INTRODUCTION

There are two fundamental operations in mineral processing: namely the release, or liberation, of the valuable minerals from their waste gangue minerals, and separation of these values from the gangue, this latter process being known as concentration.

This is achieved by comminution, in which the particle size of the ore is progressively reduced by crushing and grinding until the clean particles of mineral can be separated by such methods as are available. Comminution in its earliest stages is carried out in order to make the freshly mined material easier to handle by scrapers, conveyors, and ore carriers, and in the case of quarry products to produce material of controlled particle size. Grinding is often the greatest energy consumer, accounting for up to 50% of a concentrator' s energy consumption.

If the ore is low grade, and the minerals have very small grain size and are disseminated through the rock, then grinding energy costs and fines losses can be high, unless the nature of the minerals is such that a pronounced difference in some property between the minerals and the gangue is available. An intimate knowledge of the mineralogical assembly of the ore is essential if efficient processing is to be carried out. A knowledge not only of the nature of the valuable and gangue minerals but also of the ore "texture" is required. The texture refers to the size, dissemination, association and shape of the minerals within the ore. The processing of minerals should always be considered in the context of the mineralogy of the ore in order to predict grinding and concentration requirements, feasible concentrate grades and potential difficulties of separation

Crushing

Crushing is accomplished by compression of the ore against rigid surfaces, or by impact against surfaces in a rigidly constrained motion path. This is contrasted with grinding which is accomplished by abrasion and impact of the ore by the free motion of unconnected media such as rods, balls, or pebbles. Crushing is usually a dry process, and is performed in several stages, reduction ratios being small, ranging from three to six in each stage. The reduction ratio of a crushing stage can be defined as the ratio of maximum particle size entering to maximum particle size leaving the crusher.

Grinding

Conventional grinding takes place in tumbling mills where the ore is introduced into a horizontal mill where the cylindrical body of the mill is turned by a motor, causing the mill charge of ore and grinding media to tumble. Grinding is accomplished by impact, attrition and abrasion of the ore by the free motion of unconnected media such as steel rods, steel or ceramic balls, or coarse ore pebbles. Grinding is usually performed “wet” to provide a slurry feed to the concentration process, although dry grinding has various applications. Primary autogenous or semi-autogenous mills are tumbling mills capable of grinding very coarse feed, thereby replacing one or two stages of crushing. There is an overlapping set of particle sizes where it is possible to crush or grind the ore.

Crushers

Introduction

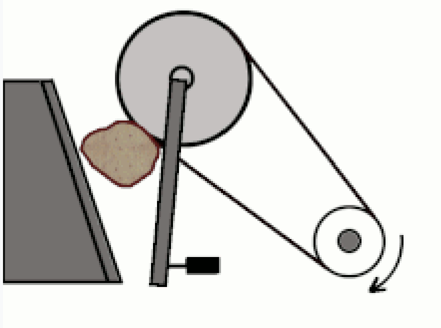
Crushing is the first step of mineral processing where the ore/rocks from the mine site is fed into the mechanical equipment in order to reduce the size of masses for subsequent usage by liberating the valuable mineral from the gangue. It is generally a dry operation and is usually performed in two or three stages. Lumps of run- of-mine ore can be as large as 1.5 m across and these are reduced in the primary crushing stage to 10-20 cm in heavy-duty machines.

The following table describes typical uses of commonly used crushers:

Type	Hardness	Abrasion limit	Moisture content	Reduction ratio	Main use
Jaw crushers	Soft to very hard	No limit	Dry to slightly wet, not sticky	3/1 to 5/1	Heavy mining, quarried materials, sand & gravel, recycling
Gyratory crushers	Soft to very hard	Abrasive	Dry to slightly wet, not sticky	4/1 to 7/1	Heavy mining, quarried materials
Cone crushers	Medium hard to very hard	Abrasive	Dry or wet, not sticky	3/1 to 5/1	Quarried materials, sand & gravel
Compound crusher	Medium hard to very hard	Abrasive	Dry or wet, not sticky	3/1 to 5/1	Mine, building materials
Horizontal shaft impactors	Soft to medium hard	Slightly abrasive	Dry or wet, not sticky	10/1 to 25/1	Quarried materials, sand & gravel, recycling
Vertical shaft impactors (shoe and anvil)	Medium hard to very hard	Slightly abrasive	Dry or wet, not sticky	6/1 to 8/1	Sand & gravel, recycling
Vertical shaft impactors (autogenous)	Soft to very hard	No limit	Dry or wet, not sticky	2/1 to 5/1	Quarried materials, sand & gravel

Jaw crusher

A jaw crusher uses compressive force for breaking of particle. This mechanical pressure is achieved by the two jaws of the crusher of which one is fixed while the other reciprocates. A jaw or toggle crusher consists of a set of vertical jaws, one jaw is kept stationary and is called a fixed jaw while the other jaw called a swing jaw, moves back and forth relative to it, by a cam or pitman mechanism, acting like a class II lever or a nutcracker. The volume or cavity between the two jaws is called the crushing chamber. The movement of the swing jaw can be quite small, since complete crushing is not performed in one stroke. The inertia required to crush the material is provided by a flywheel that moves a shaft creating an eccentric motion that causes the closing of the gap.



Operation of a dodge type jaw crusher

Dodge type jaw crusher

Jaw crushers are heavy duty machines and hence need to be robustly constructed. The outer frame is generally made of cast iron or steel. The jaws themselves are usually constructed from cast steel. They are fitted with replaceable liners which are made of manganese steel, or Ni-hard (a Ni-Cr alloyed cast iron). Jaw crushers are usually constructed in sections to ease the process transportation if they are to be taken underground for carrying out the operations.

Jaw crushers are classified on the basis of the position of the pivoting of the swing jaw

1. **Blake crusher-the swing jaw is fixed at the lower position**
2. **Dodge crusher-the swing jaw is fixed at the upper position**
3. **Universal crusher-the swing jaw is fixed at an intermediate position**

The Blake crusher was patented by Eli Whitney Blake in 1858. The Blake type jaw crusher has a fixed feed area and a variable discharge area. Blake crushers are of two types- single toggle and double toggle jaw crushers.

In the single toggle jaw crushers, the swing jaw is suspended on the eccentric shaft which leads to a much more compact design than that of the double toggle jaw crusher. The swing jaw, suspended on the eccentric, undergoes two types of motion- swing motion towards the fixed jaw due to the action of toggle plate and vertical movement due to the rotation of the eccentric. These two motions, when combined, lead to an elliptical jaw motion. This motion is useful as it assists in pushing the particles through the crushing chamber. This phenomenon leads to higher capacity of the single toggle jaw crushers but it also results in higher wear of the crushing jaws. These type of jaw crushers are preferred for the crushing of softer particles.

In the double toggle jaw crushers, the oscillating motion of the swing jaw is caused by the vertical motion of the pitman. The pitman moves up and down. The swing jaw closes, i.e., it moves towards the fixed jaw when the pitman moves upward and opens during the downward motion of the pitman. This type is commonly used in mines due to its ability to crush tough and abrasive materials.

In the Dodge type jaw crushers, the jaws are farther apart at the top than at the bottom, forming a tapered chute so that the material is crushed progressively smaller and smaller as it travels downward until it is small enough to escape from the bottom opening. The Dodge jaw crusher has a variable feed area and a fixed discharge area which leads to choking of the crusher and hence is used only for laboratory purposes and not for heavy duty operations.

Gyratory crusher

A gyratory crusher is similar in basic concept to a jaw crusher, consisting of a concave surface and a conical head; both surfaces are typically lined with manganese steel surfaces. The inner cone has a slight circular movement, but does not rotate; the movement is generated by an eccentric arrangement. As with the jaw crusher, material travels downward between the two surfaces being progressively crushed until it is small enough to fall out through the gap between the two surfaces.

A gyratory crusher is one of the main types of primary crushers in a mine or ore processing plant. Gyratory crushers are designated in size either by the gape and mantle diameter or by the size of the receiving opening. Gyratory crushers can be used for primary or secondary crushing. The crushing action is caused by the closing of the gap between the mantle line (movable) mounted on the central vertical spindle and the concave liners (fixed) mounted on the main frame of the crusher. The gap is opened and closed by an eccentric on the bottom of the spindle that causes the central vertical spindle to gyrate. The vertical spindle is free to rotate around its own axis. The crusher illustrated is a short-shaft suspended spindle type, meaning that the main shaft is suspended at the top and that the eccentric is mounted above the gear. The short-shaft design has superseded the long-shaft design in which the eccentric is mounted below the gear.

Crushers range in size up to gapes of 1830 mm and can crush ores with top size of 1370 mm at a rate of up to 5000t h -1 with a 200 mm set. Power consumption is as high as 750 kW on such crushers. Large gyratories often dispense with expensive feeding mechanisms and are often fed direct from trucks. They can be operated satisfactorily with the head buried in feed. Although excessive fines may have to be "scalped" from the feed, the modem trend in large-capacity plants is to dispense with grizzlies if the ore allows. This reduces capital cost of the installation and reduces the height from which the ore must fall into the crusher, thus minimizing damage to the spider. Choked crushing is encouraged to some extent, but if this is not serious, the rock-torock crushing produced in the primaries reduces the rock-to-steel crushing required in the secondaries, thus reducing steel consumption. Choke feeding of a gyratory crusher has been claimed to be also beneficial when the crusher is followed by SAG mills, whose throughput is sensitive to the mill feed. Operating crushers under choke feeding conditions gives more even mantle wear and longer life.

Jaw vs. Gyratory Crusher

In deciding whether a jaw or a gyratory crusher should be used in a particular plant, the main factor is the maximum size of ore which the crusher will be required to handle and the capacity required. Gyratory crushers are, in general, used where high capacity is required. Since they crush on full cycle, they are more efficient than jaw crushers, provided that the chamber can be kept full, which is normally easy, since the crusher can work with the head buried in ore. Jaw crushers tend to be used where the crusher gape is more important than the capacity. For instance, if it is required to crush material of a certain maximum diameter, then a gyratory having the required gape would have a capacity about three times that of a jaw crusher of the same gape. If high capacity is

required, then a gyratory is the answer. If, however, a large gape is needed but not capacity, then the jaw crusher will probably be more economical, as it is a smaller machine and the gyratory would be running idle most of the time.

The capital and maintenance costs of a jaw crusher are slightly less than those of the gyratory, but they may be offset by the installation costs, which are lower with the gyratory, since it occupies about two-thirds the volume and has about two-thirds the weight of a jaw crusher of the same capacity. This is because the circular crushing chamber allows a more compact design with a larger proportion of the total volume being accounted for by the crushing chamber than in the jaw crusher. Jaw-crusher foundations need to be much more rugged than those of the gyratory, due to the alternating working stresses.

The better self-feeding capability of the gyratory compared with the jaw results in a capital cost saving in some cases, with the elimination of expensive feeding devices, such as the heavy-duty chain feeder. This is, however, often false economy as the capital cost saving is considered of less importance in many cases than the improved performance and the pre-crusher scalping which is available with separate feeding devices.

Secondary Crushers

Secondary crushers are much lighter than the heavy-duty, rugged primary machines. Since they take the primary crushed ore as feed, the maximum feed size will normally be less than 15 cm in diameter and, because most of the harmful constituents in the ore, such as tramp metal, wood, clays, and slimes have already been removed, it is much easier to handle. Similarly, the transportation and feeding arrangements serving the crushers do not need to be as rugged as in the primary stage. Secondary crushers also operate with dry feeds, and their purpose is to reduce the ore to a size suitable for grinding. In those cases where size reduction can be more efficiently carried out by crushing, there may be a tertiary stage before the material is passed to the grinding mills.

Tertiary crushers are, to all intents and purposes, of the same design as secondaries, except that they have a closer set.

Cone Crusher

The basic principle is straightforward:

The material to be crushed (the feed), drops into the crushing chamber. The mantle is a moving part that gyrates in an eccentric motion. That is, it doesn’t remain completely centered–it swings slightly as it rotates, continually altering the gap between the mantle and the concave (the ring outside the mantle that stays fixed in place). As the mantle moves, it crushes the material against the concave at the points where the gap is smallest (the stones in the feed are also compressed against each other – that’s known as interparticle crushing).

The cone crusher is a modified gyratory crusher. The essential difference is that the shorter spindle of the cone crusher is not suspended, as in the gyratory, but is supported in a curved, universal beating below the gyratory head or cone.

Power is transmitted from the source to the countershaft through a V-belt or direct drive. The countershaft has a bevel pinion pressed and keyed to it and drives the gear on the eccentric assembly. The eccentric has a tapered, offset bore and provides the means whereby the head and main shaft follow an eccentric path during each cycle of rotation.

As the feed is crushed, it falls and exits the crusher through the space at the bottom. The eccentric gyration of the mantle means that at any moment this space is narrowest at one point, and widest at the opposite point. The widest distance is known as the open side setting (OSS) and the narrowest, the closed side setting

(CSS). These settings are important. The OSS is the largest distance between the concave and the mantle at the bottom of the crusher, so it determines the largest particle size of the outgoing product. As the smallest distance between the concave and the mantle, the CSS is the final crushing zone, and is vital for determining the product size, as well as energy consumption and crusher capacity.

Compound cone crushers

Compound cone crusher (VSC series cone crusher) can crush materials of over medium hardness. It is mainly used in mining, chemical industry, road and bridge construction, building, etc. As for VSC series cone crusher, there are four crushing cavities (coarse, medium, fine and superfine) to choose. Compared with the same type, VSC series cone crusher, whose combination of crushing frequency and eccentricity is the best, can make materials have higher comminution degree and higher yield. In addition, VSC series cone crusher's enhanced laminating crushing effect on material particles makes the cubic shape of crushed materials better, which increases the selling point.

Symons cone crusher

Symons cone crusher (spring cone crusher) can crush materials of above medium hardness. And it is widely used in metallurgy, building, hydropower, transportation, chemical industry, etc. When used with jaw crusher, it can be used as secondary, tertiary or quaternary crushing. Generally speaking, the standard type of Symons cone crusher is applied to medium crushing. The medium type is applied to fine crushing. The short head type is applied to coarse fine crushing. As casting steel technique is adopted, the machine has good rigidity and large high strength.

The Symons cone crusher is the most widely used type of cone crusher. It is produced in two forms:

The Standard for normal secondary crushing and the Short-head for fine, or tertiary duty. They differ mainly in the shape of their crushing chambers. The Standard cone has "stepped" liners which allow a coarser feed than in the Short-head. They deliver a product varying from 0.5 to 6cm. The Short-head has a steeper head angle than the Standard, which helps to prevent choking from the much finer material being handled. It also has a narrower feed opening and a longer parallel section at the discharge, and delivers a product of 0.3-2.0 cm.

The gyradisc crusher

This is a specialized form of cone crusher, used for producing very fine material, and such crushers have found application in the quarrying industry for the production of large quantities of sand at economic cost.

The main modification to the conventional cone crusher is that the machine has very short liners and a very flat angle for the lower liner. Crushing is by interparticle comminution by the impact and attrition of a multi-layered mass of particles.

At no time does single-layer crushing occur, as with conventional crushers. Crushing is by particle on particle, so that the setting of the crusher is not as directly related to the size of product as it is on the cone crusher.

Their main use is in quarries, for producing sand and gravel. When used in open circuit they will produce a product of chippings from about 1 cm downwards, of good cubic shape, with a satisfactory amount of sand, which obviates the use of blending and rehandling. In closed circuit they are used to produce large quantities of sand. They may be used in open circuit on clean metalliferous ores with no primary slimes to produce an excellent ball-mill feed. Less than 19 mm material may be crushed to about 3 mm.

The Rhodax crusher

This is a specialized form of a cone crusher, referred to as an inertial cone crusher. Developed by the FCB Research Centre in France, the Rhodax crusher is claimed to offer process advantages over conventional cone crushers and is based on inter- particle compression crushing. It consists of a frame supporting a cone and a mobile ring, and a set of rigid links forming a set of ties between the two parts. The frame is supported on elastic suspensions isolating the environment from dynamic stresses created by the crushing action. It contains a central shaft fixed on a structure. A grinding cone is mounted on this shaft and is free to rotate. A sliding sleeve on this shaft is used to adjust the vertical position of the cone and therefore the gap, making it simple to compensate for wear. The ring structure is connected to the frame by a set of tie rods.

Roll crushers

Roll crushers, or crushing rolls, are still used in some mills, although they have been replaced in most installations by cone crushers. They still have a useful application in handling friable, sticky, frozen, and less abrasive feeds, such as limestone, coal, chalk, gypsum, phosphate, and soft iron ores. Jaw and gyratory crushers have a tendency to choke near the discharge when crushing friable rock with a large proportion of maximum size pieces in the feed.

The mode of operation of roll crushers is extremely simple, the standard spring rolls consisting of two horizontal cylinders which revolve towards each other. The set is determined by shims which cause the spring-loaded roll to be held back from the solidly mounted roll.

Unlike jaw and gyratory crushers, where reduction is progressive by repeated pressure as the material passes down to the discharge point, the crushing process in rolls is one of single pressure.

Roll crushers are also manufactured with only one rotating cylinder, which revolves towards a fixed plate. Other roll crushers use three, four, or six cylinders. In some crushers the diameters and speeds of the rolls may differ. The rolls may be gear driven, but this limits the distance adjustment between the rolls; and modern rolls are driven by V-belts from separate motors.

Impact Crushers

In this class of crusher, comminution is by impact rather than compression, by sharp blows applied at high speed to free-falling rock. The moving parts are beaters, which transfer some of their kinetic energy to the ore particles on contacting them. The internal stresses created in the particles are often large enough to cause them to shatter. These forces are increased by causing the particles to impact upon an anvil or breaker plate.

Impact crushers are also favoured in the quarry industry because of the improved product shape. Cone crushers tend to produce more elongated particles because of their high reduction ratios and ability of such particles to pass through the chamber unbroken. In an impact crusher, all particles are subjected to impact and the elongated particles, having a lower strength due to their thinner cross section, would be broken.

Horizontal shaft impactor (HSI) / Hammermill

The HSI crushers break rock by impacting the rock with hammers that are fixed upon the outer edge of a spinning rotor. HSI machines are sold in stationary, trailer mounted and crawler mounted configurations. HSI's are used in recycling, hard rock and soft materials. In earlier years the practical use of HSI crushers is limited to soft materials and non-abrasive materials, such as limestone, phosphate, gypsum, weathered shales, however improvements in metallurgy have changed the application of these machines.

Impact Mill

For much coarser crushing, the fixed hammer impact mill is often used. In these machines the material falls tangentially on to a rotor, running at 250- 500 rev/min, receiving a glancing impulse, which sends it spinning towards the impact plates. The velocity imparted is deliberately restricted to a fraction of the velocity of the rotor to avoid enormous stress and probable failure of the rotor bearings. The fractured pieces which can pass between the clearances of the rotor and breaker plate enter a second chamber created by another breaker plate, where the clearance is smaller, and then into a third smaller chamber. This is the grinding path which is designed to reduce flakiness and gives very good cubic particles. However, they are a good choice for primary crushing when high reduction ratios are required (the ratio can be as high as 40:1) and a high percentage of fines, and the ore is relatively non- abrasive.

Vertical shaft impactor (VSI)

VSI crushers use a different approach involving a high-speed rotor with wear resistant tips and a crushing chamber designed to 'throw' the rock against. The VSI crushers utilize velocity rather than surface force as the predominant force to break rock. In its natural state, rock has a jagged and uneven surface. Applying surface force (pressure) results in unpredictable and typically noncubical resulting particles. Utilizing velocity rather than surface force allows the breaking force to be applied evenly both across the surface of the rock as well as through the mass of the rock. Rock, regardless of size, has natural fissures (faults) throughout its structure. Using this method also allows materials with much higher abrasiveness to be crushed than is capable with an HSI and most other crushing methods.

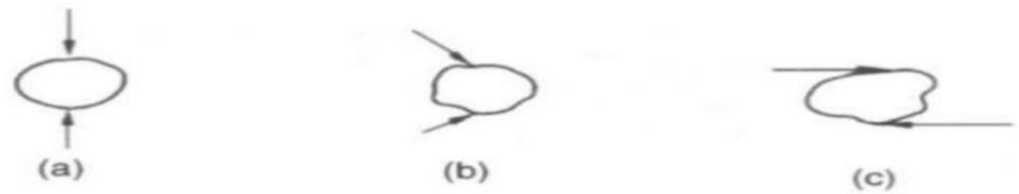
Grinders

Introduction

Grinding is the last stage in the process of comminution; in this stage the particles are reduced in size by a comminution of impact and abrasion, either dry or in suspension in water. It is performed in rotating cylindrical steel vessels which contain a charge of loose crushing bodies - the grinding medium which is free to move inside the mill, thus comminating the ore particles. According to the ways by which motion is imparted to the charge, grinding mills are generally classified into two types: tumbling mills and stirred mills.

All ores have an economic optimum particle size which will depend on many factors, including the extent to which the values are dispersed in the gangue, and the subsequent separation process to be used.Under-grinding of the ore will, of course, result in a product which is too coarse, with a degree of liberation too low for economic separation; poor recovery and enrichment ratio will be achieved in the concentration stage. Much expensive energy is wasted in the process. It is important to realize that grinding is the most energy-intensive operation in mineral processing.

Grinding can be done by several mechanisms, including impact or compression, due to forces applied almost normally to the particle surface; chipping due to oblique forces; and abrasion due to forces acting parallel to the surfaces (Figure 7.1). These mechanisms distort the particles and change their shape beyond certain limits determined by their degree of elasticity, which causes them to break.



Mechanisms of breakage: (a) impact or compression, (b) chipping, (c) abrasion

Grinding is usually performed wet, although in certain applications dry grinding is used. When the mill is rotated, the mixture of medium, ore, and water, known as the mill charge, is intimately mixed, the medium comminuting the particles by any of the above methods depending on the speed of rotation of the mill and the shell liner structure.

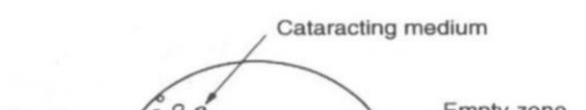
Although the correct degree of liberation is the principal purpose of grinding in mineral processing, this treatment is sometimes used to increase the surface area of the valuable minerals even though they may already be essentially liberated from the gangue.

<u>Tumbling Mill</u>

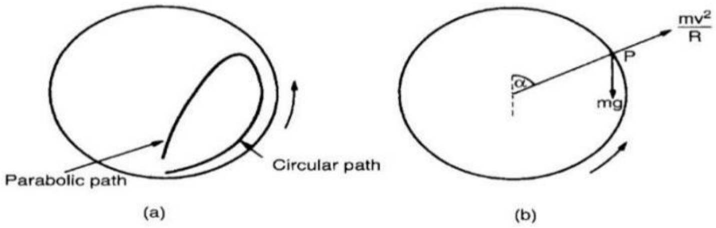
Tumbling mills are of three basic types: rod, ball, and autogenous. Structurally, each type of mill consists of a horizontal cylindrical shell, provided with renewable wearing liners and a charge of grinding medium. The drum is supported so as to rotate on its axis on hollow trunnions attached to the end walls. In tumbling mills the mill shell is rotated and motion is imparted to the charge via the mill shell. The grinding medium may be steel rods, balls, or rock itself. Tumbling mills are typically employed in the mineral industry for coarse grinding processes, in which particles between 5 and 250 mm are reduced in size to between 40 and 300 µm. Grinding within a tumbling mill is influenced by the size, quantity, the type of motion, and the spaces between the individual pieces of the medium in the mill.

<u>Motion of charge in tumbling mill</u>

The distinctive feature of tumbling mills is the use of loose crushing bodies, which are large, hard, and heavy in relation to the ore particles, but small in relation to the volume of the mill, and which occupy slightly less than half the volume of the mill. Due to the rotation and friction of the mill shell, the grinding medium is lifted along the rising side of the mill until a position of dynamic equilibrium is reached, when the bodies cascade and cataract down the free surface of the other bodies, about a dead zone where little movement occurs, down to the toe of the mill charge.



Mills are driven, in practice, at speeds of 50-90% of critical speed, the choice being influenced by economic considerations. Increase in speed increases capacity, but there is little increase inefficiency (i.e. kWh/t) above about 40- 50% of the critical speed. Very low speeds are sometimes used when full mill capacity cannot be attained. High speeds are used for high-capacity coarse grinding. Cataracting at high speeds converts the potential energy of the medium into kinetic energy of impact on the toe of the charge and does not produce as much very fine material as the abrasive grinding produced by cascading at lower speeds.



(a) Trajectory of grinding medium in tumbling mill, (b) forces acting on the medium

Construction of mills

Shells

Mill shells are designed to sustain impact and heavy loading, and are constructed from rolled mild steel plates, buttwelded together. Holes are drilled to take the bolts for holding the liners.

Mill ends

The mill ends, or trunnion heads, may be of nodular or grey cast iron for diameters less than about 1 m. Larger heads are constructed from cast steel, which is relatively light, and can be welded. The heads are fibbed for reinforcement and may be flat, slightly conical, or dished. They are machined and drilled to fit shell flanges.

Trunnions and bearings

The trunnions are made from cast iron or steel and are spigoted and bolted to the end plates, although in small mills they may be integral with the end plates. They are highly polished to reduce bearing friction. Most trunnion bearings are rigid high- grade iron castings with 120-180 ~ lining of white metal in the bearing area, surrounded by a fabricated mild steel housing, which is bolted into the concrete foundations.

Some manufacturers install large roller bearings, which can withstand higher forces than plain metal bearings.

Drive Tumbling mills are most commonly rotated by a pinion meshing with a girth ring bolted to one end of the machine. The pinion shaft is driven from the prime mover through vee-belts, in small mills of less than about 180 kW. For larger mills the shaft is coupled directly to the output shaft of a slow-speed synchronous motor, or to the output shaft of a motor-driven helical or double helical gear reducer. Large mills can be rotated by a central trunnion drive, which has the advantage of requiting no expensive ring gear, the drive being from one or two motors, with the inclusion of two- or three- speed gearing.

The larger the mill, the greater are the stresses between the shells and heads and the trunnions and heads. In the early 1970s, maintenance prob- lems related to the application of gear and pinion and large speed reducer drives on dry grinding cement mills of long length drove operators to seek an alternative drive design. As a result, a number of gearless drive (ring motor) cement mills were installed and the technology became relatively common in the European cement industry. The gearless drive design features motor rotor elements bolted to a mill shell, a stationary stator assembly surrounding the rotor elements, and electronics converting the incoming current from 50/60 Hz to about 1 Hz. The mill shell actually becomes the rotating element of a large low speed synchronous motor. Mill speed is varied by changing the frequency of the current to the motor, allowing adjustments to the mill throughput as ore grindability changes.

Liners

The internal working faces of mills consist of renewable liners, which must withstand impact, be wear-resistant, and promote the most favourable motion of the charge. Rod mill ends have plain fiat liners, slightly coned to encourage the self-centering and straight-line action of rods. They are made usually from manganese or chrome-molybdenum steels, having high impact strength. Ball- mill ends usually have ribs to lift the charge with the mill rotation. These prevent excessive slip- ping and increase liner life. They can be made from white cast iron, alloyed with nickel (Ni-hard), other wear-resistant materials, and rubber (Durman, 1988). Trunnion liners are designed for each application and can be conical, plain, with advancing or retarding spirals. They are manufactured from hard cast iron or cast alloy steel, a rubber lining often being bonded to the inner surface for increased life.

Shell liners have an endless variety of lifter shapes. Smooth linings result in much abrasion, and hence a fine grind, but with associated high metal wear. The liners are therefore generally shaped to provide lifting action and to add impact and crushing, the most common shapes being wave, Lorain, stepped, and shiplap.

Rod mill liners are also generally of alloyed steel or cast iron, and of the wave type, although Ni- hard step liners may be used with rods up to 4 cm in diameter. Lorain liners are extensively used for coarse grinding in rod and ball mills, and consist of high carbon rolled steel plates held in place by manganese or hard alloy steel lifter bars. Ball mill liners may be made of hard cast iron when balls of up to 5 cm in diameter are used.

Mill liners are a major cost in mill oper- ation, and efforts to prolong liner life are constantly being made. There are at least ten wear-resistant alloys used for ball-mill linings, the more abrasion-resistant alloys containing large amounts of chromium, molybdenum, and nickel being the most expensive (De Richemond, 1982). However, with steadily increasing labour costs for replacing liners, the trend is towards selecting liners which have the best service life regardless of cost (Malghan, 1982).

Mill feeders

The type of feeding arrangement used on the mill depends on whether the grinding is done in open or closed circuit and whether it is done wet or dry. The size and rate of feed are also important. Dry mills are usually fed by some sort of vibratory feeder. Three types of feeder are in use in wet-grinding mills. The simplest form is the spout feeder,

consisting of a cylindrical or elliptical chute supported independently of the mill, and projecting directly into the trunnion liner.

Drum feeders

it may be used as an alternative to a spout feeder when headroom is limited. The entire mill feed enters the drum via a chute or spout and an internal spiral carries it into the trunnion liner. The drum also provides a convenient method of adding grinding balls to a mill.

Combination drum-scoop feeders

These are generally used for wet grinding in closed circuit with a spiral or rake classifier. New material is fed directly into the drum, while the scoop picks up the classifier sands for regrinding. the counter-balancing effect of the double-scoop design serves to smooth out power fluctuation and it is normally incorporated in large-diameter mills. Scoop feeders are sometimes used in place of the drumscoop combination when mill feed is in the fine-size range.

Types of mills

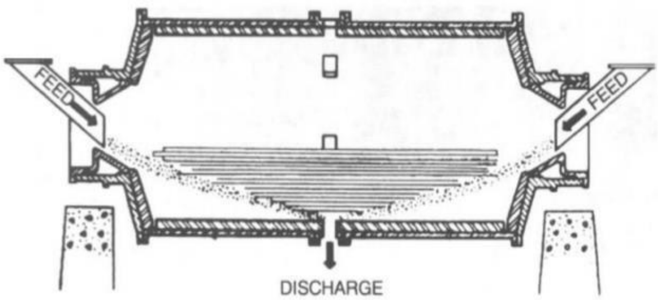
<u>Rod mills</u>

These may be considered as either fine crushers or coarse grinding machines. They are capable of taking feed as large as 50mm and making a product as fine as 300txm, reduction ratios normally being in the range 15-20:1. They are often preferred to fine crushing machines when the ore is "clayey" or damp, thus tending to choke crushers.

The distinctive feature of a rod mill is that the length of the cylindrical shell is between 1.5 and 2.5 times its diameter. This ratio is important because the rods, which are only a few centimetres shorter than the length of the shell, must be prevented from turning so that they become wedged across the diameter of the cylinder. The ratio must not, however, be so large for the maximum diameter of the shell in use that the rods deform and break. Since rods longer than about 6 m will bend, this establishes the maximum length of the mill. Thus, with a mill 6.4 m long the diameter should not be over 4.57 m. Rod mills of up to 4.57 m in diameter by 6.4 m in length are in use, run by 1640 kW motors (Lewis et al., 1976). Rod and other grinding mills are rated by power rather than capacity. Rod mills are classed according to the nature of the discharge. A general statement can be made that the closer the discharge is to the periphery of the shell, the quicker the material will pass through and less overgrinding will take place.

Centre peripheral discharge mills

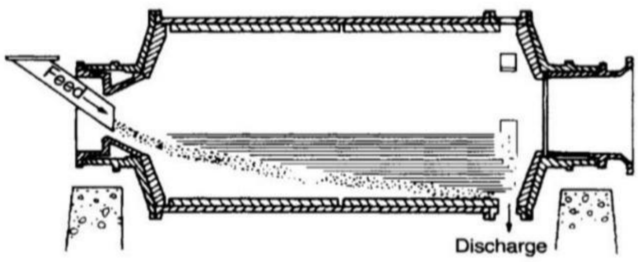
These are fed at both ends through the trunnions and discharge the ground product through circumferential ports at the centre of the shell. The short path and steep gradient give a coarse grind with a minimum of fines, but the reduction ratio is limited. This mill can be used for wet or dry grinding and has found its greatest use in the preparation of specification sands, where high tonnage rates and an extremely coarse product are required.



Central peripheral discharge mill

End peripheral discharge mills

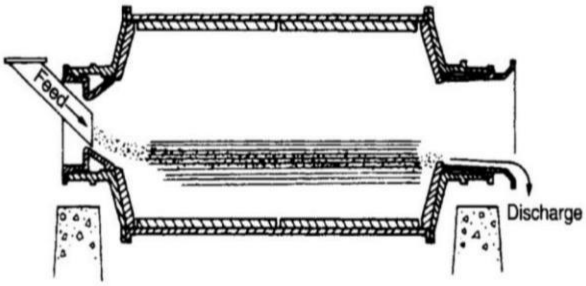
These are fed at one end through the trunnion, discharging the ground product from the other end of the mill by means of several peripheral apertures into a close-fitting circumferential chute. This type of mill is used mainly for dry and damp grinding, where moderately coarse products are involved.



End peripheral discharge mill

Trunnion overflow mill

The most widely used type of rod mill in the mining industry is the trunnion overflow, in which the feed is introduced through one trunnion and discharges through the other. This type of mill is used only for wet grinding and its principal function is to convert crushing- plant product into ball-mill feed. A flow gradient is provided by making the overflow trunnion diameter 10-20 cm larger than that of the feed opening.



Overflow mill

Rod mills are charged initially with a selection of rods of assorted diameters, the proportion of each size being calculated to provide maximum grinding surface and to approximate to a seasoned or equilibrium charge. A seasoned charge will contain rods of varying diameters ranging from fresh replacements to those which have worn down to such a size as to warrant removal. Actual diameters in use range from 25 to 150mm. Generally, rods should be removed when they are worn down to about 25 mm in diameter or less, depending on the application, as small ones tend to bend or break. High carbon steel rods are used as they are hard, and break rather than warp when worn, so do not entangle with other rods. Optimum grinding rates are obtained with new rods when the volume is 35% of that of the shell. This reduces to 20-30% with wear and is maintained at this figure by substitution of new rods for worn ones. the rods cascade rather than cataract; many operating mills have been sped up to close to 80% of critical speed without any reports of excessive wear (Mclvor and Finch, 1986). The feed pulp density is usually between 65 and 85% solids by weight, finer feeds requiring lower pulp densities. The grinding action results from line contact of the rods on the ore particles; the rods tumble in essentially a parallel alignment, and also spin, thus acting rather like a series of crushing rolls. The coarse feed tends to spread the rods at the feed end, so producing a wedge- or cone-shaped array. This increases the tendency for grinding to take place preferentially on the larger particles, thereby producing a minimum amount of extremely fine material. This selective grinding gives a product of relatively narrow size range, with little oversize or slimes. Rod mills are therefore suitable for preparation of feed to gravity concentrators, certain flotation processes with slime problems, magnetic cobbing, and ball mills. They are nearly always run in open circuit because of this controlled size reduction.

Ball mill

It is a type of grinder used to grind or blend materials for use in mineral dressing processes, ceramics etc. This mill works on the principle of impact and attrition. It consists of cylindrical container filled with number of balls made up of steels. The final stages of comminution are performed in tumbling mills using steel balls as the grinding medium and so designated “ball mills.”

Since balls have a greater surface area per unit weight than rods, they are better suited for fine finishing. The term ball mill is restricted to those having a length to diameter ratio of 1.5 to 1 and less.

Tube mill

It consists of a long revolving tube containing flint pebbles or steel balls and is used for pulverizing. Ball mills in which the length the length to diameter ratio is between 3 and 5 are designated tube mills. It is made narrow to prevent breakage of the pebbles.

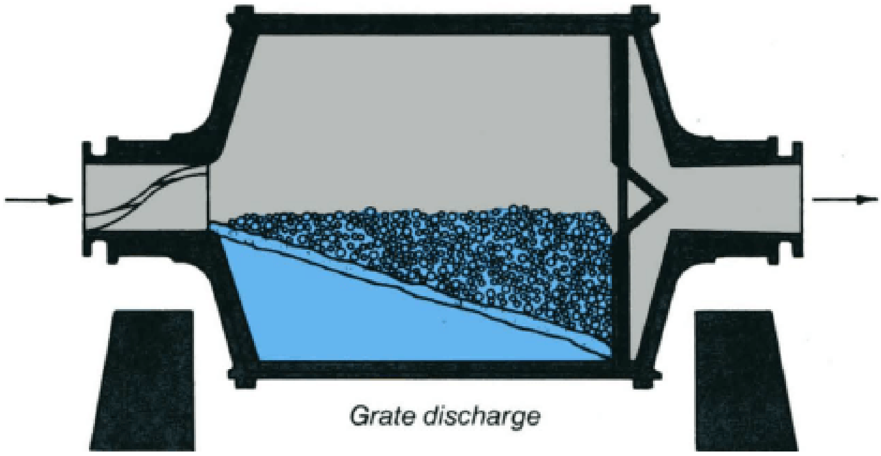
Pebble mills

Tube mills having only one compartment and a charge of hard, screened ore particles as the grinding medium are known as the pebble mills. Since the weight of pebbles per unit volume is 35-55% of that of steel balls, and as the power input is directly proportional to the volume weight of the grinding medium, the power input and capacity of pebble mills are correspondingly lower.

By the nature of discharge, ball mills are classified as: grate discharge mills and trunnion over flow mill.

Grate discharge mill

These mills have lower pulp level than overflow mills, thus reducing the dwell time of particles in the mill. Very little over grinding takes place and the product contains a large fraction of coarse material, which is returned to the mill by some form of classifying device. Grate discharge mills usually take a coarser feed than overflow mills and are not required to grind so finely, the main reason being with many small balls forming the charge the grate open area plugs very quickly.



Trunnion over flow mills

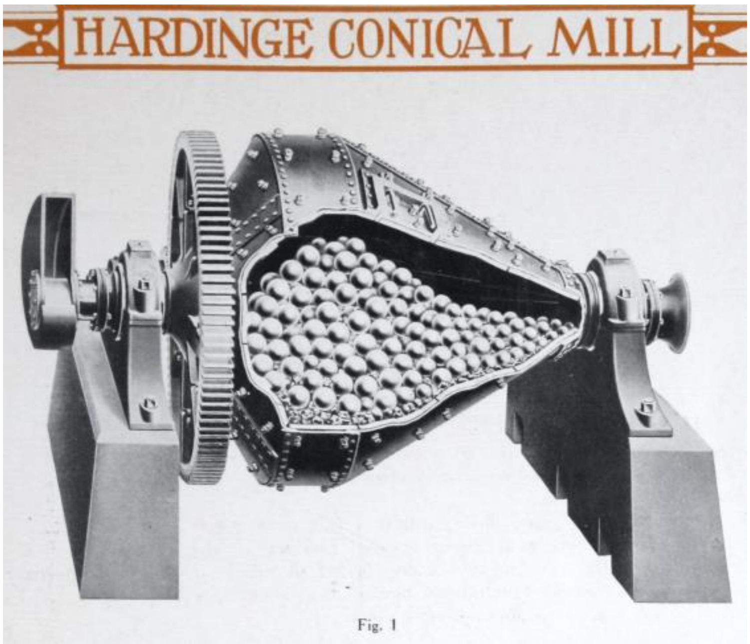
It is the simplest mill to operate and is used for most ball mill applications, especially for fine grinding and regrinding. Energy consumption is said to be about 15% less than that of grate discharge mill of the same size, although the grinding efficiencies of the two mills are the same.

Grinding in a ball mill is effected by point contact of balls and ore particles and, given time, any degree of fineness can be achieved. The process is completely random- the probability of a fine particle being struck by a ball is the same as that of a coarse particle.

Several factors influence the efficiency of ball mill grinding. The pulp density of the feed should be as high as possible, consistent with ease of flow through the mill. It is essential that the balls are coated with a layer of ore; too dilute a pulp increases metal-to-metal contact, giving increased steel consumption and reduced efficiency. The viscosity of the pulp increases with the fineness of the particles, therefore fine grinding circuits may need lower pulp densities.

The efficiency of grinding depends on the surface area of the grinding medium. Thus, balls should be as small as possible and the charge should be graded such that the largest balls are just heavy enough to grind the largest and hardest particles in the feed. A seasoned charge will consist of a wide range of ball sizes and new balls are added to the mill are usually of the largest size required. Undersize ball leave the mill with the ore product and can be removed by passing the discharge over screens.

Segregation of the ball charge within the mill is achieved in the hardinge mill. The conventional drum shape is modified by fitting a conical section, the angle of the cone being about 30 degree. Due to the centrifugal force generated, the balls are segregated so that the largest diameter and greatest centrifugal force, and the smallest are at the discharge. By this means, a regular gradation of ball size and of size reduction is produced.



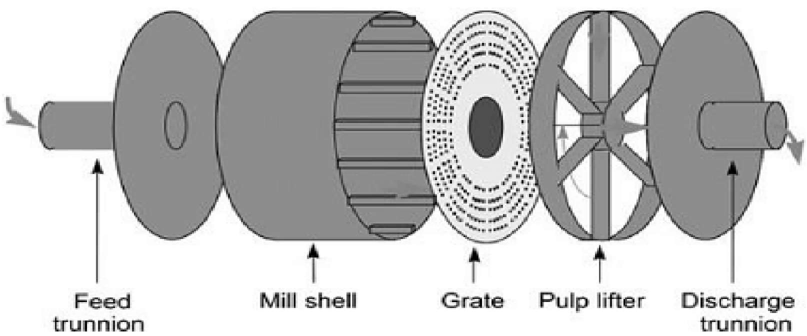
The charge volume is about 40-50% of the internal volume of the mill about 40% of this being void space. The energy input to a mill increases with the ball charge, and reaches a maximum at a charge volume of approximately 50%, but for a number of reasons, 40-50% is rarely exceeded. In overflow mills the charge volume is usually 40%, but there is a greater choice in the case of grate discharge mills.

Grinding balls are usually made of rolled high carbon or alloy steel, or cast alloy steel. Ball mills are often operated at higher speeds than rod mills, so that the larger balls cataract and impact on the ore particles. The work input to a mill increases in proportion to the speed, and ball mills are run at as high a speed as is possible without centrifuging.

Autogenous mills

One of the major developments in the mining industry during recent years is the use of autogenous grinding (AG) and semi-autogenous grinding (SAG) mills. An AG mill is a tumbling mill that utilises the ore itself as grinding media. An SAG mill is an autogenous mill that utilises steel balls in addition to the natural grinding media. Experience indicates that the ball charges used in SAG have generally been most effective in the range of 4-15% of the mill volume, including voids.

The main advantage of AG/SAG mills are their lower capital cost, the ability to treat a wide range of ore type including sticky and clayey feeds, relatively



Schematic of various sections of an AG
(Courtesy Latchireddi, 2002).

simple flow sheets, the large size of available equipment, lower manpower requirements, and reduced grinding media expense.

A schematic of various sections of the autogenous mill is shown in the figure given below:

The grate as shown in figure above is used to hold back the grinding media and allow fine particles and slurry to flow through its holes. Shapes of the grates apertures can be square, round, or slotted, with size varying from 10 to 40 mm.

Autogenous milling may be performed wet or dry. Dry mills have more environmental problems, do not handle materials clay well, and are more difficult to control than wet mills. The main mechanism of comminution in AG/SAG mills is considered to be abrasion and impact. Smoother particles surfaces are also obtained, which is desirable for floatation, particularly for the attachment of air bubbles. Investigations have shown that ores ground autogenously float faster and with better selectively than if ground conventionally. The AG and SAG mills respond in a different manner to feed size changes. In general, AG mill performance is better with coarser feeds. The coarser feed rocks provide less of a role in providing grinding media and will instead provide a rock burden which requires to be ground. By reducing the feed size in these circumstances the grinding burden will be reduced.

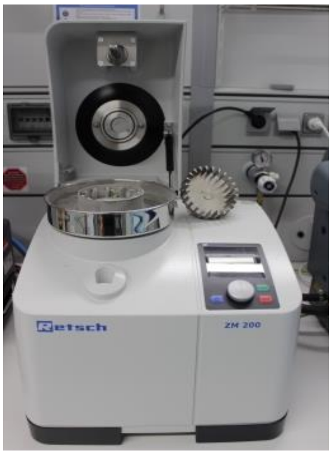
Unlike rod or ball mills, autogenous or semi-autogenous mills cannot usually be selected from bench scale grinding tests as they require more extensive testing. While grinding rods and balls can be obtained in the required sizes and quantities and their actions during milling can be reasonably predicted, in an autogenous mill the grinding medium is also the material to be ground and consequently is itself a variable.

Vibratory mills

Vibratory mills are designed for continuous, or batch, grinding to give a very fine end product from wide variety of materials, the operation being performed either wet or dry. The outstanding features of correctly designed vibratory ball mills are their small size and lower energy consumption relative to throughout when compared with other types of mill.

Centrifugal mill

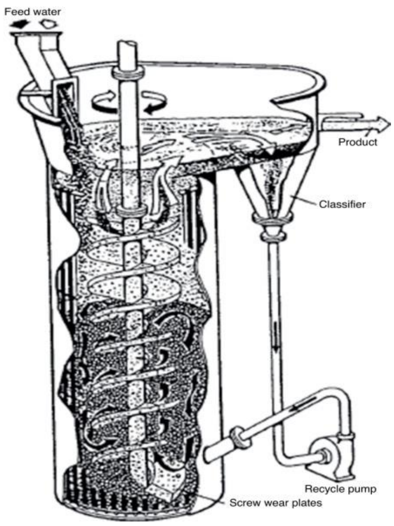
The concept of centrifugal grinding is an old one and although a patent of 1896 describes this process, it has so far not gained full-scale industrial application. In centrifugal milling, the forces on the charge inside the mill are increased by operating the mill in a centrifugal, rather than a gravitational field. Comminution is more rapid, and the size of machine needed for a given grinding duty is thus reduced.



Tower mill

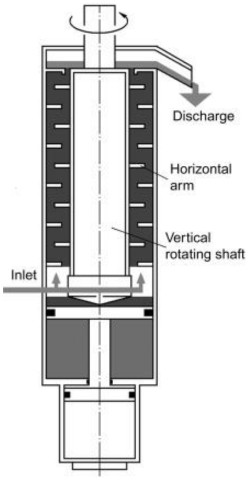
As tumbling mills such as ball and AG/SAG mills are not very effective in fine grinding due to their relatively low power intensity alternatives for fine/ ultra fine grinding are tower mills and stirred mill

In contrast to tumbling mills where motion is imparted to the charge via the rotational mill shell, in tower and stirred mills motion is imparted to the charge by the movement of an internal stirrer while the shells are stationary. In a tower mill such as that manufactured by Kubota in Japan and the Metso Vertimill, steel balls or pebbles are placed in a vertical grinding chamber in which an internal screw flight provides medium agitation.



Stirred mill

Finer grinding is normally achieved with stirred mills. These employ stirrers comprising a shaft with pins or disks. It can be classified by their shell orientations: vertical such as the Sala Agitated Mill (SAM) or horizontal such as the Isa Mill. They are distinguished by the designed power intensity. For tower mills, the power intensity is 20-40kW/m^3; for a vertical pin stirrer mill it is 50-100kW/m^3 and; for horizontal stirred mills it is around 300-1000kW/m^3. The power intensity for horizontal stirred mills is thus an order of magnitude higher than that of vertical ones.



Stirred Media Detritors (SMD)

Unlike the stirred mill, which uses a shaft with discs or pins rotating at a very high speed, the SMD uses impellers rotating at a low speed. Normally, a natural silica or ceramic media is used as the grinding media (hence it is also called Sand Mill). Grinding media is added through a pneumatic feed port or the manual feed chute located on top of the mill. Feed slurry enters through a port in the top of the unit.

Rolled mill

These mill are often used for the dry grinding of medium soft materials made of up to 4-5mohs. Above this hardness, excessive wear offsets the advantage of lower energy consumption compared with conventional mills.

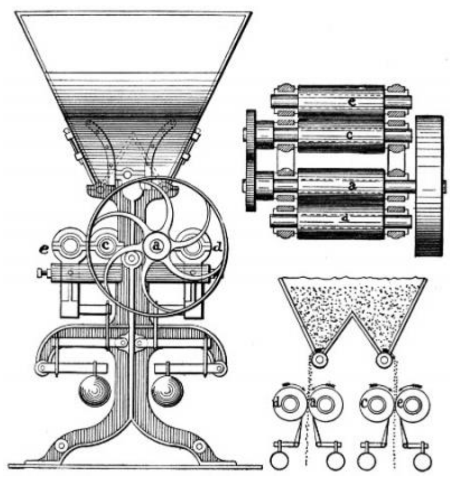


Table and roller mills

These are used to grind medium hard materials such as coal, limestone, phosphate rock, and gypsum. Two or three rollers, operating against coiled springs, grind material which is fed onto the centre of a rotating grinding table. Ground material spilling over the edge of the table is air-swept into a classifier mounted on the mill casing, coarse particles being returned for further grinding.

Pendulum roller mills

These are used for fine grinding non-metallic minerals such as barytes and lime-stones. Materials is reduced by the centrifugal action of suspended rollers running against a stationary grinding ring. Ground material is air-swept from the mill into a classifier, oversize material being returned.