United States Patent

[11] 3,596,839

[72] Inventor Richard E. J. Putman
Pittsburgh, Pa.
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[73] Assignee Westinghouse Electric Corporation
Pittsburgh, Pa.
Continuation of application Ser. No. 601,608, Dec. 14, 1966, now abandoned.

[54] **SLURRY PARTICLE SIZE DETERMINATION**
14 Claims, 6 Drawing Figs.

[52] U.S. Cl. 241/20, 241/21, 241/30, 241/34
[51] Int. Cl. B02c 21/00, B02c 25/00
[50] Field of Search .... 241/15, 20—21, 24, 33—38, 97, 61

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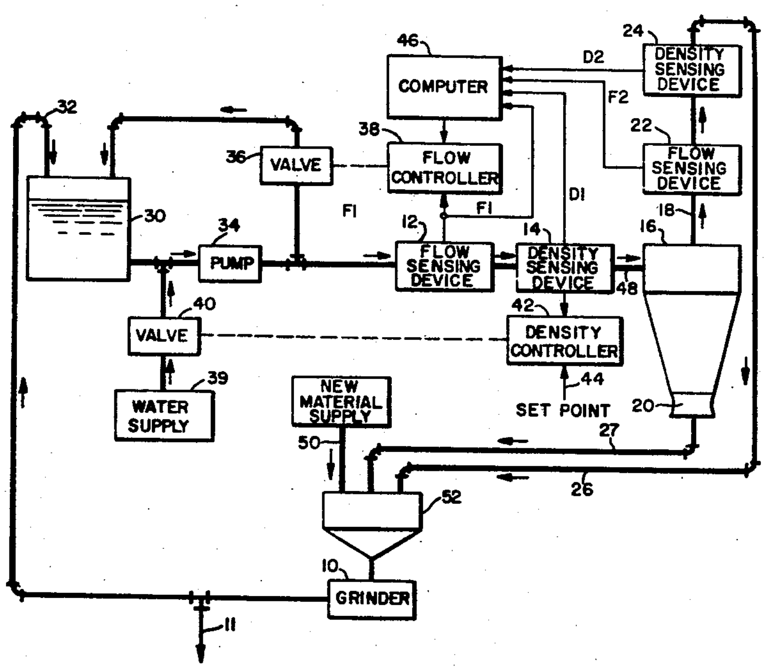
Primary Examiner—Donald G. Kelly
Attorneys—F. H. Henson and R. G. Brodahl

ABSTRACT: Method and apparatus for determining the particle size distribution in a slurry in a grinding circuit with the method and apparatus operative in an online manner and at frequent intervals for effecting this determination. A high-speed computer is used to better control the operation of the circuit. Such particle size distribution, obtained through a determination of the cumulative percentage of solids in the grinder output slurry, is regulated in relation to the infeed of slurry material into the grinder as a predetermined function of the weight of new material introduced into the grinder unit circuit, the known particle size distribution of that new material from classifiers returned as infeed to the grinder and the calculated particle size distribution of that overflow material.



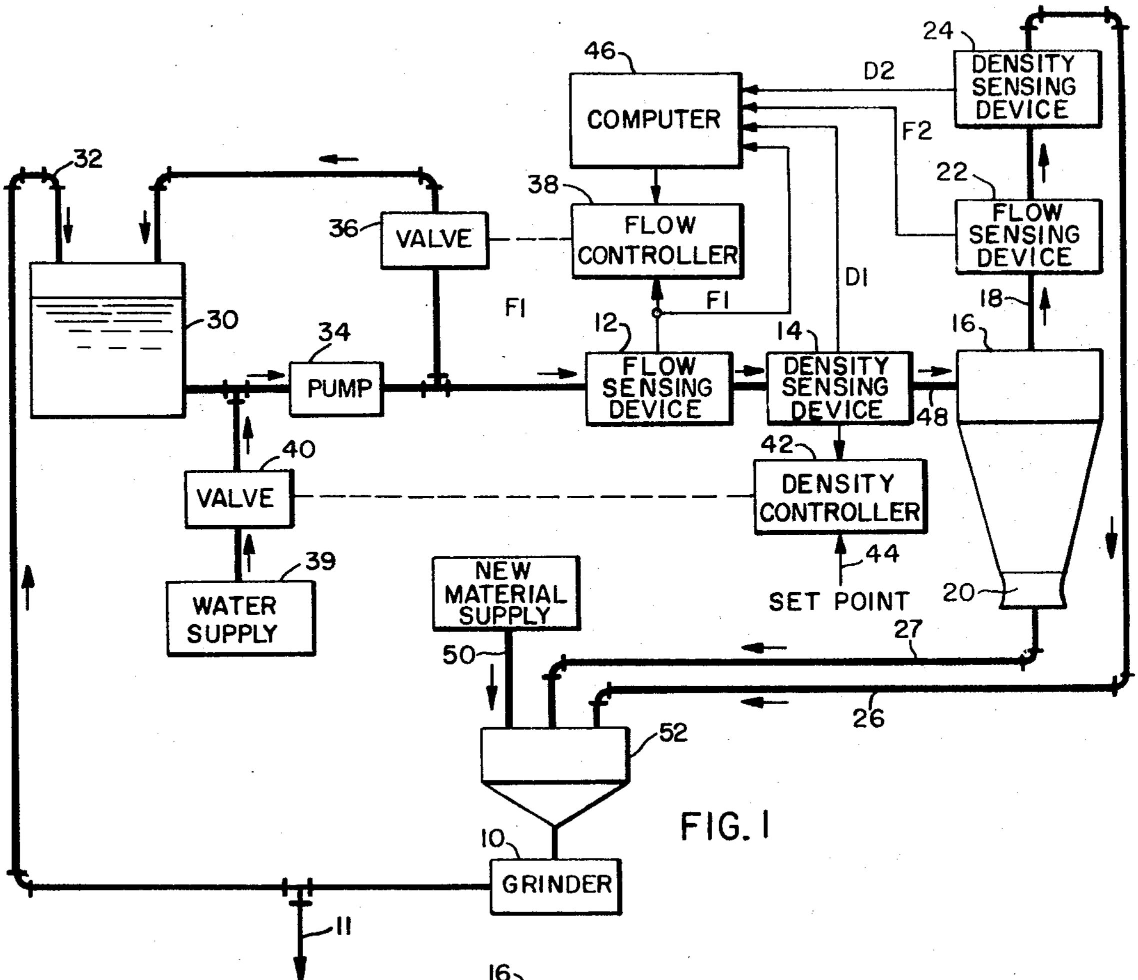


FIG. 1

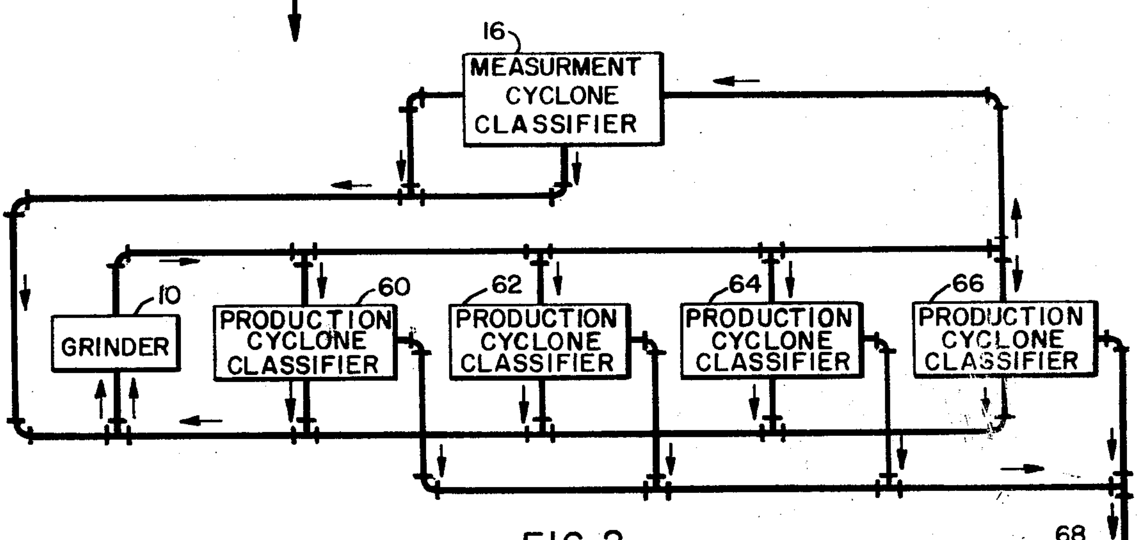


FIG. 2

WITNESSES

Helen M. Harkas

James F. Young

INVENTOR

Richard E.J. Putman

BY R.J. Brodahl

ATTORNEY

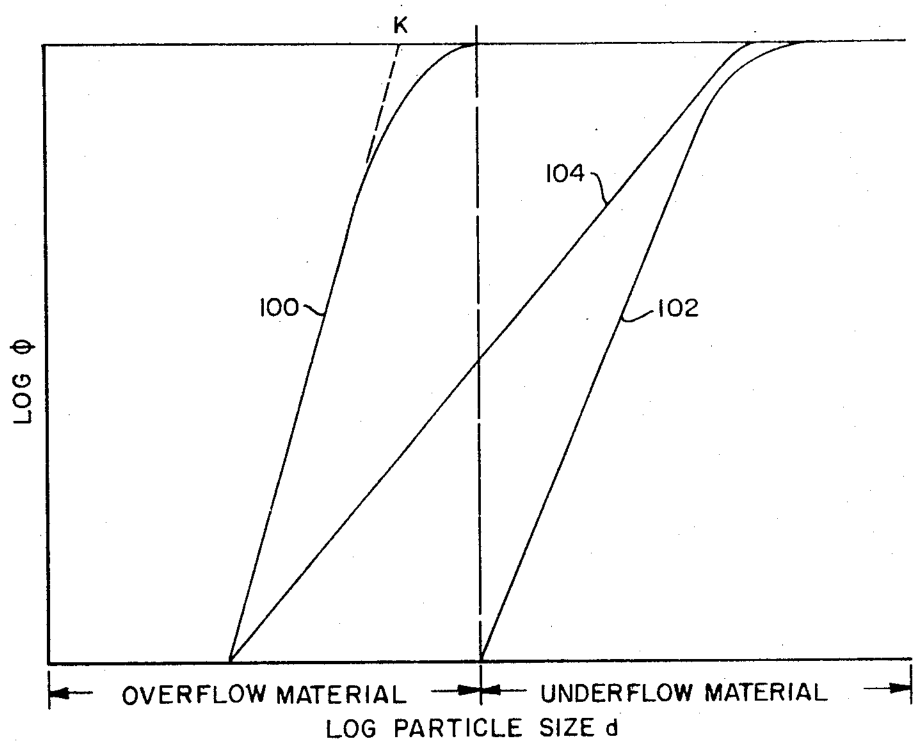

K
104
100
102
LOG Φ
OVERFLOW MATERIAL
UNDERFLOW MATERIAL
LOG PARTICLE SIZE d

FIG. 6

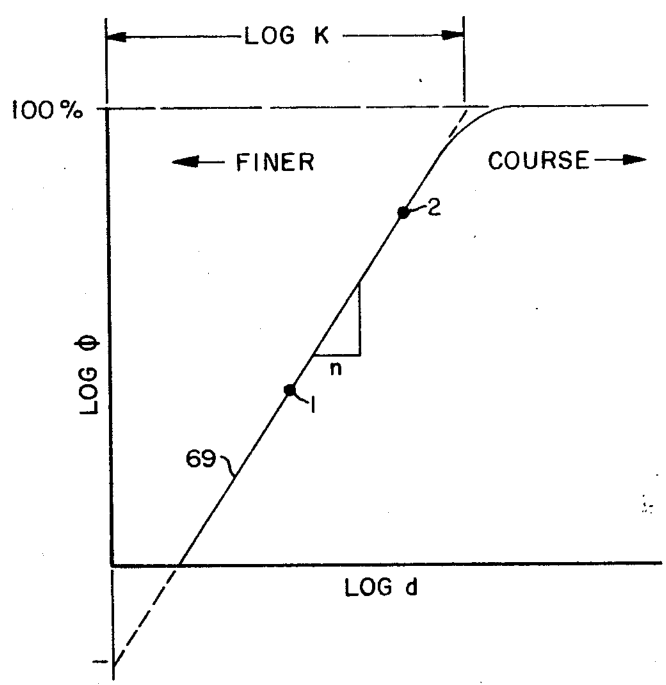

LOG K
100%
FINER
COURSE
2
n
1
69
LOG Φ
LOG d

FIG. 3

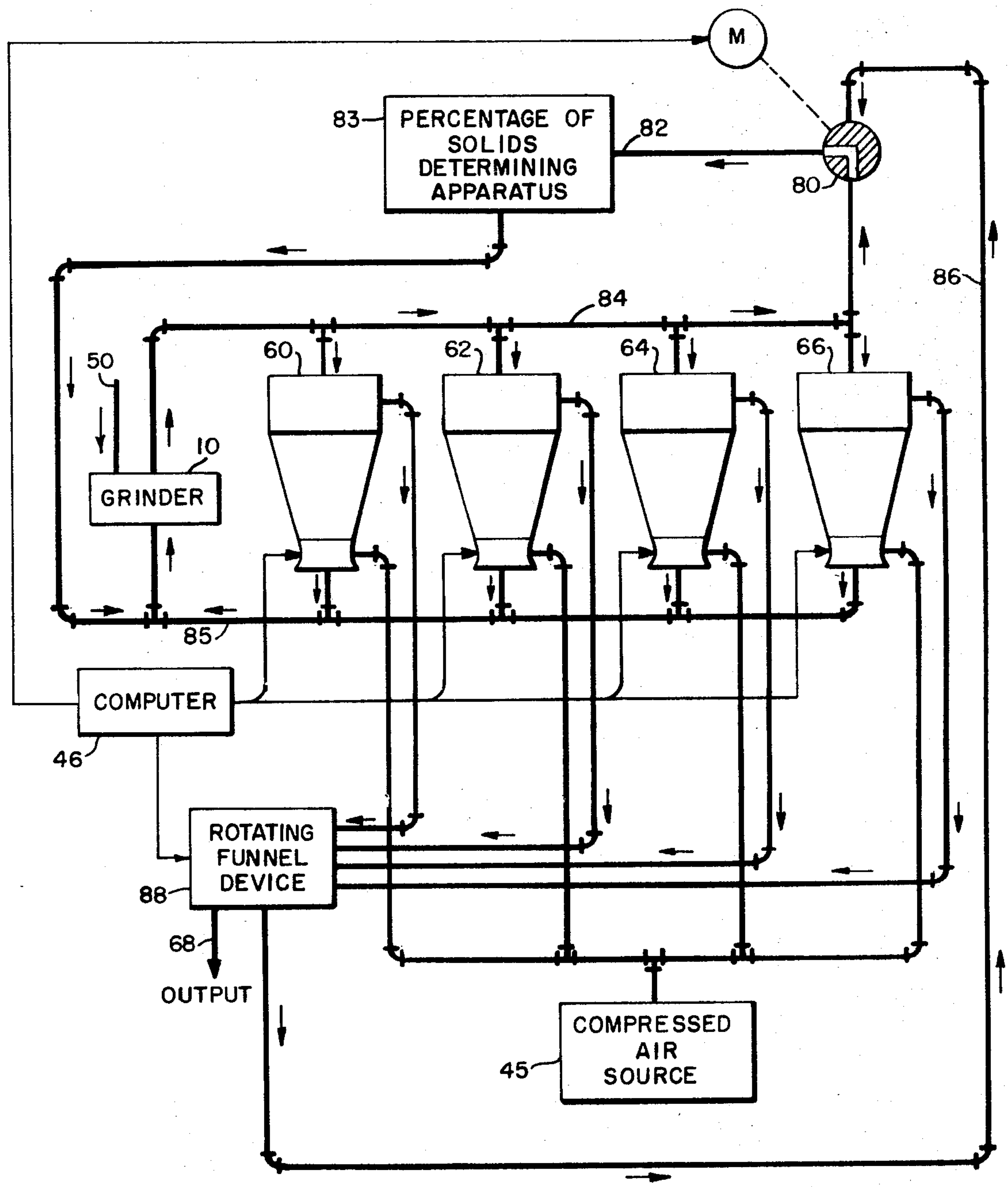

M
PERCENTAGE OF SOLIDS DETERMINING APPARATUS
83
82
80
86
84
60
62
64
66
50
10
GRINDER
85
COMPUTER
46
ROTATING FUNNEL DEVICE
88
68
OUTPUT
COMPRESSED AIR SOURCE
45

FIG. 4

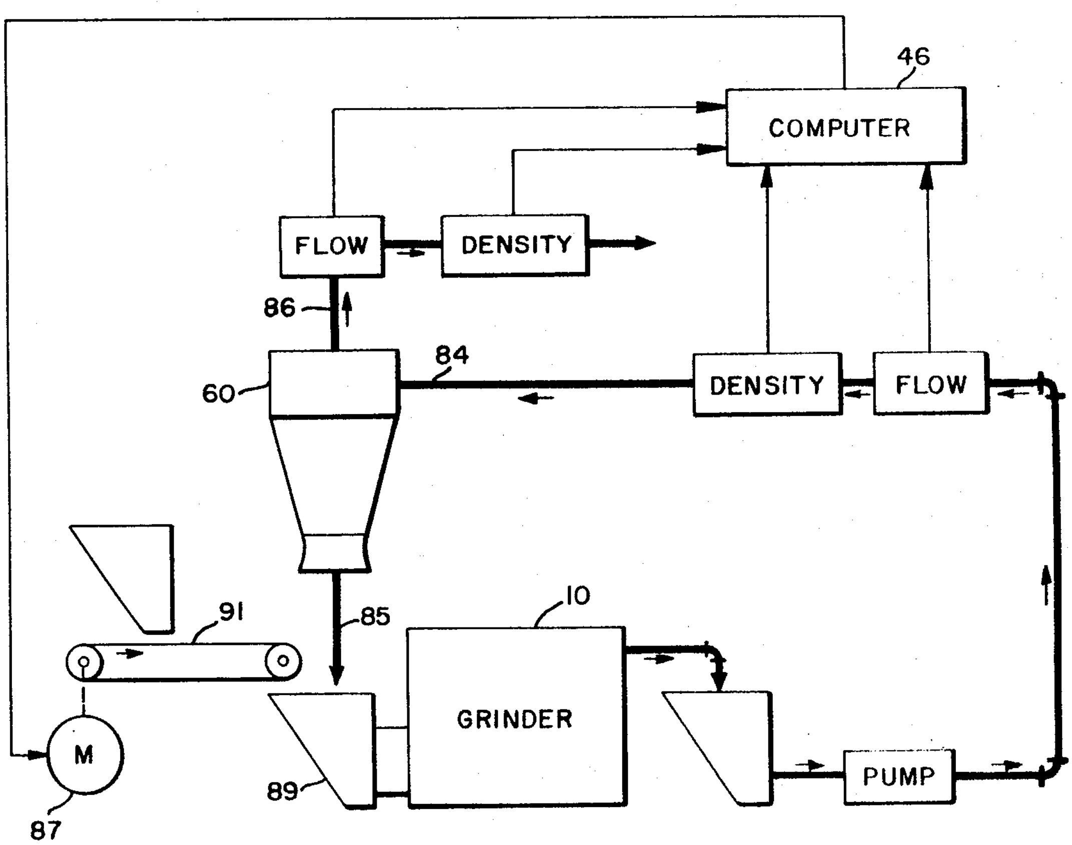

46
COMPUTER
FLOW
DENSITY
86
84
60
DENSITY
FLOW
91
85
10
GRINDER
M
89
87
PUMP

FIG. 5

SLURRY PARTICLE SIZE DETERMINATION

The present patent application is a continuation of an earlier-filed patent application Ser. No. 601,608, filed Dec. 14, 1966 now abandoned.

In the milling and grinding of mineral ores, it is desirable to know the particle size distribution at frequent and regular intervals in order to determine how the grinding operation is proceeding, to check the operation of the classifiers and to ascertain whether liberation of the desirable mineral elements has proceeded as intended.

It has been known in the prior art to take a sample of the output slurry from the grinding circuit and apply it to a device in diluted form, the size and number of the particles being counted by photoelectric or other methods. Another prior art particle measurement technique is to wash the sample through a series of screens having different mesh sizes, and to then dry and weigh the amount of solid material retained on each screen.

In the desired operation of the grinding mill, the particle size in the output slurry has to be fine enough such that the right and desired grade is reached. If the particles are ground too fine, slimes are formed which inhibit flotation and cause valuable mineral to pass to tailings. On the other hand, if the particles are ground too coarse this results in an inadequate separation of the desired mineral from the host rock. It should be further noted that the subsequent flotation process, employing a coating agent such as lead xanthate which has a special affinity for metal sulfide particles and causes them to adhere to air bubbles, themselves produced by the presence of a frothing agent, requires a consistent particle size distribution in the feed slurry for optimum performance of the flotation process.

It is an object of this invention to provide an improved measurement method and apparatus operative to better determine the particle size distribution in the output of a mineral-grinding circuit where the output is contained in a form which is adapted for sensing of the density and flow conditions thereof.

It is another object of the present invention to provide an improved technique for the determination of particle size in the output of a mineral ore-grinding circuit, which technique is better adapted for online operation with a high-speed computer for better controlling the operation of the grinding circuit.

It is further object to provide an improved control method and apparatus for the operation of a mineral-grinding circuit wherein a better control of particle size distribution is obtained through a determination of the cumulative percentage of solids in the output slurry from the grinding device.

Experimentation shows that the separation of solids fed to a fixed cyclone classifier is a function of the inlet velocity and particle size. Thus, for a given output slurry from the grinder at a given density and inlet velocity, the fraction of solids in the overflow from the classifier cyclone to the total solids fed to the inlet of the classifier cyclone is a measure of the percentage of solids which were below the corresponding particle size or mesh number for that particular mineral ore. By varying the inlet velocity, the percentage at the particle size corresponding to that new velocity may also be determined, and repeatedly so on over the range of particle sizes which is of interest in the particular application where this technique is applied.

In accordance with the teachings of the present invention, at any given instant of time, the cumulative percentage of solids Φ in the overflow from the cyclone classifier may be expressed in accordance with the following formula:

$$\phi=\frac{F_2(D_2-1)}{F_1(D_1-1)}$$

where F_1 and F_2 are in volumetric units and D_1 and D_2 are in specific gravity units. Experimentally the mesh number or limiting particle size d corresponding to a given F_1 and D_1 will have been determined. The computer will set F_1 at various values, measure the quantities D_1, F_2 and D_2, and calculate the corresponding values of Φ. These may be printed out and/or the data used to regulate the classifiers and mesh so that the desired particle size distribution information is obtained for the grinder device.

Additionally, in accordance with the teachings of the present invention, the particle size distribution is regulated in relation to the infeed of slurry material into the grinder unit as a predetermined function of the weight of new material introduced into the grinder unit circuit, the known particle size distribution of that new material, the weight of the overflow material from the classifiers returned as infeed to the grinder unit and the calculated particle size distribution of that overflow material.

For a more detailed understanding of the present invention both as to its organization and its method of operation together with additional objects and advantages thereof, reference should be made to the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a diagrammatic showing of the present control apparatus, including the condition-sensing devices, operative to determine the particle size distribution in accordance with the teachings of the present invention;

FIG. 2 shows the general arrangement of a typical ore-grinding installation and including the measurement cyclone classifier in accordance with the teaching of the present invention;

FIG. 3 shows a curve to illustrate the technique for determining the reduction modulus N and the size modulus K in accordance with the present invention;

FIG. 4 illustrates a modification of the particle size distribution sensing apparatus which enables the regulation of the particle size distribution;

FIG. 5 illustrates the additional feature of regulating the particle size distribution of the infeed material supplied to the grinding mill; and

FIG. 6 illustrates the already well-known relationship between particle size distribution, particle size and percentage of solids in the slurry.

In FIG. 1 there is shown a grinder 10 for grinding a water slurry of mineral ore to a desired particle size for some subsequent separation operation which is per se well known at the present time, The output of the grinder 10 is fed through a conduit 11, while a sample of the output is fed to a measurement cyclone classifier 16 which is per se well known in the art and operative to overflow the smaller size particles of mineral ore through an overflow outlet 18, In the overflow slurry from the measurement cyclone classifier 16 as supplied through conduit 18 there is included a flow-sensing device 22 and a density sensing device 24 from which the overflow slurry is fed back to the grinder through a conduit 26.

In FIG. 1 there is shown a slurry-holding tank 30 for receiving at least a sample amount of the output slurry from the grinder 10 supplied through conduit 32. A pump 34 is operative to pump material slurry from the tank 30 and supply it through the flow-sensing device 12 and density-sensing device 14 leading to the measurement cyclone classifier device 16. The slurry pump 34 is preferably operated in a continuous manner and should not be throttled, but rather maintains a constant flow, with the bypass valve 36 being regulated by a flow controller 38 as determined by the computer 46 to be operative to bypass the undesired portion of the mineral slurry back into the holding tank 30 as will be subsequently explained. Water is supplied from a water supply 39 through a control valve 40 in accordance with the operation of a density controller 42 having a manual set point signal applied to input 44 to provide a predetermined percentage operation of solids by weight in the flow of slurry fed into the measurement cyclone classifier device 16.

The flow-sensing device 12 is operative with the material slurry supplied by the pump 34 to provide a control signal to the flow controller 38 in accordance with the instantaneous flow into the measurement cyclone classifier 16. The flow controller **38** is operative with a reference flow set point signal supplied by the computer **46** to determine the operation of the bypass valve **36** to provide this predetermined and desired flow F_1 through the conduit **48** leading to the measurement cyclone classifier device **16**. The density-sensing device **14** is operative as a transducer to provide an output signal D_1 in accordance with the instantaneous density of the slurry passing through the conduit **48**, which control signal is supplied to a density controller **44** to be compared with the reference density set point supplied through the input **44** for determining the operation of the control valve **40** to regulate the instantaneous density in terms of solids by weight in the slurry passing through the conduit **48**.

The computer **46** similarly receives a control signal F_2 in accordance with the flow of the slurry in the overflow conduit **26** from the measurement cyclone classifier device **16** and the density-sensing device **24** provides a control signal D_2 to the computer **46** in accordance with the density of the overflow slurry passing through the conduit **26** from the measurement cyclone classifier device **16**.

The output underflow slurry flow from the fixed bottom apex valve **20** of the cyclone classifier device is returned to the grinder through the conduit **27**. The overflow mineral slurry from the cyclone classifier device **16** is returned to the grinder through the conduit **26**. New material is supplied to the grinder circuit through the feeder conduit **50**. A mixing device **52** collects the various input feeds of slurry to the grinder **10** and feeds these to the grinder device **10**.

In FIG. **2** the grinder **10** is shown operative with the measurement cyclone classifier **16** and additionally with a plurality of production of cyclone classifiers **60**, **62**, **64** and **66**. The measurement cyclone classifier **16** is a smaller device handling 40 or 50 gallons per minute whereas the output from the grinder **10** may be in the order of a 1,000 gallons per minute or so and the production cyclone classifiers are substantially large devices handling a much greater flow of mineral slurry for production classification, with the desired overflow output slurry therefrom being passed through the conduit **68** to a subsequent process such as a well-known flotation process to separate the mineral ore from the remaining rock and similar undesired materials.

It was known in the prior art to operate a measurement cyclone classifier manually on a sampling basis by initially calibrating the classifier by feeding it with slurry of a given density and a given velocity and then manually measuring the limiting particle size d of the overflow slurry through a mesh screen or photocell-type device or the like, This operation was repeated several times to establish the relationship between input slurry flow and overflow particle size. The operation contemplated by the measurement technique of the present invention leads itself to an online operation particle size classification installation.

In the operation of the control apparatus shown in FIGS. **1** and **2**, and with particular reference to FIG. **1**, the flow controller **38** is operative to control the valve **36** for varying the bypass of mineral slurry from the constant speed pump **34** in a predetermined manner as determined by the computer **46** to set a reference inlet velocity and its corresponding flow F_1. The computer **46** then senses the respective output control signal F_1 from the inlet flow-sensing device **12** and the control signal D_1 from the inlet density-sensing device **14** and the control signal F_2 from the outlet flow-sensing device **22** and the control signal D_2 from the outlet density-sensing device **24** and calculates Φ in accordance with the formula relationship:

$$\phi=\frac{F_2(D_2-1)}{F_1(D_1-1)}$$

to provide a determination of Φ the cumulative percentage of solids in the overflow slurry from the measurement cyclone classifier device **16**. Then this is repeated for several predetermined inlet velocities and corresponding values of F_1 is determined by the operation of the computer **46** to vary the set point of the flow control **38**, with the density-sensing device **14** and density controller **42** being operative to regulate and maintain a reference density set point such as 40 per cent solids by weight for the mineral slurry supplied to the measurement cyclone classifier device **16** through the conduit **48**. In this manner a table for control operation of the grinder **10** may be plotted with the cumulative percentage of solids Φ plotted as the ordinate versus the associated particle size d as the abscissa. With such a table any desired limiting particle size d can be obtained by a selection of the proper value of Φ from that plotted table and then effecting the necessary control of the flow controller **38** to achieve the required operation of the bypass valve **36**.

In FIG. **3** there is shown a curve to illustrate the plotted relationship of log Φ versus log d, where Φ is the cumulative percentage of solids and d is limiting particle size. The limiting particle sizes d of each of a given two samples are known from previous calibration and the cumulative percentage of solids Φ for those samples are calculated as previously explained. This will yield the quantities d_1 and d_2 as well as Φ_1 and Φ_2 for those samples.

On the resulting straight line portion of the curve **69** including points **1** and **2** for the respective two samples as shown in FIG. **3**, any point can be defined according to the following equation:

$\log \Phi = n \log d + \log C$

when $\Phi = 100$, $\log d = \log K$

therefore, $\log 100 = \log K + \log C$

from which, $\log C = \log 100 - n \log K$

therefore, $\log \Phi = \log 100 + n (\log d - \log K)$

or $\log \theta/100 = n \log d/k$

Using the values Φ_1 and d_1 for sample 1 in one application of the last equation and Φ_2 and d_2 for sample 2 in a second application of the last equation, this will provide simultaneous equations which the computer can solve for the value n, the reduction modulus, and for the value K, the size modulus.

The value n does not change appreciably throughout the normal particle size distribution range from a grinder for a given ore material, but the value K does change. The computer can use the value K determined in this manner to provide a control signal to regulate the size of the bottom apex value of the respective production classifiers in an effort to regulate the value K to a desired and known value for correcting undesired changes in the particle size distribution from the grinder output. The slope of the curve **69** shown in FIG. **3** is determined by the values n and K_1 with the intersection of the curve **69** being the value K. With the n not changing appreciably throughout the desired operative particle size distribution from the grinder **10**, the value K can be controlled between predetermined limits by the computer and in this manner control the overflow particle size distribution from the cyclone classifiers. It is preferable that the curve **100** shown in FIG. **6** not become too low since the smallest particle in the overflow should not be too small and it is also preferable that the curve **100** not become too high. For taconite ore, for example, 95 percent of the material should be less than 325 mesh or 40 microns in size. By controlling K in a manner to be later explained, the position of the curve **100** can be maintained within predetermined limits of K to yield the preferred particle size distribution from the grinding circuit. The following mathematical derivation for the calculation of the amount of solids in a mineral slurry can be utilized to derive the cumulative percentage of solids formula as above set forth.

Computer Calculation of Amount of Solids in a Slurry

Let D' = density of slurry (lb./ft.^{3}) as measured by a gamma gauge

F = volumetric flow of slurry (ft.^{3}/min.) as measured by a magnetic flow meter.

x = weight of solids (lbs.) per ft.^{3} slurry

y = weight of water (lbs.) per ft.^{3} slurry

δx = density of solids lb./ft.^{3}

δy = density of water lb./ft.^{3}

c = fraction of solids by weight in slurry (100 percent = 1.0)

Let $K_x = 1/\delta x$ and $ky = 1/\delta y$

Then one cu. ft. slurry, equating volumes,

$$K_xX+K_yY=1$$

dividing by

$$xK_x+Ky\frac{Y}{X}=\frac{1}{X}$$

and

$$\frac{y}{x}=\frac{1}{Ky}\left(\frac{1}{x}-K_x\right)=\frac{1}{Ky}\;\frac{(1-xK_x)}{X} \qquad (1)$$

Also

$$C=\frac{X}{x+y}$$

$$Cx+Cy=x$$

$$Cy=x(1-C)$$

and

$$\frac{y}{x}=\frac{1-C}{C} \qquad (2)$$

From (1) and (2)

$$\frac{1}{Ky}\;\frac{(1-xKx)}{x}=\frac{1-C}{C}$$

$$C-CxK_x=K_yX-KyXC$$

$$X=\frac{C}{Ky-KyC+K_xC}=\frac{C}{Ky-C(Ky-K_x)} \qquad (3)$$

Now

$$D'=x+y=\frac{x}{C}=\frac{C}{C(Ky-C(Ky-K_x)}=\frac{1}{Ky-C(Ky-K_x)} \qquad (4)$$

For taconite: If

$$Ky=\frac{1}{62.3\text{ lb. ft.}^3}\text{ and }K_x=\frac{1}{5\times 62.3\text{ lb./ft.}^3}$$

$$D'=\frac{1}{\frac{1}{62.3}-C\left(\frac{1}{62.3}-\frac{1}{5\times 62.3}\right)}=\frac{62.3}{1-0.8C}\text{lb./ft.}^3 \qquad (5)$$

Total mass flow $=D'F$ lb./min.

Solids flow $=CD'F$ lb./min.

Rearranging (5):

$$1-0.8C=\frac{62.3}{D'}$$

$$C=\left(1-\frac{62.3}{D'}\right)\frac{1}{0.8}$$

$$\text{Solids flow in any slurry}=\left(1-\frac{D'}{62.3}\right)\cdot\frac{L'}{0.8}F$$

$$=\frac{F}{0.8}(D'-62.3)-\frac{62.3}{0.8}F\left(\frac{D'}{62.3}-1\right)$$

$$TfD=\frac{D'}{62.3}=\text{Sp. gr. then }D'$$

$$=62.3D\text{ and solids flow}=\frac{62.3}{0.8}F(D-1) \qquad (6)$$

Assuming at cyclone inlet there is a flow F_1 and sp. gr. D_1 and at cyclone outflow there is a flow F_2 and sp. gr. D_2

$$\text{Then cumulative }\%=\phi=\frac{F_2(D_2-1)}{F_1(D_1-1)} \qquad (7)$$

The measurement cyclone classifier is initially calibrated by manual experiment to determine the limiting particle size d in its overflow in relation to the inlet velocity or the directly related flow F.

It should be noted that the present invention is applicable to particle size distribution control of a dry grinding process, such as is practiced in the grinding of hematite and in the manufacture of cement. A sample is removed and fed into a container of water, and then passed through a measurement cyclone classifier as already described, and then returned to the initial container. When the density of the resulting slurry has reached some desired value, for example 60 percent solids by weight, the determination of particle size distribution can take place as above described. The slurry is then passed back into the grinding mill. Since the flow of this slurry material will be small in relation to the new material infeed, and considerable heat is generated in the grinding process, no adverse effect on the moisture content of the raw material leaving the grinding mill will be realized. The associated computer can be programmed to control the sampling of the material to be tested into the container of water and to continue the same until the resulting density of the slurry is as desired, to stop the sampling and conduct the particle size testing by varying the flow rates as above described according to the particle size being measured. The computer can be made to periodically repeat this testing procedure on a regular basis, such as every 5 minutes, to give a continuous and current measurement of particle size distribution at the mill discharge.

An alternative presentation of the data may be made in the form of the instantaneous values of both size and reduction moduli current at the time of sampling.

In FIG. 4 there is shown a modification of the slurry grinder arrangement, with a two-way rotary valve **80** being operative in the conduit **82** to permit the slurry sample to be selectively removed from either one of the conduits **84** and **86** as desired. There can result under certain conditions of grinder operation, and when only the slurry sample is removed from the conduit **84** as shown in FIG. 2, a surging of the grinder operation due to corrections made through operation of the measurement cyclone classifier **16**. However, by rotation of the valve **80** to permit a sampling of the slurry from the conduit **86** to provide a control anticipation effect, suitable control apparatus can be provided and the computer **46** can be programmed to vary the bottom apex values of the respective production classifiers **60**, **62**, **64** and **66** to vary the slurry underflow therefrom and thereby control the overflow particle size distribution.

As shown in FIG. 4 a slurry-sampling device, such as a four-section rotating funnel unit **88** having one section operative to divert a sample of the slurry, could be made operative with each of the production classifiers and periodically stepped in rotary position to sample sequentially the output overflow slurry from a different one of the production classifiers, on a one-at-a-time basis, such that the conduit **86** would then receive the overflow slurry sample from only the production classifier supplying a slurry sample through the funnel unit **88** during the particular period of time under consideration. During the operation of the funnel unit **88**, the rotary position of the funnel unit **88** is determined by the associated computer **46** or other suitable controller. There are many well-known position-stepping devices that would be suitable in operation to control the rotary position of the funnel unit **88** as well as the position of the valve **80** in response to a control signal from the associated computer **46**. In conjunction with positioning the rotating funnel unit **88** to sample the overflow output slurry from a selected one of the production classifiers, the computer **46** could control the size of the inflatable bottom apex valve of that same one production classifier to vary the underflow therefrom as desired to maintain the desired range of output particle size distribution from the grinder apparatus shown in FIG. 4. The size modulus K is calculated by the computer sequentially utilized to regulate the actual size of the bottom apex from of the involved production cyclone classifier.

More specifically, the rotary valve **80** is shown in FIG. 4 permits a determination of the particle size distribution both before and after the slurry material from the grinder passes through the production cyclone classifiers. With the valve **80** positioned as shown in FIG. 4, the measurement cyclone classifier within the percentage of solids-determining apparatus **83**, corresponding to the apparatus shown in FIG. 1, operates in a manner already described in relation to the showing of FIG. 1, with the conduit **82** of FIG. 4 corresponding with the conduit **32** of FIG. 1. On the other hand, with the valve **80** positioned to connect the conduit **86** to the conduit **82**, the computer **46** is instructed in its program to sequentially position the funnel unit **88** to sample the overflow output from each respective production cyclone classifier on a one-at-a-time basis and additionally to control the flow within the percentage of solids determining apparatus to provide a first flow F_1 and then a second flow F_2, as previously described, to permit a calculation of Φ_1 and Φ_2 corresponding to those two flows. With the known limiting particle sizes d_1 and d_2 relative to those provided flows F_1 and F_2, the particle size modulus K *can be calculated as set forth regarding FIG. 3 to enable the computer 46 to regulate within predetermined limits the actual size of the bottom apex valve of the particular production cyclone classifier involved. The instruction program of the computer 46 includes the predetermined limits for the particle size modulus K,* and the regulation of the apex valve size accordingly is readily accomplished upon the calculation of the particle size modulus K as above described. The compressed air source **45** is utilized to vary the inflation and thereby the actual size of the bottom apex valve for each production cyclone classifier in sequence.

In FIG. **5**, there is an arrangement for regulating the particle size distribution of the infeed material supplied to the grinding mill **10**. Through a mass balance technique, since the sum of the weights of the materials leaving a given cyclone classifier in the overflow and in the underflow is equal to the infeed of material, the computer **46** can determine the underflow particle size distribution from the calculated size modulus and corresponding particle size distribution in the conduit **84** leading to a cyclone classifier, such as the production cyclone classifier **60** for example, and the calculated overflow particle size modulus and corresponding particle size distribution in the conduit **86** leading away from the cyclone classifier. The computer **46** knows the weight W_1 of the underflow slurry in the conduit **85** and the weight W_1+W_2 of the infeed slurry in conduit **84** and the weight W_2 of the overflow slurry in the conduit **86**; it is per se already well known in this particular art how to determine these weights through the use of presently available devices employed for this purpose. The computer **46** determines the particle size distribution in the conduit **85** by solving for psd_{85} in accordance with the following relationship:

$$W_1 f(psd_{85}) +_2 f(psd_{86}) = (W_1+W_2)\, f\,(psd_{84})$$

Now the computer **46** can control the speed of the motor **87** and thereby the feed of new material supplied to the grinder **10** to regulate the particle size distribution of the slurry within the container **89**. FIG. **6** is provided to show the presently well-known relationship of particle size modulus K and corresponding particle size distribution of the overflow material from a cyclone classifier illustrated by curve **100**, the particle size distribution of the underflow material per curve **102** and the particle size distribution of the infeed material to the cyclone classifier illustrated by the curve **104**. A family of these curves can be empirically determined and plotted in relation to variations of the limiting particle size d and the cumulative percentage of solids Φ for a given cyclone classifier by persons skilled in this particular art. The curve **100** has been extended in a straight dotted line manner to indicate the size modulus K for the particular curve **100**. Assuming the slope of the curve **100** does not appreciably change for the intended particle size range of the controlled grinding operation, the control of this size modulus K effectively determines the particle size distribution as desired. This information can be included in the programmed instructions given to the computer **46** to enable the computer to provide the desired particle size distribution information in relation to measured limiting particle size d and calculated cumulative percentage of solids Φ in accordance with the above description.

The computer 46 can regulate the operation of the motor 87 shown in FIG. 5 to maintain a predetermined particle size distribution within the container 89 leading into the grinder 10, through operation of the following relationship between the readily determinable quantities, the known weight W_n of new material supplied by the feed conveyor 91 driven by the motor 87, the known weight W_1 of underflow slurry from the cyclone classifier 60, the known particle size distribution psd_n of the new material, such as one-fourth inch to one thirty-second inch or the like, and the particle size distribution psd_{85} of the underflow slurry from the conduit **85**, and the combined weight $W_n=W_1$ of the slurry within the container **89**. The particle size distribution psd_{89} within the container **89** can now be calculated by the computer **46** from the following relationship:

$$W_1 F(psd_{85}) +_n f(psd_n) = W_1 + W_n f(psd_{89})$$

and solving for psd_{89}. Any difference from a predetermined or reference particle size distribution psd_R desired within the container **89** can be corrected through operation of the computer **46** to vary the speed of the motor **87** and thereby to vary the feeding of new material into the container **89** to hold more uniform the desired particle size distribution within the container **89**. This greatly improves the operation of the grinder **10** in its operation to provide the desired particle size distribution to enhance the efficiency of subsequent mineral removal processes.

While a preferred embodiment of the present invention has been illustrated and disclosed herein, the present invention is not to be limited thereto in that many modifications are within the scope of the present teachings.

I claim:

1. In a control system for grinding apparatus supplying an output slurry to a measurement device, the combination of

first means for initially providing a first inlet flow operation of said slurry to said measurement device and subsequently providing a second inlet flow operation of said slurry to said measurement device,

second means for establishing a first cumulative percentage of solids in the overflow slurry leaving said measurement device during said first inlet flow operation and for subsequently establishing a second cumulative percentage of solids in the overflow slurry leaving said measurement device during said second inlet flow operation,

third means for establishing the particle size modulus of said output slurry in accordance with a predetermined relationship between at least said first cumulative percentage of solids and said second cumulative percentage of solids,

and fourth means for controlling the apparatus in accordance with said particle size modulus.

2. In a system for controlling the particle size distribution from a grinder supplying an output slurry to a measurement device, the combination of

means for sensing predetermined flow and density conditions relative to a first operation of said grinder and for sensing said predetermined flow and density conditions relative to a second operation of said grinder,

means for establishing a first cumulative percentage of solids in the slurry leaving said measurement device in accordance with said flow and density conditions for said first operation of said grinder and for establishing a second cumulative percentage of solids in the latter said slurry leaving said measurement device in accordance with said flow and density conditions for said second operation of said grinder,

means for establishing the particle size modulus of said output slurry in accordance with a predetermined relationship between said first cumulative percentage of solids and said second cumulative percentage of solids,

and means for controlling the particle size distribution of said output slurry from said grinder in accordance with said particular size modulus.

3. In a control system for a grinding device supplying an output slurry to a classifier device, the combination of,

first means operative with said output slurry from the grinding device for determining at least one of a first flow characteristic and a first density characteristic of the slurry supplied to said classifier device,

second means operative with the slurry leaving said classifier device for determining at least one of a second flow characteristic and a second density characteristic of the slurry leaving said classifier device,

third means operative with said first and second means for establishing the percentage of solids relationships in said output slurry in accordance with a predetermined relationship between at least said one of said first flow characteristic and said first density characteristic and said predetermined relationship between at least said one of said second flow characteristic and said second density characteristic,

and control means operative to control the operation of said grinding device in accordance with said percentage of solids relationship.

4. The control system of claim 1 with said measurement device being a measurement cyclone classifier and with said grinding apparatus including a production cyclone classifier, with said measurement cyclone classifier being operative with the output slurry from the grinding apparatus which appears in the overflow slurry from said production cyclone classifier,

and with said third means for establishing the particle size modulus being operative in relation to the percentage of solids in the overflow from said production cyclone classifier.

5. The control system of claim 3, with said grinding device having a portion of said output slurry returned to said grinding device and including a new material supply,

with said third means being operative to determine the particle size distribution in at least the slurry returned to said grinding device and with said control means being operative to control said new material supply to maintain a predetermined particle size distribution in the slurry supplied to said grinding device.

6. The control system of claim 1, with said grinding apparatus including a plurality of production cyclone classifiers, said combination including

overflow slurry sampling means operative to supply said output slurry to said measurement device for sequentially sampling the overflow slurry from each one of the respective production cyclone classifiers,

and with said fourth means being operative in response to said particle size modulus to control the particular production cyclone classifier being sampled.

7. The method of controlling a grinding system including a grinding device connected to supply an output slurry to a classifier device, the steps of

determining a first flow and a first density of the slurry leading to said classifier device,

determining a second flow and a second density of the slurry leaving said classifier device,

establishing the particle size modulus of said output slurry in accordance with a predetermined relationship between said first and second flow and said first and second density,

and controlling the particle size distribution of said output slurry in response to said particle size modulus.

8. The method of claim 7 with said classifier device being a measurement classifier device and with said grinding system including a plurality of production particle size classifiers, said method including the steps of

determining in sequence the particle size modulus of a sample of the output slurry from each selected one of the respective production classifiers,

and controlling the particle size distribution of the output slurry from the selected production classifier corresponding with the particular sample for which the particle size modulus has been determined.

9. In a control system for a grinding device connected to supply an unknown slurry to a classifier device having an output slurry, the combination of

first flow-sensing means and first density-sensing means operative with the unknown slurry from the grinding mill for determining respectively the inlet flow F_1 and the inlet density D_1 of the slurry supplied to said classifier device,

second flow-sensing means and second density-sensing means operative with the output slurry of said classifier device for determining respectively the output flow F_2 and the output density D_2 of the output slurry of said classifier device,

third means operative with said flow and density sensing means for establishing a percentage of solids relationship Φ in said output slurry in accordance with the predetermined formula

$$\phi=\frac{F_2(D_2-1)}{F_1(D_1-1)}$$

and control means responsive to said percentage of solids Φ in accordance with formula for controlling of operation of said grinding device to provide a desired operation of said grinding device.

10. The control system of claim 1, with said measurement device being a measurement cyclone classifier, with said grinding apparatus being operative with a production cyclone classifier, and with said measurement cyclone classifier being operative with said output slurry from the grinding apparatus which appears in the overflow slurry from said production cyclone classifier, the combination including

said third means being further operative to calculate the particle size modulus in relation to the particle size distribution in said overflow slurry,

and with said fourth means being responsible to said particle size modulus to control the particle size distribution from said grinding apparatus.

11. The control system of claim 1, with said grinding apparatus having a portion of said output slurry returned to said grinding apparatus and including a new material supply,

with said third means being further operative to determine the particle size distribution in at least said output slurry returned to said grinding apparatus and being operative to control said new material supply to maintain a predetermined particle size distribution in said output slurry from said grinding apparatus.

12. The control system of claim 3, with said grinding device including a plurality of production cyclone classifiers, said combination including

overflow slurry sampling means operative with said first means for sequentially sampling the overflow slurry from each one of the respective production cyclone classifiers,

and with said control means being operative to control the particle size distribution of the particular production cyclone classifier being sampled.

13. The method of controlling a grinding system connected to supply an output slurry to a classifier device, the steps of

determining at least one of the flow and density of the slurry leading to said classifier device,

determining at least one of the flow and density of the slurry leaving said classifier device,

establishing the particle size modulus of said output slurry,

and controlling the particle size distribution of said output slurry in response to said particle size modulus.

14. The method of claim 13 with said classifier device being a measurement classifier device and with said grinding system including a plurality of production particle size classifiers, said method including the steps of

determining in sequence the particle size modulus of a sample of the output slurry from each one of the respective production classifiers

and controlling the particle size distribution of the output slurry from each one of said production classifiers in sequence before performing the same operation on a sample of the output slurry from the next sequence production classifier.