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CRUSHING

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Crushing is only one facet of comminution, which is the successive reduction in size of ore particles containing wanted values in intimate association with unwanted gangue or tailings. The particle size is progressively reduced until the desired mineral can be liberated and separated from the gangue. Crushing may take place by compression of the ore between rigid surfaces or by impacting the particle against a massive surface.

An understanding of the mechanisms of comminution is essential to rational development of a particular process flow chart. Moving from initial run-of-mine feed to final product size involves reductions through a series of machines, each of which has a considerable latitude in application.

In the more than 100 years of mechanical crusher development, a large number of types and machine configurations have been produced. The variety of materials to be crushed and differing requirements of various industries for economic balance between investment and operational costs are the chief reasons for the proliferation.

Crushers can be classified into six major categories: Blake, Dodge (obsolete), and overhead eccentric-type machines; gyratory crushers, including primary, secondary, cone, and "Gyradisc" units; impactors, which include single and double rotor, hammer, and cage-type machines; roll crushers, consisting of smooth or double and toothed or single and double units; shredders, consisting of toothed, cage, and disc machines; and roller mills, including ring, bowl, and roll units.

Cohesive or clay-like ore, when moist, requires an impact-type crusher, provided the ore is relatively non-abrasive containing a maximum 5-10% silica. Higher silica content reduces crusher availability, because maintenance requirements are high. Harder ores require jaw and gyratory crushers. Toothed roll crushers perform well on soft, cohesive ore but are limited in terms of throughput and feed size. Roller mills are generally used in dry, soft ore applications, where the rock is friable.

The Blake jaw crushers (Fig. 1) were the first to be developed and remain pre-eminent as heavy-duty crushers. The size of the receiving aperture is fixed, because the moving jaw is pivoted at the top. There is a variable discharge opening. The differential from the smallest to largest opening is known as the throw. The angle between the jaws is 25-30°, the more acute angle being used for greater compression. Too large an angle may cause slippage in the initial crushing blows, with a resultant reduction in throughput and an increase in wear of the jaw liner plates.

Ore proceeds through the crushing chamber or cavity in a series of bites. The material is arrested during crushing and falls freely as the jaw opens. The volume of material expands with each stroke. Since the cavity tapers downward, there is a tendency to "choke," except that a downwardly increasing jaw motion of "swing" allows freer discharge at a rate that accommodates new feed to the machine. The jaw setting (the closest approach at the discharge end) is adjusted by shims or wedges. Crusher size and speed are inversely proportional

Fig. 1—Blake jaw crusher

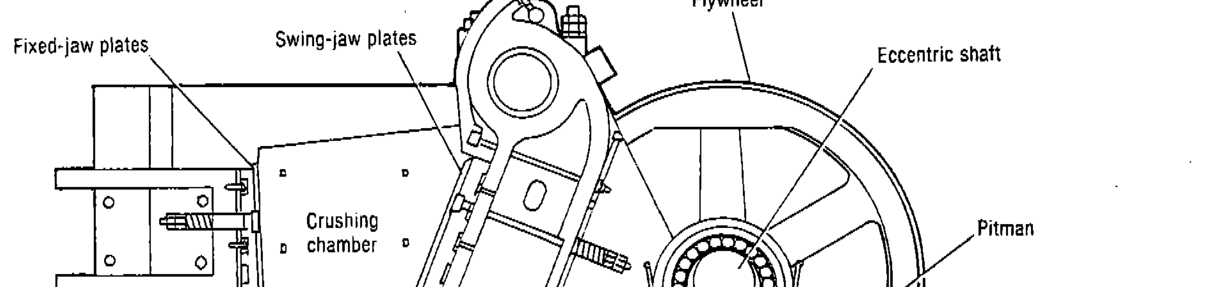
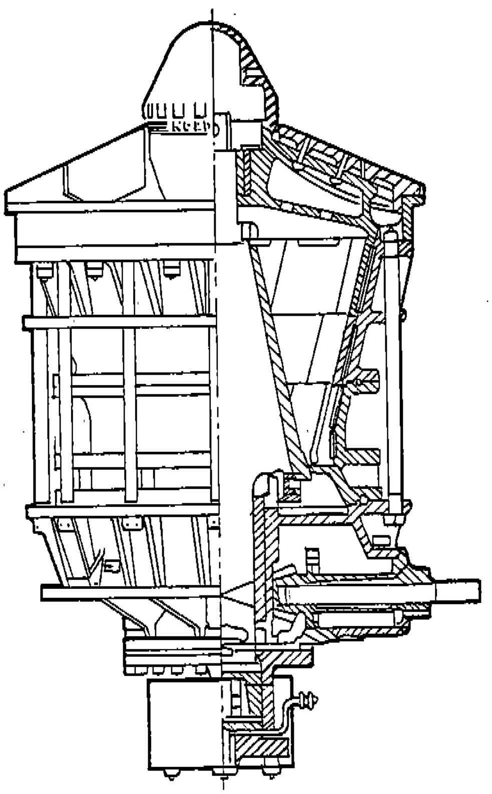


Fig. 2—Primary gyratory crusher —hydraulic support



because of the high inertial and impact forces that characterize crushing operations.

The throw is determined by the physical properties of the ore, and may vary from 1/4 to 3 in., the former being used for hard, friable ore and the latter for tough, resilient material. Large throw reduces the choking potential, but the greater reduction produces more fines and requires a sturdier machine.

Jaw crushers are designated by feed opening dimensions and are built in sizes up to 64-in. opening by 80 in. wide, a size that can produce 750 stpy at an 8-in. setting when crushing run-of-mine ore at 48-in. size. The jaw crusher, unlike the gyratory and its derivatives—cone crushers—is only occasionally used for secondary stage crushing.

THE GYRATORY CRUSHER

The gyratory crusher incorporates a shrouded spindle suspended at the upper end of the machine. At the lower end, the spindle is retained through a sleeve bearing in an eccentric driven by a bevel and countershaft drive. The spindle and shroud, together referred to as the crushing head, taper down conically to a larger diameter. The eccentric rotation causes the head to sweep out a conical path, which is determined by the throw of the eccentric, inside a conically tapered crushing chamber or shell. The angle between the shell and the head is the nip angle, which is analagous to the nip angle in the jaw crusher. Another point of similarity between gyratory and jaw crushers is the small motion at the feed inlet with increasing motion toward the discharge, which helps prevent choking. The primary crushers are designated by the width of the feed opening at the top, between the head and shell, and by the largest diameter of the head, which determines the discharge capacity.

Of the suspended, fixed, or hydraulically supported gyratory designs, the hydraulic design (Fig. 2) is the most popular for mining applications, since it provides some protection from tramp material and a setting that can be adjusted by raising or lowering the crushing head on a hydraulic support cylinder.

The crushing stroke of a gyratory greatly affects the crusher capacity and gradation of the crushed product. A short stroke provides a more uniform product at lower capacities. A long stroke gives greater capacity but also a greater proportion of product material exceeding the closed-side setting.

Most manufacturers offer a throw from 3/4 in. to 2 in., depending on size and application. The throughput and power draw of the gyratory depend on the throw, on the material hardness, and on the relative quantity of the coarse gradation in the feed. Large amounts of "near size" and fines tend to chute through the crusher unless blocked by the crushed material. If this happens, heavy power draws can be induced. In such application, the gyratory may be fed across a stationary scalping grizzly to remove fines, which may be as high as one-third the total feed. Crusher sizes offered by several manufacturers tend to be similar, differing only in design detail; the sizes are determined by blasting practice, shovel size, truck or train loadings, and plant requirements for single- or multiple-shift operation. Gyratories produce a product with open side setting of 5 in. to 10 in., at discharge rates from 600 to 6,000 tph, depending on size.

CHOICE OF A PRIMARY CRUSHER

Largest particle size of the feed dictates the size of the crusher, and production requirements dictate the crusher type, gyratory or jaw. To avoid blockage in the crusher, blasting practice should be adjusted to produce a feed size about 80% to 90% that of the designated crusher opening, with a maximum of 80% of the feed passing two-thirds of the feed opening. Table 1 shows the capacity and opening for a 42-70 machine.

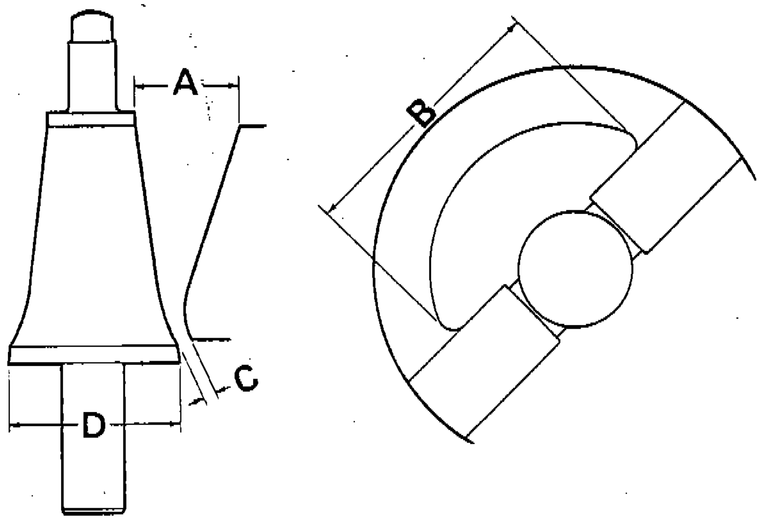
The gyratory's operating continuity and higher capacity are its principal advantages. Jaw crushers are used if accommodating feed size is more important than throughput and if plant tonnage requirements are low. A gyratory that accepts the same maximum feed tonnage as a jaw crusher might accommodate several times the tonnage of the jaw crusher but be uneconomic to buy and operate at reduced capacity. For a given size, capital and maintenance costs—but not installation costs—are lower for a jaw. The setting in either type crusher may be changed to perform increased or decreased reduction in later crushing stages; however, this can be done more easily in the hydraulically supported gyratory than in the jaw crusher.

The segmented nature of the liner material in the gyratory and the need for partial dismantling for access to the cavity when relining is a disadvantage at plants that process abrasive ores such as taconites. In recent years, however, the use of reinforced alloyed white irons (Ni-hards) has led to a remarkable reduction in frequency of liner changes in the high wear areas at the throat of the machine, with wear increases of 200-300% over conventional manganese steel liners.

Relining, maintenance, and product handling require more room above and below the gyratory than the jaw. Most manufacturers furnish the recommended clearance and component weight handling requirements for either type of machine, as well as recommended foundation setting and mass.

Choice of crushers for mining, versus aggregate, applications is determined almost entirely by the need for continuity

Table 1—Capacity for a 42-70 primary crusher



CAPACITIES IN TONS PER HOUR (2000 Lbs.)

Size	A x B Feed Opening (Inch)	D Head Diameter (Inch)	Gyra per Min.	Cntr. Shaft RPM	Eccentric Throw Inch	Max. HP	Open Side Discharge Setting — C									
							3 1/2	4	4 1/2	5	5 1/2	6	6 1/2	7	7 1/2
42-70 HD	42 x 114	70	137	514	3/4	200				525	625	730	835	925	1020
					1	250				700	830	975	1110	1230	1360
					1 1/8	270				785	936	1100	1250	1385	1530
					1 1/4	300					1040	1220	1390	1540	1700
42-70 XHD	42 x 114	70	137	514	3/4	240			430	525	625	730	835	925	1020
					1	320				700	830	975	1110	1230	1360
					1 1/8	360				785	936	1100	1250	1385	1530
					1 1/4	400					1040	1220	1390	1540	1700

of production and crusher availability in the mining application. In nonmetallic applications, impactors and hammermills are frequently used for primary crushing, with one or two shifts per day left for maintenance and replacement of hammers, etc.

FINE CRUSHING

Secondary crushers are much lighter and perform less rigorous work than primary machines. Their feeding and discharge arrangements do not require the ruggedness of those needed for primary crushers, nor do they have to accommodate such extremes of feed rate and ore size. Secondary units prepare mill feed directly or provide feed to a third crushing stage. The greatest proportion, by far, of secondary and subsequent-stage crushing of ores is performed by cone crushers, of which there are numerous versions. All cone crushers operate in accordance with the Symons' principle, after the inventor. A converging cavity permits several arrested crushing strokes, while the outward and downward flare of the crushing head and bowl accommodates the swelling of crushed ore by providing increased volumetric capacity toward the discharge at the periphery of the head. The movement of the head is gyratory, as it is in the primary crusher, but the gyrations are two to three times faster, and the throw, as measured at the largest head diameter, is proportionally greater. Closer sizing is accomplished through a series of arrested impacts and results from the number of blows received at the liner discharge or so-called parallel zone.

Two basic makes of cone crusher have found general acceptance in mineral processing because of their size, high strength, rigidity, and ability to absorb high power inputs consistent with high ore reduction ratio. One is Rexnord's Symons cone crusher[1], which accounts for the bulk of all crushers in use in the most extreme duty. A distinctive feature of this design is operation at a fixed setting, although recent developments in controls allow adjustment under load. The other type of cone crusher is the Allis-Chalmers hydraulic-supported machine[2] (Fig. 3).

Cone crushers range in size from 2 to 10 ft, measured at the largest diameter of head over which crushing occurs.

Another type of fine crusher is the "Gyrasdisc" (Fig. 4), whose mechanical features are similar to other fine crushers, except that the liners are shorter and flatter. The machine setting is not directly related to the desired top product size, since several layers of material are crushed at once, in contrast to the arrested single-layer crushing in gyratory, cone, and jaw crushers. The Gyradisc uses inter-particle comminution to produce fines.

OPEN AND CLOSED CIRCUITS

Any crusher can be used in either "open" or "closed" circuit (Fig. 5), depending on whether all the crusher product passes on to the next stage or a portion of it is returned for recrushing. Closed circuiting is accomplished by passing the crusher output over a screen deck that has an opening

Fig. 3—Cone crusher—variable setting

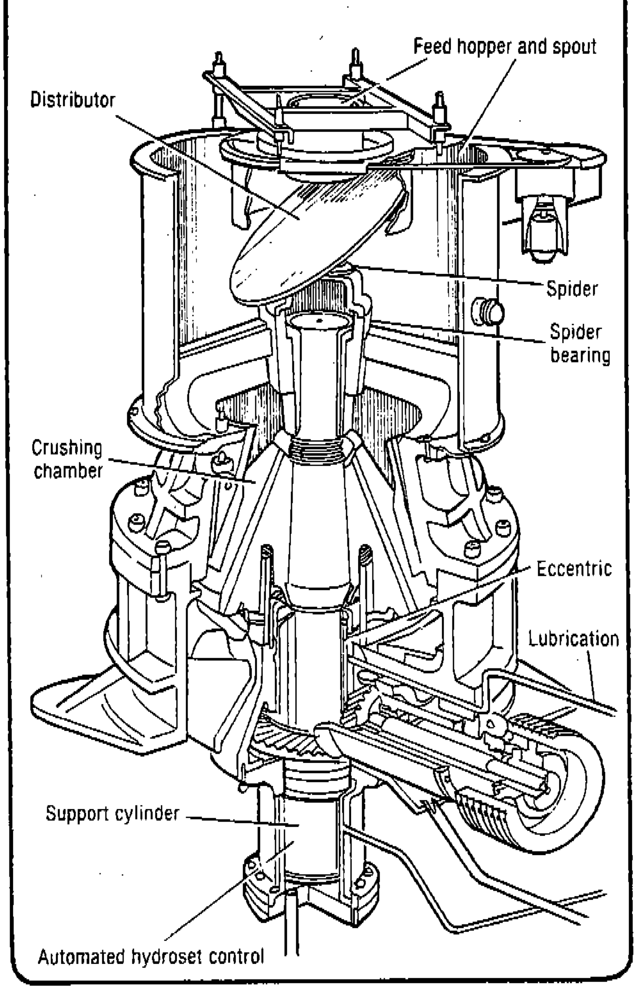


Fig. 4—Fourth stage crusher—"Gyradisc"

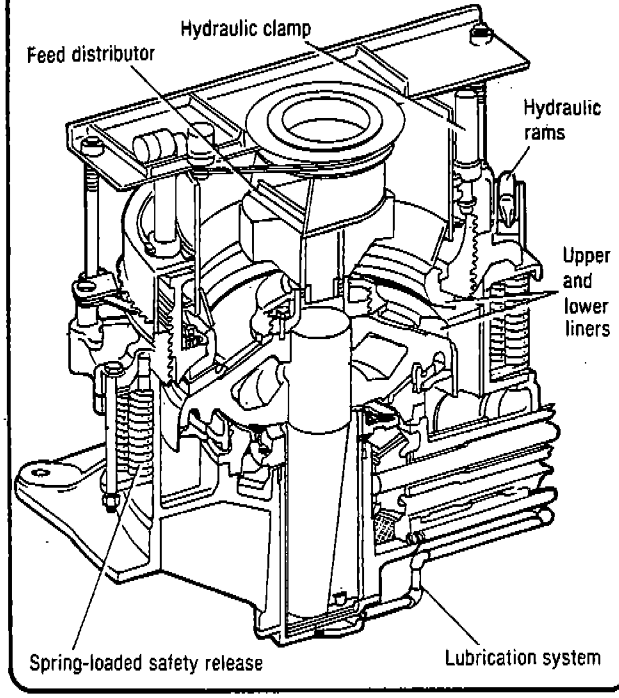
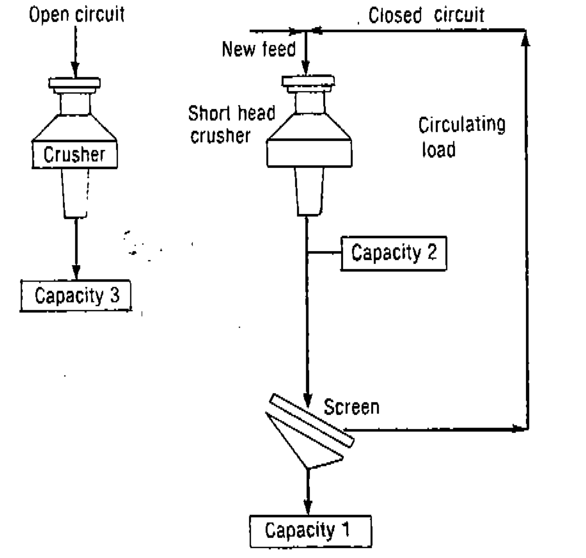


Fig. 5—Open and closed circuit operation



slightly larger than the crusher setting. The oversize from the screen is recirculated to the crusher; the undersize is usable product or is fed to the next stage. Primary and secondary stages are usually open-circuited, although on occasion the secondary may be closed-circuited. Tertiary stages are usually closed-circuited for accurate sizing. If a fourth stage (Gyradisc) is included, it may be open or closed-circuited.

Since the 7-ft cone crusher is the most popular for intermediate- to large-scale mineral crushing applications, the typical capacity charts relating to that size are given in Table 2.

Fig. 6 illustrates a typical flowsheet[3] of a plant producing ball mill feed of minus ½ in. at a rate of 900 tph. Operating times are not stipulated, but it is assumed that the availability of the primary crusher will be about two-thirds to three-quarters that of the subsequent stages. The lower availability of the primary results from a need to stockpile if the primary goes down for liner changeout, or if pit material is oversized or trucks are delayed. Accordingly, the capacity of the gyratory must be 1,200 to 1,300 tph to supply the plant adequately. The run-of-mine top size is assumed to be 28 to 30 in. The 300-hp 42-70 gyratory shown is the correct machine for this operation.

The flowsheet is typical of current practice in that the secondary product is screened and conveyed to a bin. Screen oversize is not discharged directly to the tertiary crusher. The intermediate bin makes it possible to obtain good mixing of the secondary screen oversize with the circulating load and also to regulate feed to the tertiary. This makes for more efficient crushing. The circuit is also more readily adaptable to automatic feed control to maintain maximum horsepower. Providing surge capacity at each stage and separating the screening and crushing functions permits more flexibility and control of the overall circuit.

CRUSHER CONTROLS

The importance of automatic control is exemplified by one crushing plant[4], in which the output increased by over 15% after controls were introduced. In the same plant, producing ball mill feed, a 10-20% increase in fineness of the critical ore size was instrumental in achieving comparable increased mill output. In crushing plants that produce a final, sized product for sale, control will maximize the production of that size.

Table 2—Capacity for a 7-ft secondary crusher

Size	Type of Cavity	Recommended Minimum Discharge Setting A	Feed Opening With Minimum Recommended Discharge Setting A: B Closed Side	B Open Side	Capacities in Tons (2000 lb.) Per Hour Passing Through the Crusher at Indicated Discharge Setting A: 1/4" (6 mm)	3/8" (10 mm)	1/2" (13 mm)	5/8" (16 mm)	3/4" (19 mm)	7/8" (22 mm)	1" (25 mm)	1 1/4" (32 mm)	1 1/2" (38 mm)	2" (51 mm)	2 1/2" (64 mm)
7 ft.	Fine	3/4"	10"	11"					370	400	500	620	750		
	Medium	1"	11 1/2"	12 3/4"						500	600	750	800	1100	
	Coarse	1 1/4"	13 1/2"	14 7/8"								750	850	1200	1400
	Extra Coarse	1 1/2"	16 3/4"	18 1/8"									850	1200	1400

A simple feed control (Fig. 7) can be achieved on either a continuous sensing or on-off basis to maintain set power, as might be recommended by the manufacturer for peak performance. A sophisticated control (Fig. 8) can be fully automatic, with a microprocessor or dedicated computer to massage input sensor data and output controls to adjust the system in response to changed conditions. The automatic system is based on selection of operating variables such as feed level, feed rate, or power draw that are suitable for continuous sensing and control.

In designing the control system, mathematical models of crushers and screens are utilized to investigate the effect of major variables, posing hypothetical questions and obtaining responses from the various parts of the system. Variables that can influence product size and throughput include hardness, quantity and gradation of new feed and circulating load, machine numbers, and liner and screen cloth wear.

Individual equipment items have been optimized during design, and little more can be done by the control scheme than to regulate operation per the manufacturer's recommendations and settings.

If screen efficiency is not seriously impaired by excessive recirculating load and the crusher can pull about 80% of its rated power on a sustained basis, there is a given setting for the crusher that will provide the highest tonnage of finished screen product. (The feed to the crusher may be increased at larger closed-side settings.) For this reason, control systems that use rapid hydraulic positioning to change crusher settings do not achieve maximum usable product, in keeping with the high power draw. Consequently, the two basic types of crushers—the Symons cone, which operates with a fixed closed side setting, and the more complex Hydrocone, which operates with a readily variable closed side setting—have different control schemes. Also, because of their inherent geometric differences, each crusher type produces differing product gradations for a given setting.

The justification for control systems lays with increased throughput and finer product. These can be best achieved by maintaining the highest possible power draw, requiring rugged machines with rigid structures to accommodate ore hardness variation or change in feed consistency at fixed setting. To maintain crusher power, operation under choked conditions also requires sensing of the upper and lower level of feed in the crusher through level, nuclear, sonic, or proximity switches.

The recent development in Symons crushers of remote

Fig. 6—Three-stage crushing flowsheet for ball mill feed

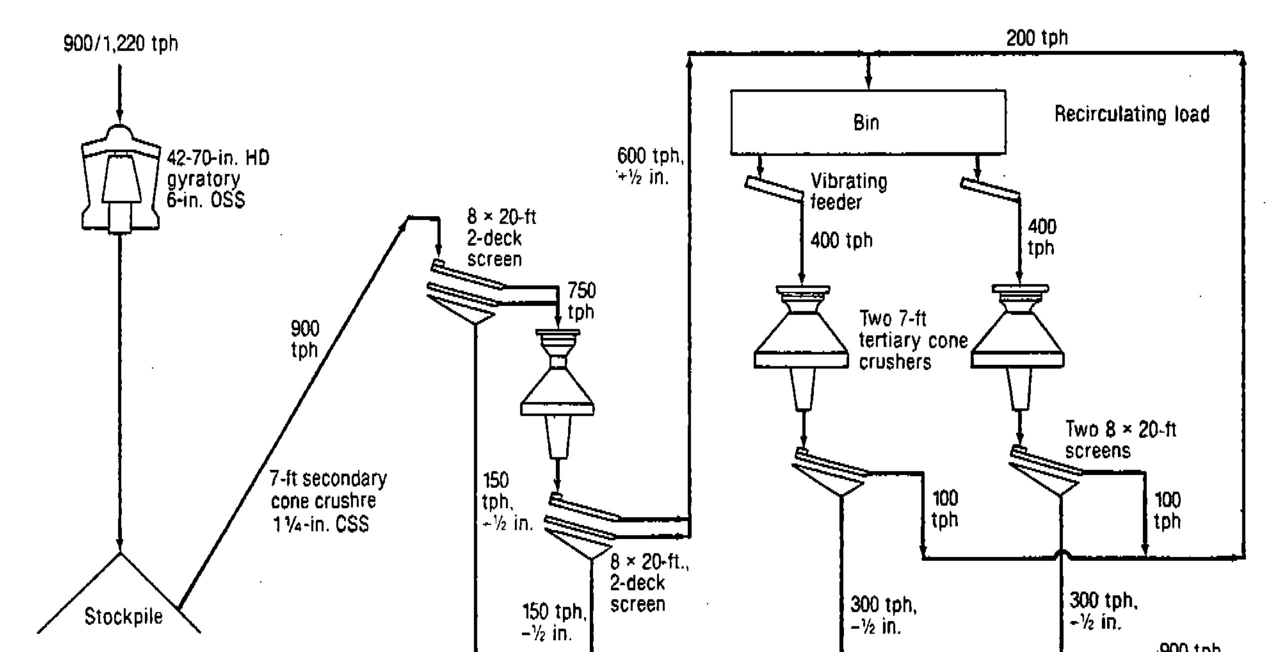


Fig. 7—Simple open circuit crusher control for maintaining power draw

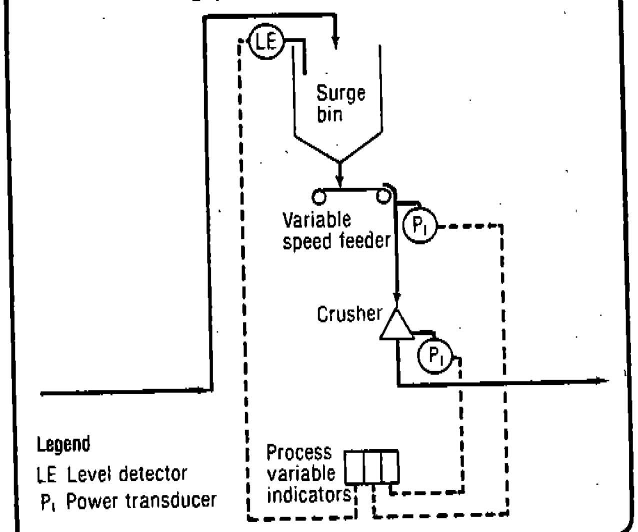
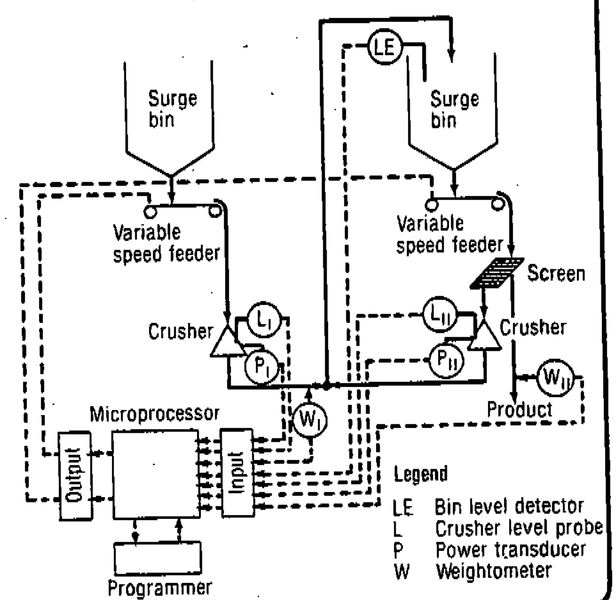


Fig. 8—"Smart" control for crusher based on microprocessor



setting capability while under load has permitted inclusion of additional control loops. Because screen efficiency decreases as screen loading increases, particularly in the percent of near-size to the screen opening, circulating load can be used to control a product size.

Additional control loops can include the crusher product surge bin, so that at high level, screen feed is increased to draw down the bin. The same indication can be used to include, in sequence, control of crusher or feeder setting in the previous crushing stage to reduce feed tonnage and to provide a finer feed to the next stage, reducing the circulating load to the surge bin.

The required variation in crusher closed-side setting can be determined from empirical testing, testing on the actual plant, use of mathematical models, or by measuring product size instantaneously and directly. The latter approach is receiving a great deal of attention. Research is being done on the use of optical imaging techniques in stream measurement. One instrument firm, Foxboro, is marketing a simpler approach that scans and classifies a size surface of product on the discharge belt. However, considerable error may result if the material on the belt is segregated.

IN THE FUTURE

Methods for ore comminution have not changed substantially since originally conceived, although much thought has been given to alternative methods.

Nonmechanical introduction of energy by thermal, shock, hydraulic, or high-voltage electrical discharge, and even high-energy particle bombardment, has been the subject of considerable investigation. The major drawback has been inefficiency as batch methods, requiring selective application. Thermal methods, using high rates of heating or cooling, produce sharp temperature gradients and internal tensile stresses that induce fracturing. Electrohydraulic shock induced by spark discharge, following methods used in metal forming, is severely limited by requirements for water immersion and high energy dissipation.

Other electrical approaches using low-frequency conduction, high-frequency (microwave) induction, and electromagnetic pulse are primarily experimental. One notable exception is the report of a high-voltage (2,500-v, 50 cycle) prod technique used in a large Soviet open-pit mine producing hard ore. Oversize is reportedly reduced at half the cost of conventional methods. Electron beams and laser beams are already in extensive use in secondary metal working and appear promising.

Many efforts have been directed at increasing the productive capacity of existing forms of equipment and processes as well as the overall energy consumption of the plant. These efforts have included:

- Extending the size range of cone crushers to 10-ft head diameter with a two- to three-fold increase in capacity.
- Using crushers to eliminate grinding stages.
- Hydrocrushing to remove fines as generated. This has shown up to a one-third increase in throughput and a decrease in power, but is not practical as yet due to the quantities of water needed.
- Combining the grinding mill and crusher circuit.
- Increasing the intensity of crushing through machine improvements, which allow the application of higher power levels and increased reduction ratio per stage. Reduced equipment sizes reduce plant area and volume and length of runs of other apparatus.
- Increasing the availability of the equipment through improved fatigue-life design of mechanical equipment.
- Reducing changeout and increasing utilization before throw-away of wear material.

It seems reasonable to expect that these efforts will continue, in view of the trends in cost of energy and capital for the vast projects that are characteristic of mining and processing of ore.■

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