METALLIC
MINERALS PROCESSING
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3

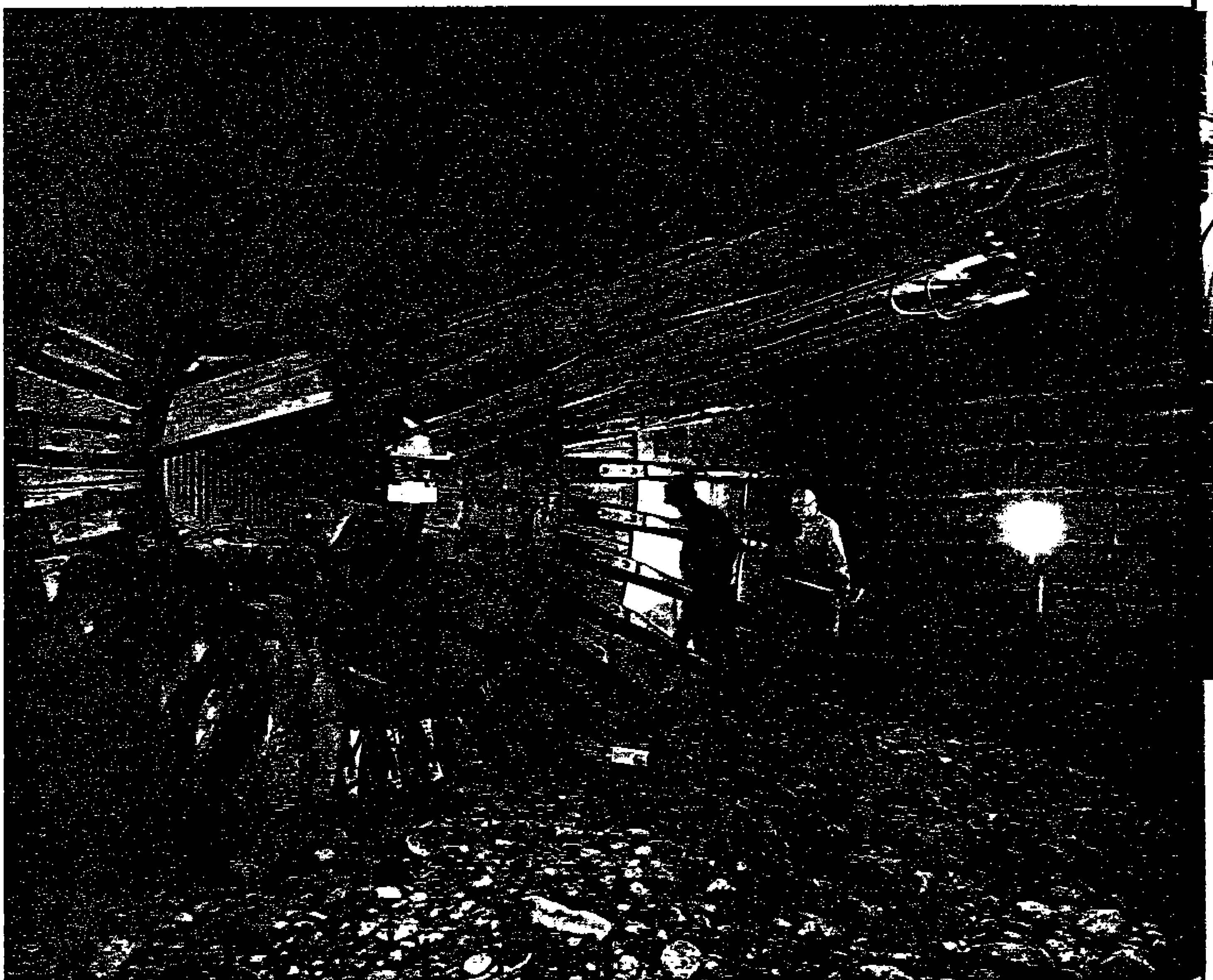
GRINDING

MILL SIZES NEAR A PEAK FOR NOW AND NEW FOCUS IS ON DRIVES, TRUNNIONS, AND CONTROLS

The demand for increased grinding capacity, coupled with steadily declining ore grades and limited capital for plant expansion, have resulted in the design and construction of increasingly larger grinding mills. This increase in mill size, which has only in recent years levelled off, has often resulted in fewer grinding machines per plant with a greater dependence on each machine. The necessity for increased equipment reliability has compelled manufacturers of mills, drives, castings, and other components to implement a number of innovative designs and refinements. The current trend focuses on stepping up refinements with respect to mill control systems design.

CONVENTIONAL GRINDING

Because of the performance characteristics of large rod and ball mills, it appears that the diameters of these mills

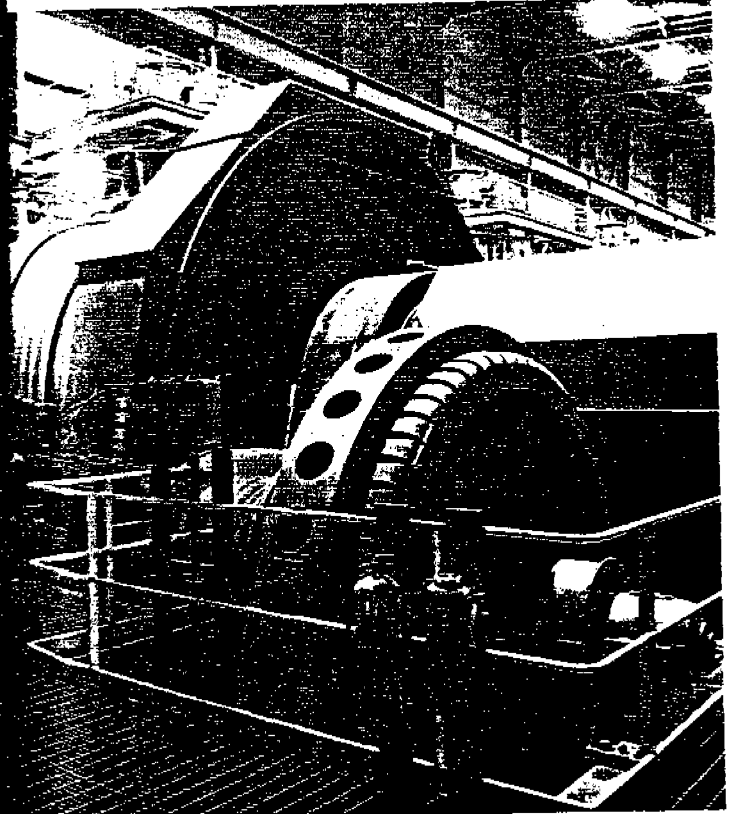


have come close to reaching their maximum limits. In some cases, th~ maximum efficient diameter may have been exceeded. Larger mills can readily be designed and manufactured, but there is no advantage in doing so when the loss in grinding efficiency more than offsets any theoretical gains.

Large wet ball mills seem to have found an efficient diameter limit at approximately 16.5 ft inside shell. Relationships not fully understood, including slurry flow rates, media size versus mill diameter, charge level, and other factors, have produced serious inefficiencies in the larger 18-ft-dia overflow-type ball mills in nonferrous ore grinding.

The length of ball mills depends on such parameters as the ore type and subsequent ore processing steps. A length of 36 ft has been proven satisfactory at Inland Steel's Minorca iron ore processing plant in Minnesota. These mills have a 6,000-hp drive rating.

Rod mills will probably not increase significantly in size because of the quality limits placed on rod media. Competent 4-in.-dia rods are unavailable in lengths greater than 20 ft. Even the premium quality rods now used in the largest rod mills must be carefully manufactured to assure that they remain straight during their life and do not break up prematurely in the mill. Unless a major breakthrough in rod metallurgy comes about as a result of industry demand, the maximum rod mill size for the 1980s will probably be 15.5 x 20.5 ft effective chamber length. A mill of this size would probably have a 2,500-hp maximum drive rating but would fully utilize an average of 2,500 hp, depending upon mill speed, charge loading, and liner and rod condition.



Left—Development of liner handlers was one of the nicer events to occur in grinding circuits. This is an interior view of a 36-ft-dia autogenous mill. **Above**—Single-stage ball mills may present cost saving opportunities, if tertiary or quaternary crushing with size control by screens can minimize the oversize in the feed entering the grinding circuit.

Rod and ball mill circuit characteristics include:

- Highest unit power efficiency of all grinding mill types.
- Low steel consumption per mt of ore.
- Low mechanical and process risk.
- High controllability of plant capacity and product size.
- Necessity for a three- or four-stage crushing plant.
- Necessity for more grinding units than a primary autogenous circuit or single-stage ball mill circuit.
- Design availability of 95%.

Generally, rod mill-ball mill circuits can be justified for use in long-life plants because of their low operating costs.

Wet rod mills are normally used in minerals processing plants. Experience with dry grinding has demonstrated numerous problems; it should be avoided unless absolutely necessary. The largest operating rod mills are 15 x 20 ft, 2,300-hp units at the Eveleth Taconite Co., US Steel's Minntac facility, and Inland Steel's Minorca plant, all of which are located on Minnesota's Mesabi Range.

Wet-type, single-stage ball mills have not been used recently in iron ore mining. This is due mainly to their sensitivity to hard, coarse feed. Rod mills operating in open circuit can handle iron ore feed more efficiently.

Large, single-stage ball mill circuits gained popularity in the 1970s mainly because of their low capital plant cost and adaptability to relatively coarse liberation grinds in the range of minus 35 mesh to minus 65 mesh. Other features include:

- Lower unit power efficiency than rod mill-ball mill circuits by 10% to 25%, depending on feed size, work index, and reduction ratio.
- Higher metal wear than a rod mill-ball mill circuit.
- Low mechanical and process risk, provided the mill feed can be properly prepared to minus ½ in.
- 97% to 98% availability.
- Fewer units for process lines are required than for rod mill-ball mill circuits.

The largest ball mills in the mining industry are in operation at Bougainville Copper Ltd., which utilizes 10 18-ft-dia. overflow-type ball mills rated at 5,360 hp; and at Eveleth Taconite Co., which operates 17-ft-dia. x 41.5-ft overflow ball mills rated at 6,900 hp.

Overflow-type ball mills characteristically exhibit lower

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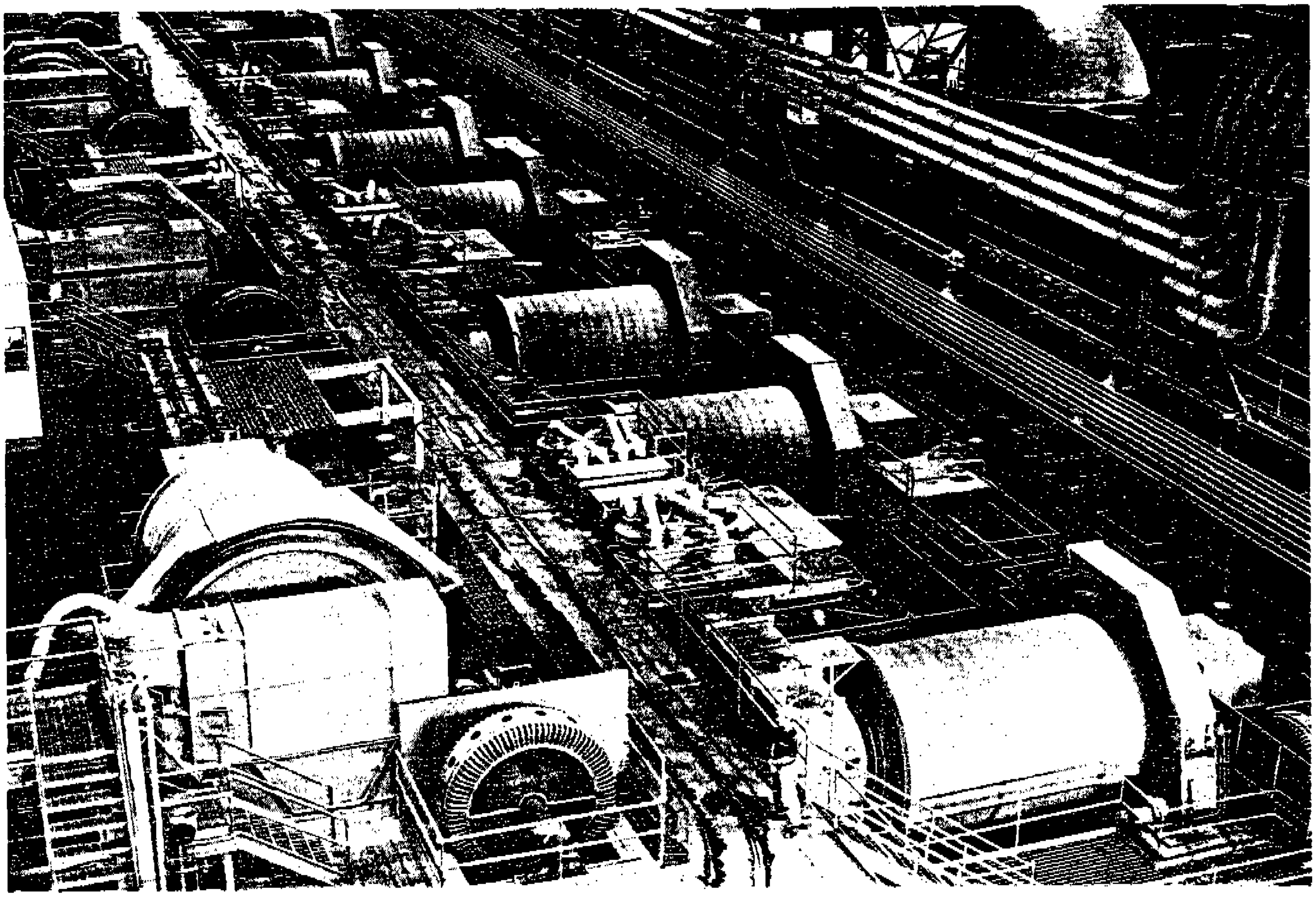


Rod mill and ball mill circuit is still a popular combination at many concentrators. This photo shows the arrangement at a copper plant.

metal wear and better availability than grate mills because of lack of grate wear and grate plugging. Grate mills, however, obtain approximately 15% more power from a given mill size than do overflow-type mills, thereby minimizing cost.

Ball mills normally carry a ball charge occupying 40% to 45% of the mill volume, but can carry up to a 50% or slightly higher charge. For plant capacity and design purposes, ball mills are frequently selected based upon carrying 40% ball charges with the mills and drives designed to carry higher charges if required.

MILL SHELLS AND LINERS

Mill shells have continued to increase in size. Areas of interest to the mill designer are the "turned in" end flanges, sectionalized shells, material quality, and fabrication facilities.

Mathematical modeling work has resulted in shell design innovations. Built up sections of the transition plate, for example, offer strength, reliability, and economy of material through appropriate distribution of stress.

Heavy-duty, single-wave shell liners cast of either alloy steel—manganese steel is not recommended—or wear-resistant alloyed cast iron are most frequently used in rod mills. Rubber backing can be used between the liners and shell to protect the shell from washing and corrosion. However, with rubber backing, care must be taken in the liner bolt specification and sealer assembly to assure that liners will stay tight and not move on the shell. This movement creates leaky liner bolts and causes the bolt holes in the shell to wear into an elongated shape.

The scoop feeder, primarily the double scoop, continues to find increasing acceptance for large ball mills. This is due to the ability of the feeder to carry high loads (up to 45% volume plus) without fear of backspill; to the entry of both new feed and recirculating loads at the mill center line, thus minimizing pumping head; and to the ease of ball addition.

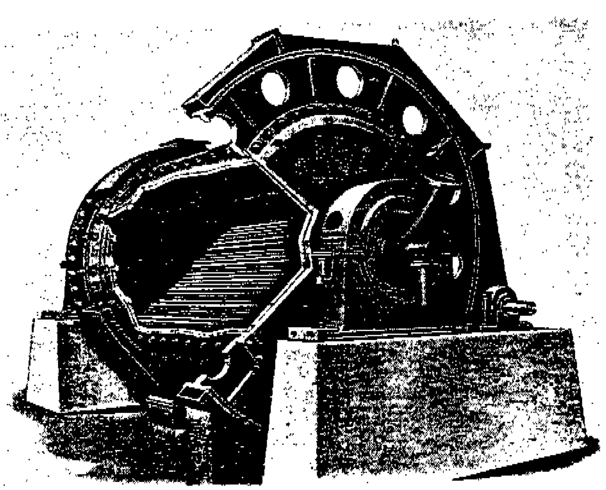
Spout feeders allow an arrangement whereby the classifier underflow flows by gravity into the spout feeder hopper. The cyclone classifiers must be installed high enough to obtain the head required for this flow. Rod mills are normally fed by spout feeders. To obtain the proper flow of feed into the mill, a minimum head of 5 ft is required above the mill center line to the bottom of the feed hopper to which the feeder is attached.

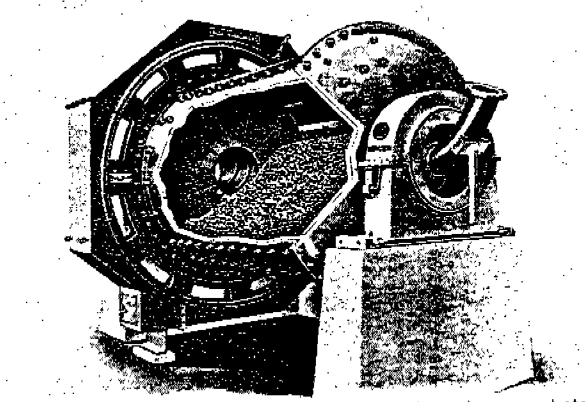
AUTOGENOUS GRINDING

The past 10 to 15 years have seen a strong emphasis placed on autogenous and semiautogenous grinding. There are currently 746,000 kw or 1 million connected hp on the approximately 340 operating units. As of 1979, the largest operating autogenous mills were 36 x 15 ft, 12,000-hp "Rockcyl" mills at the Hibbing Taconite Co. in Minnesota. The growth in autogenous milling came during a period of low energy costs. Although autogenous and semiautogenous grinding have taken their places in mineral comminution, it is now known that they are not the panacea for grinding.

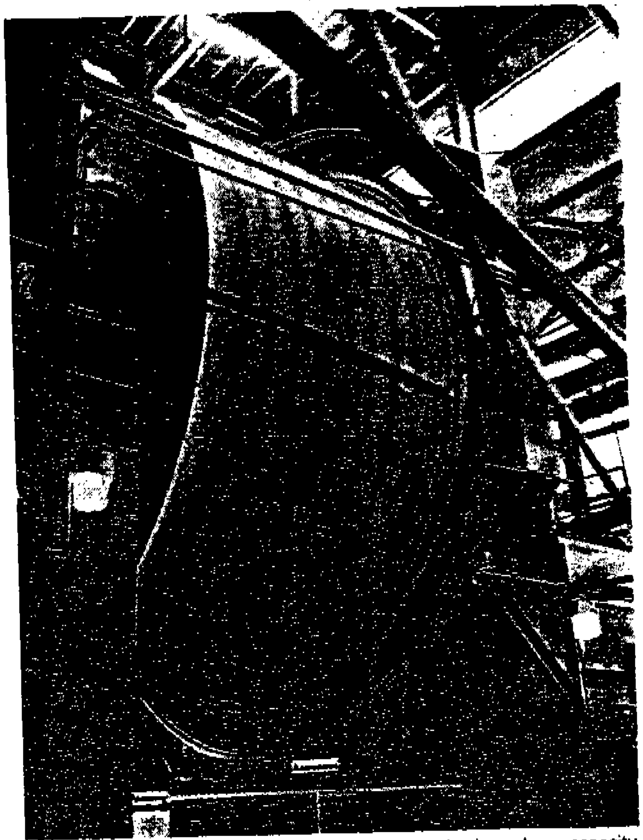
Autogenous mill sizes have not grown beyond those of late 1973 primarily because of problems with drive components, including gears, pinions, and reducers; and because of world-wide economic conditions, which have slowed the pace of mineral development.

For primary autogenous grinding to be a viable grinding process in the future, a number of points will have to be weighed:





Rod mill having a grate discharge and spout feed is shown in upper photo while the lower one shows a spout-fed ball mill with overflow discharge.



Semi-autogenous grinding is not limited to plants having a large capacity. View above shows a single-stage unit at Anaconda's Bluewater U_3O_8 mill.

- Unit power costs for autogenous milling can be higher than conventional crushing and grinding by 25% (for a well-operated semiautogenous installation) to 100% (for a fully autogenous plant with an ore of "marginal" competency). This is a critical factor in selecting the proper circuit.
- Metal wear will be only 55% to 60% of the theoretical savings because of higher liner and chute wear compared with a conventional circuit. If balls are used as supplemental media, the savings will be even less.
- Availability will be 90% at best for autogenous grinding, ranging down to 80% for semiautogenous grinding.
- An approximate six-month to two-year "learning curve" will be required with the commercial circuit before the operating principles and characteristics are well-understood by the operators on a new ore. The implication is that full production may not always be achieved at start-up.

The main advantage of fully autogenous grinding—no steel media consumption—is the main reason behind considering these circuits. In addition to low operating costs, the risks in operation of autogenous mills are relatively low; conventional, proven circuit equipment is used; pilot plant testing is minimal; and, if the sizes of the mills are cleverly selected, they can be converted to rod mills and ball mills if the character of the ore changes unexpectedly.

Secondary autogenous grinding (pebble milling) and intermediate autogenous milling (lump milling) feature unit power costs very comparable to conventional milling. Secondary milling can generally be carried out for very close to conventional ball milling unit power costs if one considers the power used to grind the pebbles too. Intermediate milling of ¾-in. material will usually take no more than 10% additional power over the conventional mill. Either type of mill—secondary or intermediate—is highly controllable and is not subject to the wide swings in capacity that characterize a primary mill.

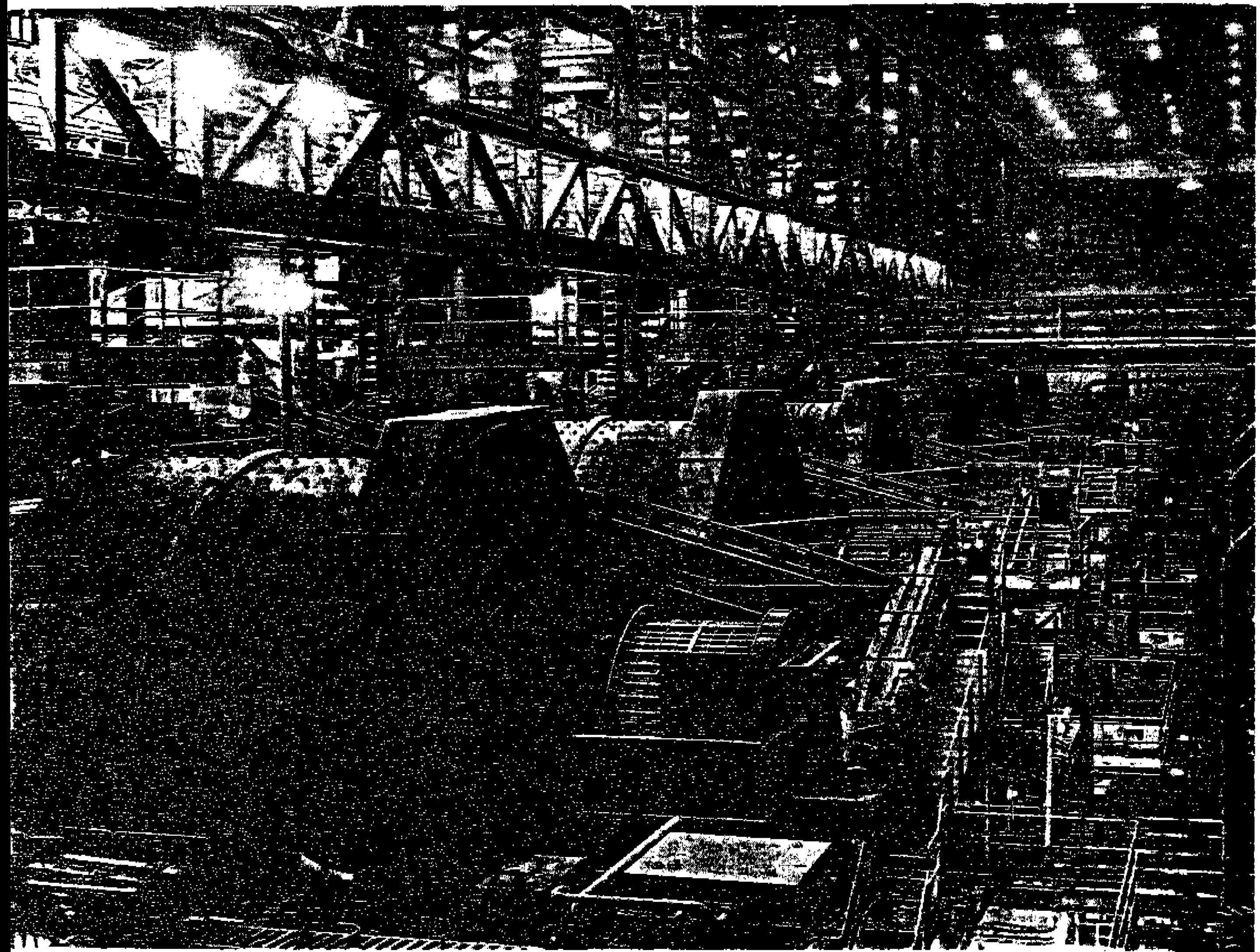
MILL DRIVE TRENDS

The trend toward larger grinding mill drives for the mineral processing industry has presented some interesting challenges. Horsepower requirements have increased because larger mills are being used. Larger units improve productivity for a given initial capital cost. The application of the drive has been a significant problem caused by this increase in size and horsepower. The problems result from power system limitations.

The simplest drive is the low-speed synchronous motor with speeds in the range of 150-250 rpm. It is connected to the mill pinionshaft by either an air clutch or flexible coupling. Using a speed reducer between the motor and pinionshaft permits the use of motors having speeds ranging from 600 to 1,000 rpm. In this range, if power factor correction is not required, induction motors can be used; squirrel cage motors can be employed when there is no restriction on in-rush current; and slip ring motors can be used when a slow start and low in-rush current is required. Air clutches can also be used to ease starting problems with squirrel cage motors. In some areas of the world, induction motors and starters are less expensive than synchronous motors, at a sacrifice of motor efficiency and power factor correction.

Dual drives (i.e. two pinions driving one gear mounted on the mill) become economical for ball mills drawing more than 3,500-4,000 hp.

Performance of drives, including reducers from various



Large autogenous mills shown in this photo are grinding iron ore.

suppliers on mills ranging from 3,500 to 12,000 hp, has not been satisfactory from a reliability standpoint. Too much of the costs and efforts to resolve serious drive problems have fallen upon mill vendors and users. Further development of "gearless drives," (i.e. low-frequency, low-speed synchronous motors with the rotor mounted on the mill shell or as an extension of one of the mill trunnions) could improve the economics of this type of drive, making it practical for large balls. Today's economics, however, still tend to favor the ring gear-pinnion approach for the mill sizes considered. The multi-pinion ring gear bridges the gap from 5,000 hp to about 12,000 hp.

If larger autogenous mills are to be gear driven, then gear suppliers must perform more fundamental studies on stress analysis, contact stresses, lubrication, materials of construction, alignment requirements, and cutting and machining accuracies.

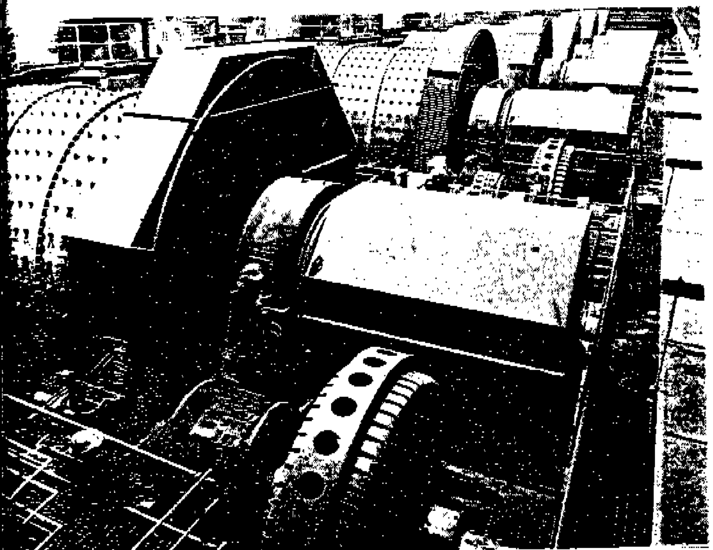
As the need for larger autogenous feeder openings has increased, the mill designer has tended to develop new trunnion bearing sizes with larger diameters and shorter lengths, and to "push" the feeder design entering the trunnion nearly horizontal. A few years ago, this probably would not have been considered.

The early trunnion liners were usually cast of alloy iron. The approach today is to minimize field maintenance difficulty by using a press-fit, fabricated trunnion liner. The press-fit is required to eliminate circumferential creep. The trunnion liner is protected with replaceable, sectionalized wear liners. This eliminates the extended downtime of trunnion liner removal and re-pressing, and requires only replacement of the wear liner segments.

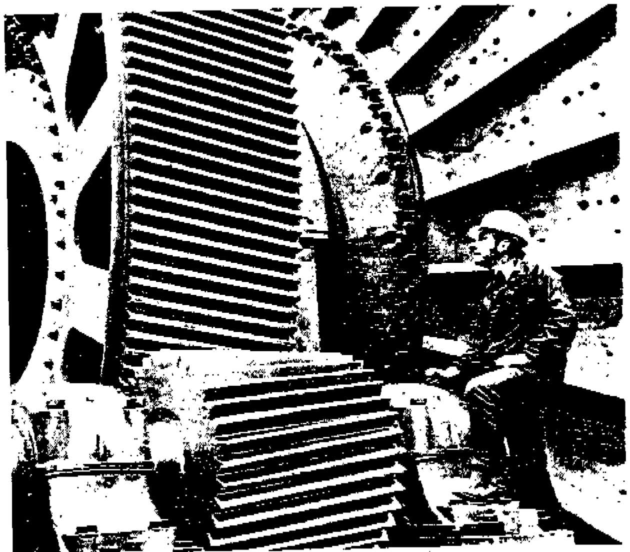
GRINDING CONTROLS

The transition in the minerals processing industry from virtually no automatic process control to the accelerated development that is now occurring depends on the advanced developments in-process-oriented instruments and controls. Additionally, the ability of the systems engineer to apply the equipment in an efficient and usable manner to the dictates of the process engineer has progressed as new instruments are developed for specific applications.

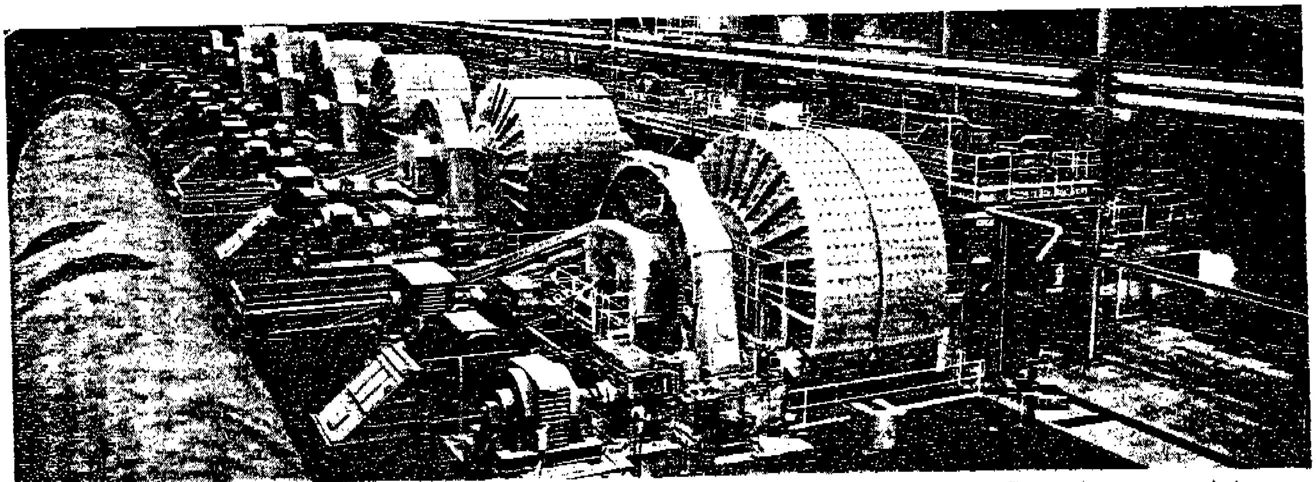
Recent developments in instrumentation devices and techniques have made more rapid measurements possible on many grinding process parameters. Developments have included the use of X-ray fluorescent equipment and analog and digital control instrumentation for grinding mill control. While costly, other control and analysis systems can be developed on a semi-standard or custom basis. In recent years, semi-in-line automatic titration and automatic spectrometer analysis systems have been installed. Additional advanced instrumentation has become available to measure



The large ball mills pictured above are installed at a copper concentrator.



Gearing for a fully autogenous grinding mill is shown in the above photo.



General arrangement of autogenous mills at an iron ore concentrator.

some of the more conventional parameters.

Mineral processing plants have committed themselves to extensive automatic control. More than ever, these systems rely for their information on primary sensors. These sensors and transmitters must produce information accurately and reliably, and no longer are permitted the wider tolerances that were previously acceptable.

Attempts at applying particle size distribution in grinding circuits are being met with reasonable success. On-line particle size measurement in control circuits improves the overall system control and increases the profitability of the operation. Improved throughputs ranging from 4% to 10% with increases in recoveries up to 5% have been experienced.

Investigative efforts are being made to learn the effects of particle size and distribution on the efficiency of an operation's concentration process. Mass-flow measurement can be obtained by means of a magnetic flow meter in combination with a nuclear density gauge. One problem that often exists is finding a suitable location for these primary sensing units, which may be complicated by the physical layout of the plant piping. Therefore, it is necessary to work closely with the plant designers to assure accessibility.

One particle size measurement technique that is gaining acceptance utilizes ultrasonic waves to develop the primary signal. Two pairs of high-frequency transmitters develop ultrasonic energy signals, which travel through the slurry (wet process) between the transmitters to the associated receivers. The receivers convert the ultrasonic energy back to high-frequency signals. The amount of ultrasonic energy that is allowed to pass through the slurry is measured and compared to a standard to obtain separate particle size and percent solids signals. The integration of these two signals along with previously mentioned necessary process measurements into the grinding system mathematical model leads to the optimization of the grinding circuit feed rate.■

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