the correction of the basic errors in connection with autogenous coarse grinding. The autogenous method of coarse grinding according to this invention is essentially characterized by size reduction through impact by such a combination of factors that while the mill operates within the supercritical speed range, the relationship between the maximum size or maximum mass of the grinding bodies and those of the material to be ground on one hand, and between the maximum mass of the grinding bodies and of the supercritical speed of the mill on the other hand are selected in such a way that the impact effect of the falling bodies coincides with the respective desired grinding result during the entire grinding operation.

The impact force of falling bodies in the process of coarse grinding according to this invention can be either increased or reduced, except by regulation of the size of grinding bodies and of pieces to be ground, also by changing the diameter of the mill and the supercritical speed of rotation of the mill. Most likely the mills best suited for autogenous coarse grinding will be very big, and the relationship between the diameter and the length of the mill might change from that of the conventional rod mill.

In a typical case of coarse grinding according to this invention, the grinding bodies represent a relatively narrow size range of pieces which can be separated e.g. in connection with the crushing circuit by means of grizzlies, screens, or other devices. The material to be ground represents screened or unscreened crushed product, the maximum size of which is less than that of the grinding bodies.

Contrary to the conventional practice, the maximum capacity of the coarse grinding mills operating according to this invention will be reached within the supercritical speed range. Simultaneously, a zone of attrition will be created between the mill lining and the outer layer of grinding media as has been explained already before, which zone will further increase the grinding capacity of the mill, especially in the range of finer size fractions.

A very important additional advantage in autogenous coarse grinding mills operating at supercritical speeds according to this invention is naturally the possibility to use automatic mill lining essentially as described before.

Just as the conventional rod mill can be operated at a subcritical speed in special cases for the production of a final product, either in open or closed circuit, wet or dry, the autogenous method of coarse grinding described in this invention may be used within the supercritical speed range similarly for the production of finely divided material. The best overall result, however, will be obtained at least in large scale operations in such a way that the coarse grinding and fine grinding will be performed in separate steps, both under conditions best suited for the particular type of grinding.

Modifications of the autogenous method of coarse grinding described above can be applied in practice also in such a way that grinding media consisting of a particular ore, rock, a product separated of them, stones occurring in the nature, artificial products such as cement clinker, slag, etc., as well as their mixtures are used in the grinding of another ore, rock, or material within the supercritical speed range. Although the addition of metallic grinding media is not necessary nor essential for the grinding process itself, certain additional advantages may result of their use in special cases.

In cases where abraded iron originating from the metallic grinding media, or lining, has detrimental effects in such subsequent phases of processing as e.g. in flotation, in certain leaching processes, or in ceramics, the additional advantage resulting of the use of autogenous method of grinding or of the modifications of it, in which non-metallic grinding media is used, may be substantial, in some cases even economically decisive.

The mill, which is used in the practice of this invention, can be cylindrical, slightly conical, or may include cylindrical or conical sections.

What I claim is:

In an autogenous grinding method carried out in a mill having a lining having a comparatively smooth interior surface and running constantly at supercritical speeds up to approximately 200%, the steps of selecting a relative constant mill speed which is a small amount below that at which a power peak consumption occurs on the curve produced for a selected load by plotting the power consumption of such mill against the relative mill speeds, running said mill at said selected relative speed and causing said load to slide with respect to said surface, thereby rotating the load at sub-critical speeds and effecting grinding by the formation of a zone of attrition between said interior surface and the load at their region of contact.

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