IV. COMMINUTION

The process of size reduction is known as comminution. In mineral processing parlance, comminution in coarse range is known as crushing and in fine range it is called grinding.

Generally, crushing is carried out in two stages, namely, primary and secondary crushing. Jaw and Gyratory type crushers are used mostly for primary crushing. They are characterized by wide input side (known as gape) and narrow discharge. They can handle large tonnage of material. Jaw crushers produce a reduction ratio of 4:1 to 9:1 while gyratory crushers produce a somewhat larger range of 3:1 to 10:1. The reduction ratio is defined as the representative feed size by representative product size.

Once the run-of-mine (ROM) ore is crushed to smaller pieces by the primary crushing units, the secondary crushers are employed to achieve further reduction in size. Examples of secondary crushers are cone crusher, impact crusher and roll crusher. Cone crushers produce reduction ratios in the range 5:1 to 8:1. Very high reduction ratios, 20:1 to 40:1, can be achieved using hammer type impact crushers. However, roll crushers do not offer high reduction ratios. They can attain ratios only in the range 2:1 to 4:1. Roll crushers also have the limitation on feed size. Very large size particles can not be gripped by the rollers and the angle of nip is the key parameter in this regard. Rotary breakers are also used for comminution in coarse size range particularly in coal preparation.

Comminution is a very energy intensive operation. Generally speaking, the more energy that is absorbed by the particle, the finer the average size of the product population. If dp is a representative size of a distribution (usually d_{80}), the relationship between comminution energy absorbed per unit mass and the representative size is defined by a differential equation:

$$dE/dd_p = -kd_p^{-n} \qquad \text{............................ (2)}$$

where, E is the energy absorbed and n is an exponent whose various values have been suggested by different workers.

The above equation can be solved with the initial condition that E=0 when $d_p = d_{pi}$ (product size = parent size) to get (for $n \neq 1$):

$$E = \frac{k}{n-1}\left[\frac{1}{d_p^{n-1}} - \frac{1}{d_{pi}^{n-1}}\right] \qquad \text{............................ (3)}$$

Thus, when n = 1 (Kick's Equation):

$$E = k \ln \frac{d_{pi}}{d_p} \qquad \text{............................ (4)}$$

When n = 1.5 (Bond's Equation):

$$E = 2k[\frac{1}{d_p^{1/2}} - \frac{1}{d_{pi}^{1/2}}] \qquad \text{.............................} (5)$$

When n = 2 (Rittinger's Equation):

$$E = k\,[\frac{1}{d_p} - \frac{1}{d_{pi}}] \qquad \text{.............................} (6)$$

The later two equations are generally used to estimate the energy consumption for comminution. The work index of a material is calculated using Equation (5), that indicates the ease or difficulty of comminution in terms of energy requirement.

Grinding machines in the mineral industry are of tumbling mill type. These mills exist in a variety of kinds such as ball, rod, pebble, autogeneous, semi-autogeneous, etc. Grinding action is induced by relative motion between the particles of media - the rods, balls or pebbles and the particles themselves. High compression roll mill and fluid energy mills are recent developments in comminution technology.

There are two different types of motion of media particles in the mill, namely, cascading and cataracting generating from the tumbling motion of the mill. When the particles move along the inner surface of the mill shell, lifted up, loses contact with the surface and travel downward in a trajectory through the empty space inside the mill resulting in an impact on contact with the inner surface again, the motion is called cataracting. This motion produces fewer amounts of fines.

When the media particles move up and then roll down along a parabolic path while remaining within the bulk itself, the motion is called cascading. This motion generates fines and to be minimised to the extent possible. Clearly, at lower rpm of the mill cascading is predominant and higher speed is necessary for cataracting motion. However, this is restricted by the critical speed, a very crucial parameter, of the mill.

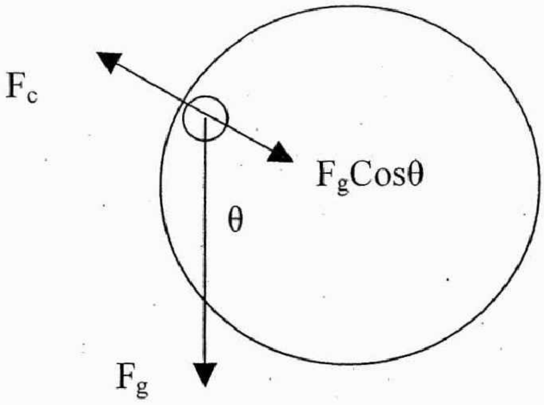

Fig. 4 : Forces on a media particle in a tumbling mill

When a media particle is moved up the two forces acting on it are the centrifugal force F_c and the gravitational force F_g. Balancing them in the radial direction and simplifying,

$$\omega = [\frac{2g}{D_m}]^{1/2} \qquad \text{.............................} (7)$$

where ω is the angular speed and D_m is the mill diameter. Expressing angular speed in revolutions per minute,

$$N_c = \frac{42.3}{D_m^{1/2}} \qquad \text{.............................. (8)}$$

This is the critical speed of the mill beyond which the media particles will remain centrifuged at the wall resulting in no impact or grinding action. Thus, the mill must be operated below the critical speed.

In industrial practice, most comminution operations are closed circuit except primary crushing. A comminution circuit is said to be closed when it operates in series with a size classifier and the coarse fraction of the classifier is re-circulated back into the comminution unit. A secondary crusher with a vibrating screen and a ball mill/rod mill with a hydrocyclone are most common closed circuit comminution operations in mineral processing plant practice.

Most industrial grinding circuits are operated under wet conditions. This circuit ensures a steady output of desired sized particles with a suitable distribution. The mass flow rate of the output of this circuit must remain reasonably constant with a pre-set value of the representative size (d_{80}). Deviation from this target will result in under-utilization or choking of downstream processing stages. There are several variables that can be monitored and controlled to achieve this target. Mill charge, feed rate, pulp density, classifier feed pressure, etc., can be measured and adjusted to the required value to ensure smooth operation and obtain output of required specifications.