

[54] GRINDING MILL METHOD AND APPARATUS

[72] Inventors: Michael P. Grant, Columbus; Edward J. Freeh, Worthington, both of Ohio

[73] Assignee: Industrial Nucleonics Corporation

[22] Filed: Feb. 4, 1970

[21] Appl. No.: 8,661

[52] U.S. Cl.....241/24, 241/34

[51] Int. Cl.....B02c 25/00

[58] Field of Search.....241/15, 20, 24, 33, 34

[56] References Cited

UNITED STATES PATENTS		
3,352,499	11/1967	Campbell, Jr.....241/34 X
3,145,935	8/1964	Wilson.....241/24
3,248,061	4/1966	Franz.....241/34 X

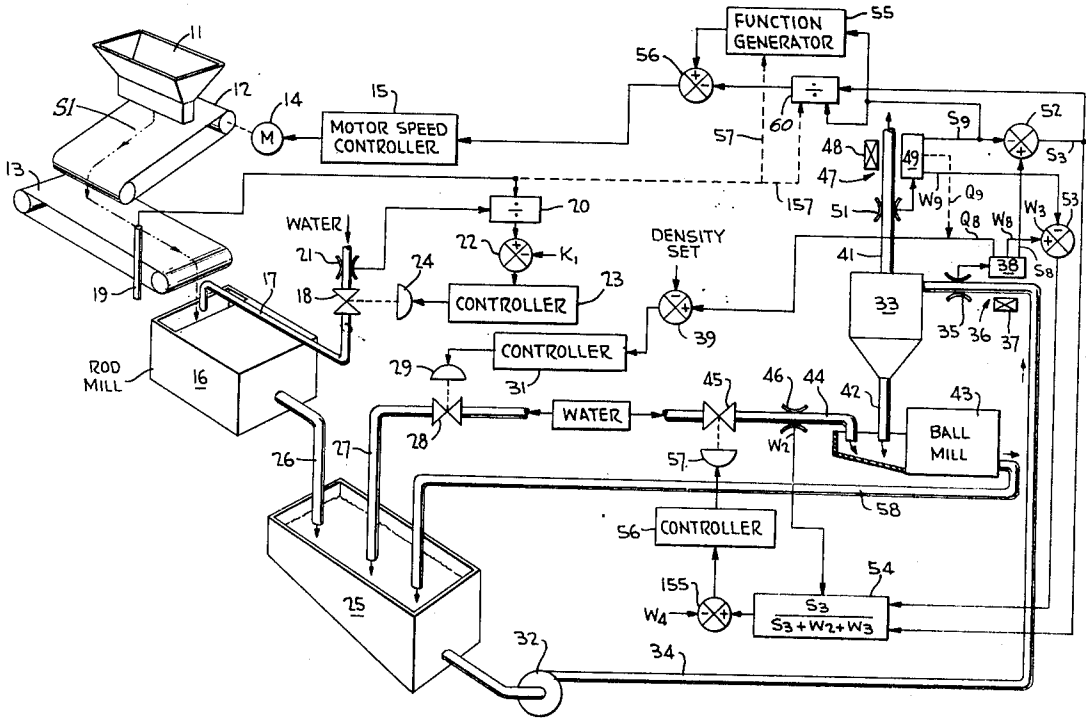
3,417,927	12/1968	Crocker et al.....241/33 X
3,596,839	8/1971	Patman.....241/30 X

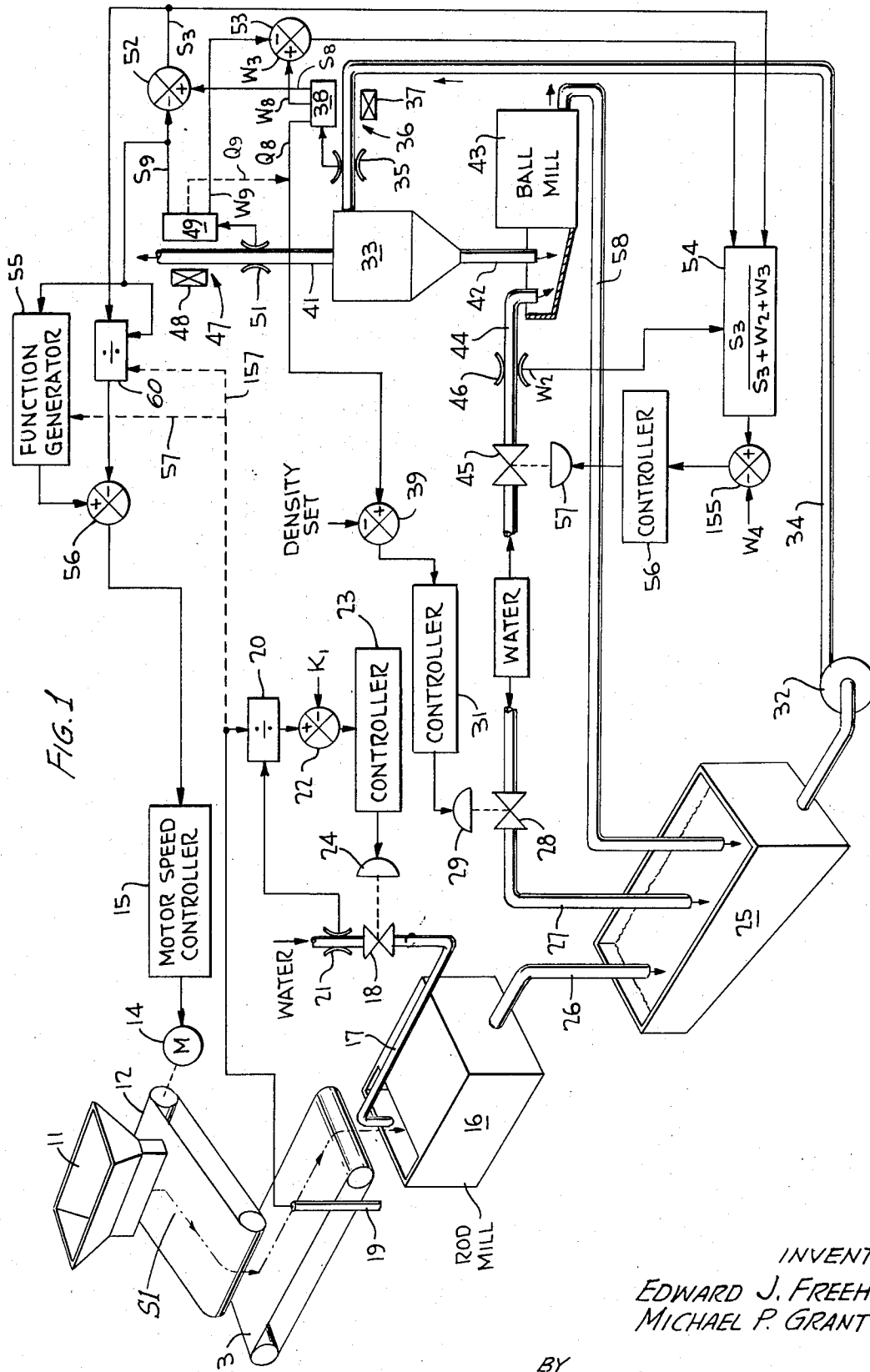
Primary Examiner—Granville Y. Custer, Jr.
Attorney—Lowe and King, William T. Fryer, III and C. Henry Peterson

[57] ABSTRACT

Rate of input ore fed to a grinding mill, including a hydrocyclone particle classifier in a recirculating loop, is controlled to maintain a predetermined relation between particle size and production rate. From the actual production rate and the predetermined relationship a value for the ratio of recycled solid feed rate to output or input solids feed rate is determined. The determined ratio value is compared with the actual ratio value derived from measurements to control input ore feed rate. The consistency of slurries fed to each of a rod mill, ball mill and the classifier is maintained constant.

14 Claims, 2 Drawing Figures





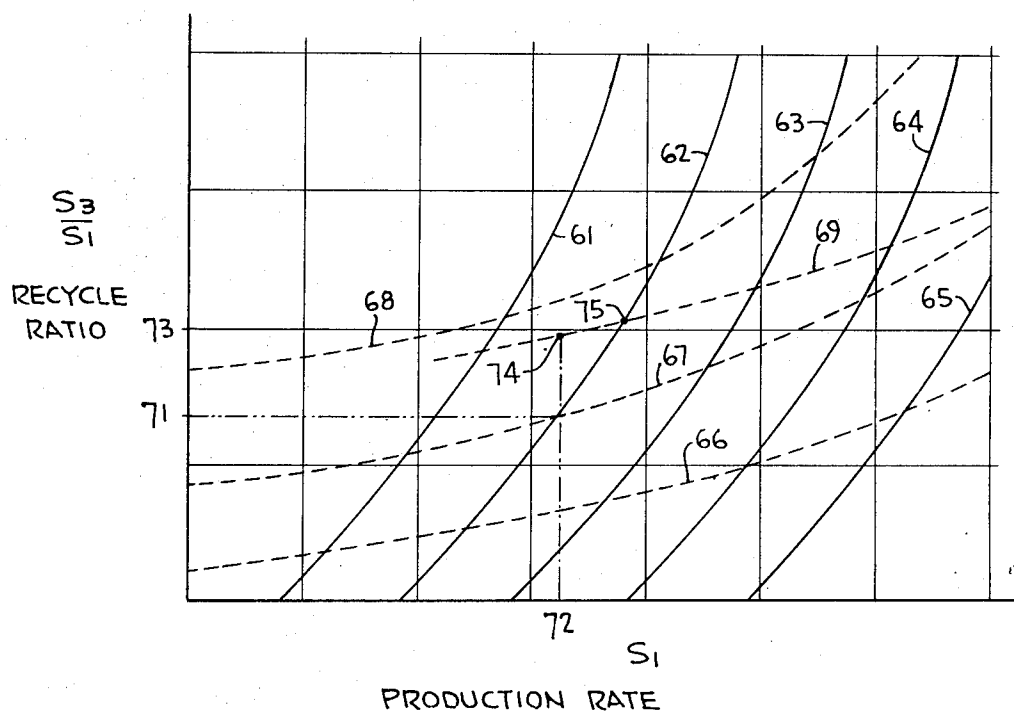
INVENTORS,

EDWARD J. FREEH
MICHAEL P. GRANT

BY

Long & King
ATTORNEYS

FIG. 2



INVENTORS,
EDWARD J. FREEH
MICHAEL P. GRANT

BY *Lowe & King*
ATTORNEYS

GRINDING MILL METHOD AND APPARATUS

The present invention relates generally to grinding mill methods and apparatus and, more particularly, to a method and apparatus for controlling a grinding mill including a recycling loop wherein particle size of the mill output is effectively controlled in response to indications of the amount of material fed to the grinding mill relative to the amount of recycled material.

Modern grinding mills generally include a ball mill connected in a recirculating loop with a hydrocyclone classifier. The classifier removes particles having a desired size by an overflow process and returns those particles having excessively large volumes to the ball mill. The particles removed from the separator or classifier are small enough to be processed for ease of extraction of a desired metal. The ease of metal extraction is a direct function of the particle size of effluent obtained from the cyclone classifier. Hence, it might appear that it is most desirable to grind the particles to the maximum extent in the ball mill. Ball mill operation, however, is quite expensive because of the large amount of power consumed thereby. Hence, it has been found that a compromise should be struck between particle size of effluent from a separator and power required for ball mill operation to enable the mill to function in an optimum manner.

According to the present invention, the feed rate of input ore to a grinding mill is controlled effectively in response to indications of particle size of effluent from a cyclone separator in a recirculating grinding mill. The feed rate is varied as a function of effective particle size to enable most efficient operation of the mill to be attained. While others have proposed to control a grinding mill in response to effluent particle size, we are unfamiliar with any apparatus capable of accurately measuring particle size on an on-line basis. In the present invention, particle size is effectively correlated with the ratio of the feed rates of input ore fed to the grinding mill to ore recycled from the cyclone classifier back to the grinding mill. We have found that a relationship exists between the recycle ratio and functions of ore grindability or hardness, cyclone separator effluent particle size and input ore feed rate to enable the mill to be optimally operated.

Because of problems in measuring the density of recycled ore fed from the cyclone classifier to the grinding mill, it has been found advantageous inferentially to measure the recycled ore feed rate by subtracting the ore feed rate of effluent overflowing the cyclone separator from the ore feed rate to the cyclone separator. It has also been found preferable, in determining the ratio of recycled to input ore feed rates, to approximate the rate of ore being fed to the grinding mill as the rate of effluent ore overflowing the cyclone separator. This approximation is valid in the steady state wherein the amount of input ore equals the amount of effluent overflowing the cyclone separator and is close enough for transient conditions to warrant its use. By approximating the cyclone separator overflow effluent as the input ore fed to the grinding mill, possible problems of inaccuracies resulting from transients in the input ore feed rate are avoided.

Ore being fed to the grinding mill is subject to perturbations of: hardness, distribution in the ore of desired element to be recovered, and the percentage of the desired element in the ore. These perturbations result

in different control requirements, which together with the economic factors required to power a ball grinding mill, are optimally attained with the control criterion of the present invention.

In accordance with a feature of the invention, the flow of water to achieve slurry densities or consistencies based on ore characteristics is determined in response to *a priori* determined set points for the percentages of solids fed from a rod mill to a sump also responsive to the ball mill. In addition, the percentage of solids in the slurry fed from the ball mill to the sump and the percentage of solids fed from the sump to the cyclone classifier are determined on a *a priori* basis. It has been found that certain values of these consistencies enable the most economic relationship between cyclone classifier overflow effluent, input ore feed rate and power required to run the ball mill to be achieved.

It is, accordingly, an object of the present invention to provide a new and improved system for and method of operating a grinding mill.

Another object of the present invention is to provide a new and improved system for and method of operating a grinding mill in response to the size of output particles emerging from the mill.

An additional object of the present invention is to provide a system for and method of controlling the rate of ore fed to a grinding mill in response to the ratio of ore fed to the mill and ore recycled from a cyclone separator back to the mill.

A further object of the invention is to provide a system for and method of operating a grinding mill wherein feed rate of ore supplied to the mill and water flow rates are regulated to enable optimum mill operation to be attained.

An additional object of the invention is to provide a new and improved system for monitoring parameters of a grinding mill.

Still a further object of the invention is to provide a new and improved system for and method of determining if the size of particles derived from a grinding mill is following desired criteria.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a block diagram of a preferred embodiment of the invention; and

FIG. 2 is an illustration of plots indicating the performance of the embodiment illustrated in FIG. 1.

Reference is now made to FIG. 1 of the drawings wherein there is illustrated, in schematic form, a mill for grinding an ore and extracting fines in accordance with a preferred embodiment of the present invention. The metal to be ultimately extracted from the ore is copper in the specific example, but the principles of the invention are applicable to any suitable metal. The ore is loaded in hopper 11 from which it is deposited onto traveling, variable speed conveyor belt 12. Conveyor belt 12 is oriented at right angles to constant speed belt 13 to deposit on the constant speed belt a controlled flow rate of ore. Ore is deposited on belt 13 at a rate determined by the speed of belt 12, driven by variable speed motor 14, in turn responsive to a conventional motor speed controller 15 in a manner described *infra*.

The ore on belt 13 is supplied to rod mill 16, together with controlled amounts of water flowing through conduit 17. The amount of water in conduit 17 is controlled by valve 18 so that a slurry emerging from rod mill 16 has a predetermined water to solid ratio, i.e., the slurry has constant consistency. The consistency of the slurry emerging from rod mill 16 is set to a predetermined value, K_1 , by monitoring the feed rate, i.e., solid mass flow rate, of ore from conveyor 13 into rod mill 16. The flow rate, S_1 , of ore into rod mill 16 is monitored by belt weightometer 19, of a type well known in the art and preferably including a nucleonic gauge. The output signal of belt weightometer 19, indicative of S_1 , is fed to dividing circuit 20, also responsive to the flow rate of water through valve 18, as monitored by flow meter 21. The responses of weightometer 19 and flow meter 21 are divided in division network 20, having an output signal that is compared in subtraction circuit 22 with a set point for the consistency of the water-ore slurry emerging from rod mill 16. An error signal output of subtraction circuit 22 drives valve controller 23 that feeds valve actuator 24 to control the flow rate of water through valve 18 and into conduit 17, whereby the consistency of ore emerging from rod mill 16 is maintained substantially constant despite variations in the feed rate of ore fed to the rod mill.

The slurry emerging from rod mill 16 is fed to sump 25 via conduit 26. Sump 25 is also responsive to a supply of water fed thereto via conduit 27 through valve 28, the position of which is set by actuator 29 in response to an output signal of controller 31. As is seen *infra*, controller 31 varies the rate of water flow into sump 25 so that the ore-water slurry emerging from the sump has constant consistency.

Slurry emerging from sump 25 is fed to pump 32, having an output fed to hydrocyclone separator or classifier 33 via conduit 34. The rate of fluid flow in conduit 34 is monitored by flow meter 35, while the density of the slurry in the conduit is monitored by a density gauge 36 including nucleonic source 37 and nucleonic detector 38. Included within detector 38 is circuitry to compute the solid and liquid feed rates, S_s and W_s , through conduit 34. This circuitry is responsive to the density indication, ρ , detected by gauge 36, as well as the fluid flow indication, Q , derived from meter 35 and predetermined constants indicative of the solid and liquid densities, ρ_s and ρ_L . The circuitry combines these quantities to compute the solid mass flow rate as:

$$S_s = \frac{Q\rho_s(\rho - \rho_L)}{\rho_s - \rho_L}$$

and the liquid mass flow rate as:

$$W_s = \frac{Q\rho_L(\rho - \rho_L)}{(\rho_s - \rho_L)}$$

The solid and liquid mass flow rates can be equated to volume flow rates by dividing the expressions for S_s and W_s by ρ_s and ρ_L , respectively. The terms solid and liquid feed rates utilized herein can therefore be equated to either mass or volume flow rates. The circuitry within detector 38 also includes means to derive an indication of the density, ρ , of material in line 34. It is to be understood that any suitable means can be employed to derive indications of the solid and liquid feed

rates and the invention is not limited to the particular apparatus disclosed.

The density output signal, Q8, of gauge 36 is compared with a set point for the density of the slurry emerging from sump 25 in subtraction network 39. Subtraction network 39 feeds controller 31 to vary the flow rate of water through pipe 27 thereby to maintain the consistency of the slurry in conduit 34 substantially constant.

Hydrocyclone classifier 33 functions in a manner well known to those skilled in the art wherein particles or fines generally having less than a predetermined size are separated from those having a size greater than a set value. The particles generally having a size equal to or less than the set value are fed to effluent or output conduit 41 as overflow from the cyclone classifier. In contrast, particles generally having greater than the predetermined size flow by gravity from conduit or down pipe 42 of separator 33 into ball mill 43 which may be of the grate type; material passing through conduit 42 is often referred to as down flow or under flow. Ball mill 43 is also responsive to a supply of water, as coupled thereto through conduit 44. The flow rate of water in conduit 44 is controlled by the setting of valve 45 and is monitored by flow meter 46.

The position of valve 45 is set so that a predetermined consistency of the slurry emerging from ball mill 43 is attained. To this end, the consistency of the slurry emerging from ball mill 43 is calculated as the ratio of the feed rate of solids fed to the ball mill to the sum of feed rate of the total material, including water and solids, fed to the ball mill. The feed rate of water and solids to ball mill 43 from cyclone separator 33 is not determined directly, however, because of problems in monitoring the under flow through conduit 42 of cyclone separator 33. Instead, the solid and liquid feed rates in down pipe 42 are calculated inferentially from the solids and liquids fed into the cyclone separator via conduit 34 and in output line 41. To monitor the fluid and solid feed rates in effluent line 41, there are provided flow meter 51 and nucleonic density gauge 47, including nucleonic source 48 and nucleonic detector 49. To derive output signals indicative of solid and liquid feed rates through conduit 41, detector 49 includes circuitry responsive to the output of flow meter 51 and functions as described *supra* for detector 38. The solid feed rate responses of detectors 38 and 49 are subtracted in difference network 52, while the liquid feed rate signals derived from detectors 38 and 49 are subtracted in difference network 53. Thereby, the output signals of difference networks 52 and 53 can be respectively considered as indicative of the feed rates of the solid and liquid materials in down pipe 42. Preferably, the output signals of networks 52 and 53 are proportional to volume, rather than mass flow rates. The mass flow rate signals derived from difference networks 52 and 53 are combined with the liquid volume flow rate indicating output of flow meter 46 in computer network 54, having an output signal indicative of the ratio of the output of difference network 52 to the sum of the outputs of networks 52 and 53, as well as flow meter 46. The output signal of computer network 54 is compared with a set point for the volume flow rate of slurry emerging from ball mill 43 in subtraction network 155. The error signal derived from

subtraction network 155 is fed to controller 56 for actuator 57 of valve 45, whereby the consistency of slurry emerging from ball mill 43 is maintained constant.

The slurry emerging from ball mill 43 is fed via conduit 58 to sump 25 to provide a complete recirculation of material from the sump inlet through pump 32 and cyclone separator 33 to ball mill 43 and back to the sump. Under steady state conditions, the feed rate of ore in the recirculating loop is considerably in excess of the feed rate of ore from hopper 11 to conveyor 12 or through conduit 41, typically three to four times as great. Under steady state conditions, the feed rates through conduit 41 and conveyor belt 12 are substantially the same and even for transient situations the feed rate through the effluent conduit 41 can be approximated as being equal to the input feed rate.

The feed rate of ore being fed by conveyor 12 to cross conveyor 13 is controlled to maintain a predetermined relation between the particle size of the effluent in conduit 41 and production rate so that the mill can operate in an optimum manner from a monetary standpoint. To effectively measure the particle size of effluent in conduit 41 the ratio of the feed rates of ore recycled from cyclone separator 33 to the ball mill 43 to the input ore fed to rod mill 16 from belts 12 and 13 is monitored. The feed rate of the ore in the recirculating loop including down pipe 42 and ball mill 43 is derived from subtraction network 52 as a signal indicated by S_3 . Since the feed rate through conduit 41 is substantially equal to the feed rate of ore from conveyor 13 into rod mill 16, the solid feed rate indication output of detector 49 provides a measure of the input ore feed rate to mill 16. This approximation minimizes the effects of inaccuracies due to transients in the input ore feed rate on the system operation. The solid feed rate indicating output signals of detector 49 and subtraction network 52 are combined in divider circuit 60, having an output signal indicative of S_3/S_9 , where S_9 is the feed rate of effluent in conduit 41. The S_3/S_9 output of divider-circuit 60 is fed to difference node 56, where it is subtracted from the output signal of function generator 55 to be described in greater detail *infra*. Difference node 56 derives an error output signal that is applied to motor speed controller 15 to vary the mill production rate through control of the speed of belt 12 and enable the mill to function in an optimum manner.

Non-linear function generator 55 is responsive to an indication of actual production rate. Preferably production rate is indicated by the solid feed rate output signal of detector 49 which is fed to the input of function generator 55; in the alternative, the function generator can be driven by the input ore feed rate indicating signal derived from weightometer 19, as indicated by dotted line 57. In function generator 55, there is stored a non-linear response relating desired particle size to production rate and recycle ratio, i.e., the ratio of the feed rate of solids in downflow line 42 to the input ore feed rate or the overflow solid feed rate (S_3/S_1 or S_3/S_9). The response stored in function generator 55 is based on hardness of ore being processed and economic factors. In response to the production rate input signal fed thereto, function generator 55 derives an output signal for the recycle ratio. The recycle ratio output signal of function generator 55 is based on the optimum particle size

response stored therein for the particular production rate. The recycle ratio output signal of function generator 55 is compared with the actual recycle ratio output signal in difference node 56 to control production rate.

While division circuit 54 is preferably responsive to the output of gauge 47, it is to be understood that in certain systems it can also be directly responsive to the ore feed rate as monitored by weightometer gauge 19. Such a situation is shown in the schematic diagram of FIG. 1 by dotted line 157.

Another possible modification to the system of FIG. 1 involves controlling the consistency of the slurry emerging from sump 25 in response to the feed rate of solids through conduit 41 rather than supply conduit 34 for cyclone separator 33. In such an event, the input to subtraction network 39 is in response to the output of density gauge 47, as indicated by dotted line Q9, rather than in response to the output of density gauge 36.

In certain systems and within the teachings of the present invention, effluent from rod mill 16 is fed directly to ball mill 43 and the ball mill supplies the only solid containing material to sump 25. In modern practice, however, sump 25 is responsive directly to both rod mill 16 and ball mill 43 to allow immediate extraction by separator 33 of the material already of suitable fineness.

Consideration is now given to the properties of function generator 55 by referring to FIG. 2. In FIG. 2, recycle ratio, i.e., the feed rate of solid material recycled from the down flow of cyclone separator 33 into ball mill 43 divided by the input or output solid feed rate (S_3/S_1 or S_3/S_9), is plotted as a function of production rate, a parameter equated with solid input feed rate, S_1 , along curves 61-65 of constant grindability, a function of input ore hardness and surface area. The constant ore grindability curves 61-65 progress in value from left to right. Hardness is inversely proportional to grindability, whereby the softest ore is associated with curve 65. The positions of curves 61-65 relative to values of production rate, S_1 , the ordinate of the FIG. 2 plot, are determined by operating factors for the particular mill with which the controller of the invention functions. For any particular ore hardness or grindability, the system inherently functions along one of the lines of constant grindability or hardness, i.e., one of curves 61-65. An important feature of the invention is that it is not required to ascertain what the hardness of input ore actually is to enable the system to function in an optimum manner.

Superimposed on curves 61-65 are curves 66-68, indicative of the particle size of ore in effluent conduit 41 as a function of solid recycle ratio. These curves are determined from empirical data wherein particle size is measured for different recycle ratios and input ore hardness. Curve 66 to 68 represent the performance of the mill in producing particles of increasing size. By virtue of FIG. 2 and making use of curves 66, 67 and 68 which are lines of constant particle size criterion, it follows that the performance of the mill in terms of this criterion can be inferred from a knowledge of the recycle ratio (S_3/S_9) and the production ratio (S_9).

Another curve 69, possibly of variable particle size, is provided. Curve 69 defines the particle size-production rate relationship for the optimum economic operation of the mill. It is found by empirical techniques,

based upon production rate, particle size, and economic factors, and varies from mill to mill and possibly within the same mill depending, e.g., upon changing costs of power or ore. Curve 69 is the non-linear relationship stored in function generator 55 to relate production rate input signals to recycle ratio output signals.

To consider the manner by which a grinding mill controlled in accordance with the present invention functions, assume that ore in hopper 11 has a hardness associated with curve 62, FIG. 2, the recycle ratio calculated by division circuit 54 has a value indicated by ordinate 71 and the production rate is indicated by abscissa 72. In response to the production rate indicated by abscissa 72, function generator 55 derives a recycle ratio output indicated by ordinate 73, at the intersection 74 of ordinate 72 and curve 69. The difference between the recycle outputs of function generator 55 and division circuit 54 is detected in subtraction node 56, which derives a positive output signal in response thereto. The positive output signal of node 56 causes the speed of belt 12 to increase, thereby raising production rate. The increased production rate causes the mill recycle ratio to increase along constant hardness curve 62. The production rate and recycle ratio increase until hardness curve 62 intersects optimum particle size curve 69 at point 75. It is noted that the recycle ratio at point 75 is greater than that at point 74, associated with the recycle ratio towards which the system was originally driving. In response to the speed of belt 12 being regulated to the production rate indicated by the ordinate of intersection 75, the flow rate of water into ball mill 16 through conduit 17 is stabilized to enable the rod mill to produce a slurry having a desired consistency. By stabilizing the input ore feed rate, i.e., production rate to the ordinate of intersection 75, the output feed rate in conduit 41 is stabilized to the same value and the rate of input feed to cyclone separator 33 is substantially stabilized. By stabilizing these feed rates, the consistency of slurries emerging from sump 25 and ball mill 43 is maintained substantially constant in response to controls respectively provided by valves 28 and 45.

From the previous description, it is seen how the system regulates production rate to an optimizing curve stored in function generator 55 regardless of perturbations to the mill or the input ore. If hardness of input ore, e.g., should change the natural response of the mill is along a different hardness curve and there is no need to monitor input ore hardness.

While there has been described and illustrated one specific embodiment of the invention, it will be clear that variations in the details of the embodiment specifically illustrated and described may be made without departing from the true spirit and scope of the invention as defined in the appended claims. For example, the calculating and function generator elements, shown in analog computer form, can be replaced by a suitably programmed digital computer.

We claim:

1. A system for controlling the production rate of a grinding mill responsive to a supply of input ore, said mill including a recirculating loop with separating means for feeding particles generally having greater than a predetermined size back to a grinding means and

for feeding particles generally having sizes equal to or less than the predetermined size to an output line, comprising means for deriving a first signal indicative of the feed rate of particles fed back to the grinding means from the separating means, means for deriving a second signal approximately equal to the feed rate of the input ore to the mill, means responsive to said second signal for deriving a third signal indicative of a desired relationship between the flow rate of particles in the recirculating means and the feed rate of input ore, means responsive to the first and second signals for deriving a fourth signal indicative of the actual relationship between the flow rate of particles in the recirculating means and the feed rate of input ore, means for comparing the third and fourth signals to derive an error signal, and means responsive to the error signal for controlling the relative feed rate of the input ore and flow rate of the recirculated particles.

2. The system of claim 1 wherein the second signal deriving means includes means for monitoring the feed rate of solids in the output line.

3. The system of claim 1 wherein said mill includes means responsive to input ore and a supply of liquid for deriving a slurry of ore and liquid, and further including means responsive to the relative feed rates of solids and liquids fed to the slurry deriving means for controlling the consistency of solids and liquids in the slurry.

4. The system of claim 1 wherein said mill includes means responsive to recirculated ore and a supply of liquid for deriving a slurry of ore and liquid, and further including means responsive to the relative feed rates of solids and liquids fed to the slurry deriving means for controlling the consistency of solids and liquids in the slurry.

5. The system of claim 1 wherein said mill includes a rod mill responsive to input ore and a first supply of liquid for producing a first slurry of ore and liquid, a ball mill responsive to particles fed from the separating means back to the grinding means and a second supply of liquid for producing a second slurry of ore and liquid, a sump responsive to said first and second slurries and a third liquid supply for producing a third slurry fed to said separating means, and means responsive to the feed rates of solids and liquids fed to each of the rod mill, ball mill and sump for separately controlling the solid liquid consistency of each of the first, second and third slurries.

6. A method of controlling the production rate of a grinding mill responsive to a supply of input ore, said mill including a recirculating loop with separating means for feeding particles generally having greater than a predetermined size back to a grinding means and for feeding particles generally having sizes equal to or less than the predetermined size to an output line, comprising effectively measuring the production rate of the mill, from the measured production rate and a function of the grindability of the input ore determining a desired relationship between the flow rate of particles in the recirculating loop and the production rate, determining an indication of the actual relationship between the flow rate of particles in the recirculating loop and the production rate, deriving an indication of the error between the desired and actual relationships, and in response to the error controlling the relative rates of the input ore feed and recirculated particle flow to maintain a desired mill operation.

9

10

7. A method, as defined in claim 6, wherein said desired relationship results in a substantially constant output particle size.

8. A method, as defined in claim 6, wherein said desired relationship is based upon particle size and economic factors.

9. The method as defined in claim 6 wherein said mill includes means responsive to input ore and a supply of liquid for deriving a slurry of ore and liquid, and controlling the relative feed rates of solids and liquids fed to the slurry deriving means to maintain the consistency of solids and liquids in the slurry substantially constant despite variation of input ore feed rate.

10. The method of claim 6 wherein the indication of the actual relationship is derived by: measuring the flow rate of particles in the recirculating loop, and combining the two rate measurements.

11. The method of claim 10 wherein the desired relationship is the desired ratio between the flow rate of the recirculating loop particles and the production rate,

and the actual relationship is the actual ratio between the recirculating loop particle flow rate and the production rate.

12. The method of claim 6 wherein the desired relationship is the desired ratio between the flow rate of the recirculating loop particles and the production rate, and the actual relationship is the actual ratio between the recirculating loop particle flow rate and the production rate.

13. The system of claim 1 wherein said third signal deriving means includes a non-linear function generator responsive to said first signal indicative of the mill production rate for deriving said third signal as being indicative of a feed rate ratio of the particles fed back to the grinding means with respect to the input ore.

14. The system of claim 13 wherein said fourth signal deriving means includes means for deriving said fourth signal as being indicative of the ratio of the first and second signals.

* * * * *

25

30

35

40

45

50

55

60

65