

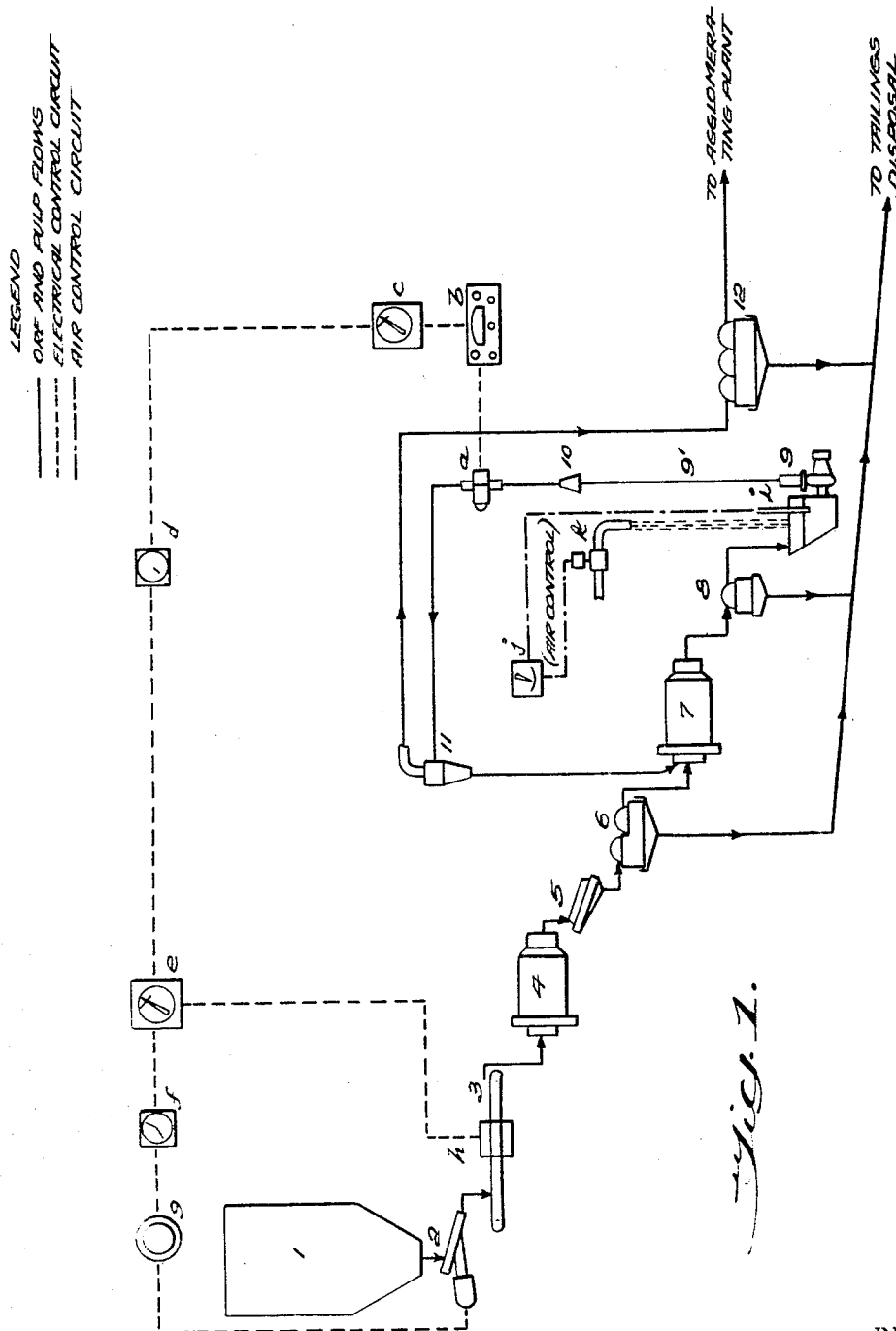
Aug. 20, 1968

H. P. WHALEY ET AL
PRODUCT SIZING CONTROL IN A GRINDING CIRCUIT
CLOSED BY A SEPARATING MEANS

3,397,844

Filed Sept. 19, 1962

2 Sheets-Sheet 1



INVENTORS

Henry P. Whaley and
Mark L. Howland,

BY Pierce, Schaffler & Parker
their ATTORNEYS

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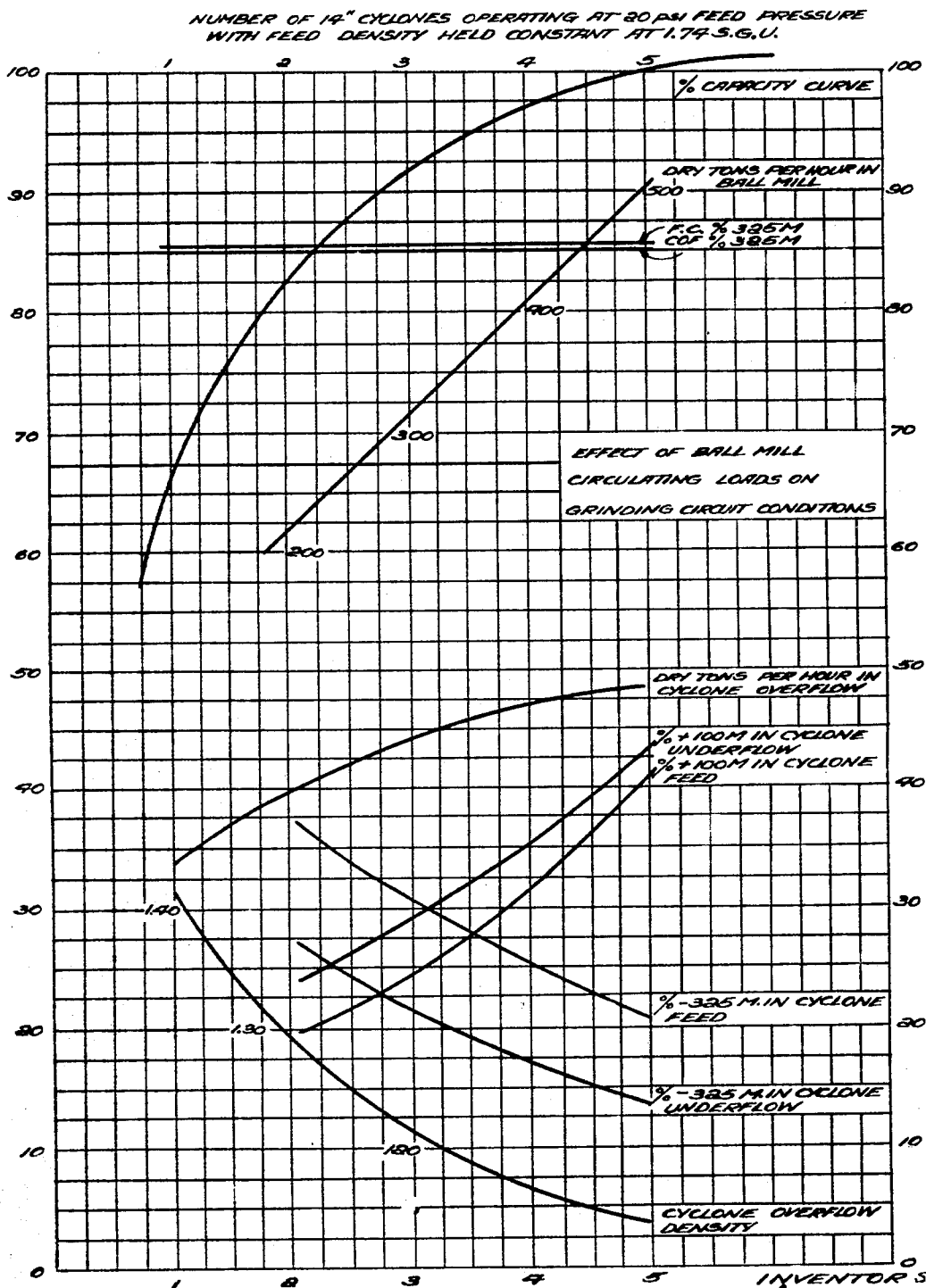


Fig. 2.

INVENTOR'S
Harry D. Whaley and
Mark L. Howland,
BY
Price Schaffer & Parker
ATTORNEYS

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3,397,844 PRODUCT SIZING CONTROL IN A GRINDING CIRCUIT CLOSED BY A SEPARATING MEANS

Henry P. Whaley, Aurora, and Mark L. Hovland, Hoyt Lakes, Minn., assignors, by mesne assignments, to Erie Development Company, Cleveland, Ohio, a corporation of Delaware

Filed Sept. 19, 1962, Ser. No. 224,776
7 Claims. (Cl. 241—21)

This invention relates to the art of subdividing solid subdividable materials, more particularly, ores, and is concerned with improved control for mill lines performing subdividing operations these latter including crushing (in one or more stages) followed by grinding (in one or more stages). The invention is particularly applicable to so-called "automatic grinding" procedures. While not restricted thereto the invention will, in the following, be described with special reference to processing of relatively low grade iron ore of the "magnetic taconite" type, found in relatively large deposits on the Eastern end of the Mesabi Range, in Northern Minnesota, and elsewhere around the world, which illustrative processing includes mining crude taconite, crushing in a plurality of stages, grinding in a plurality of stages along with a plurality of stages of magnetic concentration, and, finally, agglomerating into pellets and heat-hardening the pellets so formed.

Illustratively, the processing in the mill line begins as the crushed ore (at, e.g., minus 1" in size) is drawn from a 2,000 ton fine ore bin by vibrating feeders and subsequently conveyed to a 10' x 14' rod mill. The rod mill, driven by an 800 H.P. synchronous motor, grinds the ore, in an aqueous medium, to a mean size of 28 mesh, and discharges it onto a vibrating screen which scalps out the plus ¼" material. The screen undersize is split to two 36" x 48" double drum electro-magnetic separators which reject a siliceous, essentially non-magnetic tailing and produce a rougher concentrate. This concentrate, in turn, is directed, in aqueous slurry form, to a 10' x 14' ball mill driven by a 1250 H.P. synchronous motor. The discharge of the ball mill is treated by four 36" x 60" single drum permanent magnet separators which reject a second tailing and produce a cleaner concentrate. This concentrate is collected, as an aqueous slurry, in a sump and pumped by a 10" x 8" rubber lined pump to a bank of five 14" wet classifying cyclones of "Erie" design, e.g., cyclones described in Herkenhoff Patent No. 2,756,878, issued July 31, 1956. The underflow from the cyclones is united with the rougher concentrate as feed to the ball mill while the cyclone overflow is split to four 30" x 60" triple drum permanent magnet separators that reject the third and final tailing and produce the final concentrate. This final concentrate is then sent on, in the form of a pumpable slurry, to the agglomerating plant to be made into high grade iron ore pellets.

The purpose of the milling process just described is to liberate and recover the magnetite contained in the crude magnetic taconite as a high grade concentrate, having a constant percentage of minus 325 mesh material, at a maximum tonnage rate. We usually grind the ore to recover a concentrate assaying 89 to 90% minus 325 mesh.

It is extremely important that the sizing analysis of the concentrate be held constant because of its effect on the subsequent filtering balling and pelletizing phases of the agglomeration process carried out in the agglomerating plant.

Since the final stage of grinding takes place in the ball mill, the operating conditions of the cyclones close-circuiting the ball mill must be controlled to obtain the desired product sizing from a grinding line. It heretofore

had been proposed to use the conventional method of controlling cyclone overflow density through manual adjustment of dilution water to the cyclone feed sump and manual adjustment of the tonnage set point on the automatic feed controller. The cyclone feed pressure was allowed to vary within limits in order to maintain the feed sump at a constant level. This was accomplished automatically through the use of an air-bubbler type, level, sensing tube inserted in the sump. The back pressure created in the tube at different levels was relayed through pneumatic control to position the speed control arm of a fluid drive which varied the speed of the cyclone pump.

When we began investigating the possibilities of automatic grinding, our earlier investigations were concerned primarily with testing different types of devices for measuring the cyclone overflow density, one of which was a radioactive gamma gauge. It was found that control of the cyclone overflow density alone could not give the consistency of product sizing results desired.

We have discovered that both cyclone feed density and the ball mill circulating load are affected by a change in any one (or more) of the following variables:

- (1) percent magnetic iron contained in the ore;
- (2) hardness, or "grindability" of the ore;
- (3) primary liberation size of the ore;
- (4) specific gravities of minerals making up the ore; and
- (5) screen analysis of the rod mill feed.

In most grinding systems, the primary purpose is to grind the ore to a point where it contains a specific weight percentage of a certain size fraction. This point may be determined by economics, liberation size characteristics of the ore, size requirements to perform further processing or any combination of the three. In the past, the common practice of obtaining a specific product sizing from a grinding circuit close-circuiting by cyclones was to measure the density of the cyclone overflow, correlate this with sizing analysis of product samples, and then subsequently adjust the density, if necessary, to hold the product sizing level desired. The basic theory behind our control system differs from any other control method in that our process is predicated on the fact that the measurement and control of the cyclone feed density is by far the most important factor in maintaining constant product sizing from any grinding system close-circuiting by cyclones.

We have discovered that so long as the cyclone feed density is held constant, the circulating load in the ball mill may be changed within relatively wide limits without any noticeable effect on the final product sizing.

It is an important object of the present invention to provide an automatic or essentially automatic grinding line control system for maintaining substantially full load on the grinding equipment whilst simultaneously maintaining constant or substantially constant the pulp density of the cyclone feed.

The invention will now be described in greater particularity, with reference to the accompanying drawing, wherein

FIG. 1 is a flow diagram of a grinding line showing application thereto of the automatic grinding control system of the present invention; and

FIG. 2 is a chart of curves showing the effect of changes in the circulating load in the ball mill circuit on the sizing analysis of the cyclone feed and underflow and the tonnage rate and density of the cyclone overflow.

In FIG. 1 of the drawing, the pieces of equipment to which reference numerals are applied are as follows:

- 1—2,000 ton fine ore bin
- 2—12 18" x 84" electro-vibrating feeders
- 3—24" rod mill feed conveyor

- 4—10' x 14' rod mill (800 H.P.)
 5—4' x 8' vibrating screen
 6—2 36" x 48" double drum electro-magnetic separators
 7—10' x 14' ball mill (1250 H.P.)
 8—4 36" x 60" permanent magnetic separators
 9—10' x 8" cyclone feed pump
 9'—8" cyclone feed pipe
 10—Demagnetized coil
 11—5 14" Erie cyclones
 12—4 30" x 60" permanent magnetic separators

And the illustrated automatic control system comprises the following components:

- a—Gamma ray density gauge
 b—Density-gauge amplifier
 c—Density recorder-controller
 d—Timer for density circuit
 e—Tonnage recorder-controller
 f—Timer for tonnage control circuit
 g—Motor driven rheostat (feeder amp. control)
 h—Belt scale (tonnage sensing load cell)
 i—Level sensing bubbler tube
 j—Level indicator-controller
 k—Automatic air-controlled water valve

The essential components of the automatic control circuit are diagrammatically shown in the accompanying drawing. The heart of the control system is a gamma ray density gauge *a*, consisting essentially of a 150 millicurie source and receiver, mounted on the 8" cyclone feed pipe 9'. The source emits gamma rays through the iron, or rubber pipe and slurry to the receiver, mounted on the opposite side of the cyclone feed pipe, where the emission is converted into an electrical signal. The amount of signal created is inversely proportional to the density of slurry within the pipe. This signal is directed through a coaxial cable to an amplifier *b* where it is stepped up and sent on to a density recorder-controller *c*. Here it is converted into terms of specific gravity units and recorded by a pen on a 24-hour circular chart graduated from 1.50 to 1.90 SGU (specific gravity units).

The control portion of the unit consists of four mercury switches that are fixed relative to a density set point indicator to give five density control zones; -0.02 and lower (-3% zone), -0.02 to -0.01 (-1½% zone), -0.01 to +0.01 (neutral zone), +0.01 to +0.02 (=1½% zone), and +0.02 and higher (+3% zone). From this controller, an electrical signal is sent through a timer to a set point positioner-relay cabinet, that allows a motor driven set point indicator in the automatic tonnage recorder-controller to be positioned up or down 1½ or 3% depending upon which percentage control zone the density pen is recording in. The timer in this circuit is set so as to allow a pre-determined amount of time to elapse after each tonnage change before another change can be made. This time lapse represents the process time lag inherent in balancing out the ball mill circuit and is tentatively set at 40 minutes.

The tonnage fed to the grinding line is controlled by the automatic tonnage control system at the set point value as positioned by signals from the density control system. This tonnage system consists of a belt scale mounted on the rod mill feed conveyor, a tonnage-recorder-controller, a tonnage system timer, and a motor driven-rheostat that controls the amperage and subsequently the output of the vibrating feeders.

Also incorporated with this automatic grind control system is a novel method of controlling the sump level. The speed of the cyclone feed pump is now held constant while the bubbler tube is switched over to operate an air-actuated water valve. The controlled discharge rate of cyclone sump make-up water from this valve now maintains the sump at a constant level.

We have found that when operating by automatic control, the screen analysis of the total mill concentrates can be held within very close limits. Table I, following,

TABLE I.—CONCENTRATOR PRODUCTION
 One hour mill concentrate grind results (percent—325 mesh)

	Time	Date			
		2/27	2/28	3/1	3/2
5	N-1.....	89.25	89.38	89.45	89.05
	N-2.....	88.06	89.36	89.82	88.85
	N-3.....	88.25	88.22	89.67	89.64
	N-4.....	89.27	89.72	89.82	88.94
	N-5.....	88.85	89.27	89.96	88.19
	N-6.....	88.28	89.69	89.75	88.99
	N-7.....	89.01	89.33	89.68	88.94
	N-8.....	88.29	90.50	89.42	88.98
10	D-1.....	88.90	89.59	89.37	88.65
	D-2.....	89.80	89.73	90.04	88.24
	D-3.....	89.35	90.49	89.50	88.76
	D-4.....	89.19	89.36	89.32	87.99
	D-5.....	88.81	89.01	88.96	87.96
	D-6.....	89.64	90.33	88.43	88.27
	D-7.....	88.27	88.79	88.99	89.39
	D-8.....	88.01	88.56	89.36	89.15
15	A-1.....	88.38	89.72	89.35	89.62
	A-2.....	88.34	89.32	88.78	88.95
	A-3.....	88.28	89.43	89.03	89.59
	A-4.....	88.23	88.84	88.71	89.33
	A-5.....	88.75	89.19	89.13	89.43
	A-6.....	89.32	89.12	89.01	89.18
	A-7.....	90.02	89.87	88.67	90.40
	A-8.....	89.17	89.86	89.27	90.50

shows typical sizings obtained from mill concentrate samples taken at one-hour intervals over a four day period. It will be noted that during this period, out of 96 one-hour samples, the coarsest assayed 87.96%, while the finest assayed 90.50%, —325 mesh. After a month of operation, it was concluded that the automatic grinding system can indefinitely hold the individual one-hour sizing analysis to within plus or minus 1½% of the desired value. Based on this, mill concentrate sampling need not be done oftener than at four hour (or, even, eight hour) intervals.

The density set point values may require some adjustment from time to time. On the average, these adjustments amount to a correction of about 0.005 density units once every four to five days.

The automatic grinding system has resulted in the realization of the following benefits:

(1) The closer control of mill concentrate sizing analysis makes it possible to maintain a very exact control of the subsequent filtering operation, resulting in close control of green ball moisture and, subsequently, a higher quality pellet.

(2) The automatic system reduces the operating manpower required in the grinding and concentrating process, with an accompanying reduction in operating costs.

(3) The increased reliability of predicting product sizing analysis allows for a reduction in sampling, sample preparation, and analytical determination of mill concentrates.

(4) The constant product sizing enables the mining operators to correlate their grading more accurately with mill results, and thereby narrow the fluctuations in chemical analysis of the concentrate.

(5) Automatic operation maintains maximum tonnage throughput at all times.

In regard to the specific features of the above described control circuit, the following statements may be made:

(1) The automatic system is based on the measured control of cyclone feed density, and is capable of sensing and correcting for any change in ore characteristics that may occur.

(2) The gamma ray density gauge provides an accurate on-line measurement of the critical cyclone feed density without coming in contact with the slurry and is thereby able to operate trouble-free insofar as plugging and wearing out are concerned.

(3) The maintenance of the electrical control system is extremely low.

(4) The tonnage set point changer provides optimum flexibility in changing the feed rate to compensate for ore characteristics changes.

FIG. 2 is composed of data curves which emphasize the importance that constant measurement and control of cyclone feed density plays in producing products of constant sizing analysis from a closed circuit grinding system. The curves are made up from daily results of samples taken and data collected over a five-day sampling period. During this period the circulating load (i.e., ball mill tonnage) was changed purposely each day in definite steps by varying the number of cyclones operating at 20 p.s.i. pressure. In this experiment, the cyclones feed density was held constant at .74 SGU during the entire period over which the ball unit tonnage was caused to change. In other words, the first day test was conducted with 5 cyclones thereby furnishing a ball mill tonnage of about 510 t.p.h.; the second day, 4 cyclones with a ball mill tonnage of about 415 t.p.h.; and so on, down to one cyclone operation. It is significant that with these variations in ball mill tonnage, the cyclone overflow product remained constant in size analysis at 85% minus 325 mesh and that the final concentrate analysis remained constant at 86% minus 325 mesh, due to the fact that the cyclone feed density was held constant.

The top, or "capacity" curve reveals how the new feed tonnage had to be reduced with each step in order to hold the feed density of the cyclone at a constant value. The remainder of the curves located at the bottom half of the chart show what happens to the sizing analysis of the cyclone feed and underflow and the tonnage rate and density of the cyclone overflow as the circulating load changes in the ball mill circuit. The important fact here is that these analyses, tonnage rates, and densities, vary considerably as the circulating load changes but that by holding a constant cyclone feed density the sizing analysis of the finished product from the circuit continues to be constant.

This chart, then, further reveals that, in reality, control of circulating load or control of cyclone overflow density are not the particular rates or measures to be regulated in order to obtain optimum control of a grinding circuit and resultant optimum product sizing analysis, but rather that control or cyclone feed density is the true pulse of the circuit.

We claim:

1. In subdividing and concentrating an ore in a grinding circuit including a ball mill, which grinding circuit is close-circuited by a cyclone separator, the improved method of ensuring constant product sizing from the circuit which consists in substantially constantly measuring the density of the feed to the cyclone separator and controlling the circuit at a predetermined density value by varying the new tonnage rate to the grinding circuit in specified increments at specified time intervals the variation being inversely proportional to variation in the density of the feed to the cyclone separator.

2. The improved method defined in claim 1, characterized in that measurement of the density of the feed to the cyclone separator is effected by constantly directing a substantially constant volume of emitted gamma radiation in a direction generally transverse to a flowing stream of aqueous slurry being fed to said separator, substantially constantly converting into an electrical signal the amount of emission which passes through the stream, and substantially constantly determining density of feed in terms of the intensity of said electrical signal.

3. The improved method defined in claim 1, further characterized in that any ascertained change in the den-

sity of the feed to the cyclone separator is compensated by an inverse change in the tonnage rate of the ore feed to the ball mill.

4. In a closed-circuit ore pulp grinding and concentrating apparatus including, in series communication with each other, a ball mill, a magnetic separator, a sump, a cyclone separator, feed pump means including a cyclone feed line for lifting pulp from said sump to the inlet of said cyclone separator, an underflow feed conduit from said cyclone separator to said ball mill, and variable means for delivering raw ore feed to said ball mill, the improvement which consists in the provision of a gamma ray density measuring device, providing a signal inversely proportional in intensity to the density, in association with said cyclone feed line, and of means responsive to said signal, for correspondingly varying the rate of delivery of raw ore feed by said delivery means.

5. In subdividing and concentrating a solid material in a grinding circuit, which grinding circuit is close-circuited by a separating device, the improved method of ensuring constant product sizing from the circuit which consists in substantially constantly measuring the density of the feed to the separating device and controlling the circuit at a predetermined density value by varying the new tonnage rate to the grinding circuit in specified increments at specified time intervals the variation being inversely proportional to variation in the density of the feed to the separating device.

6. The improved method defined in claim 5, characterized in that measurement of the density of the feed to the separating device is effected by constantly directing a substantially constant volume of emitted gamma radiation in a direction generally transverse to a flowing stream of aqueous slurry being fed to said separator, substantially constantly converting into an electrical signal the amount of emission which passes through the stream, and substantially constantly determining density of feed in terms of the intensity of said electrical signal.

7. In a closed-circuit grinding and concentrating apparatus having a raw feed delivery means, the improvement which consists of a gamma ray density measuring device providing a signal inversely proportional in intensity to the density of a slurry produced by grinding; and means responsive to said signal for correspondingly varying the rate of delivery of raw feed by said delivery means.

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65 GERALD A. DOST, *Primary Examiner*.