

[54] **CONTROL SYSTEM AND METHOD FOR BALL MILL AND SPIRAL CLASSIFIER IN CLOSED CIRCUIT**

[75] Inventor: **Richard E. Rutman**, Pittsburgh, Pa.

[73] Assignee: **Westinghouse Electric Corporation**, Pittsburgh, Pa.

[22] Filed: **Apr. 21, 1972**

[21] Appl. No.: **246,206**

[52] U.S. Cl. **235/151.1, 241/34**

[51] Int. Cl. **G06f 15/46**

[58] Field of Search 235/151.1, 151; 444/1; 241/DIG. 2, 33, 34, 35, 68, 96, 97, 24, 37

[56] **References Cited**
UNITED STATES PATENTS

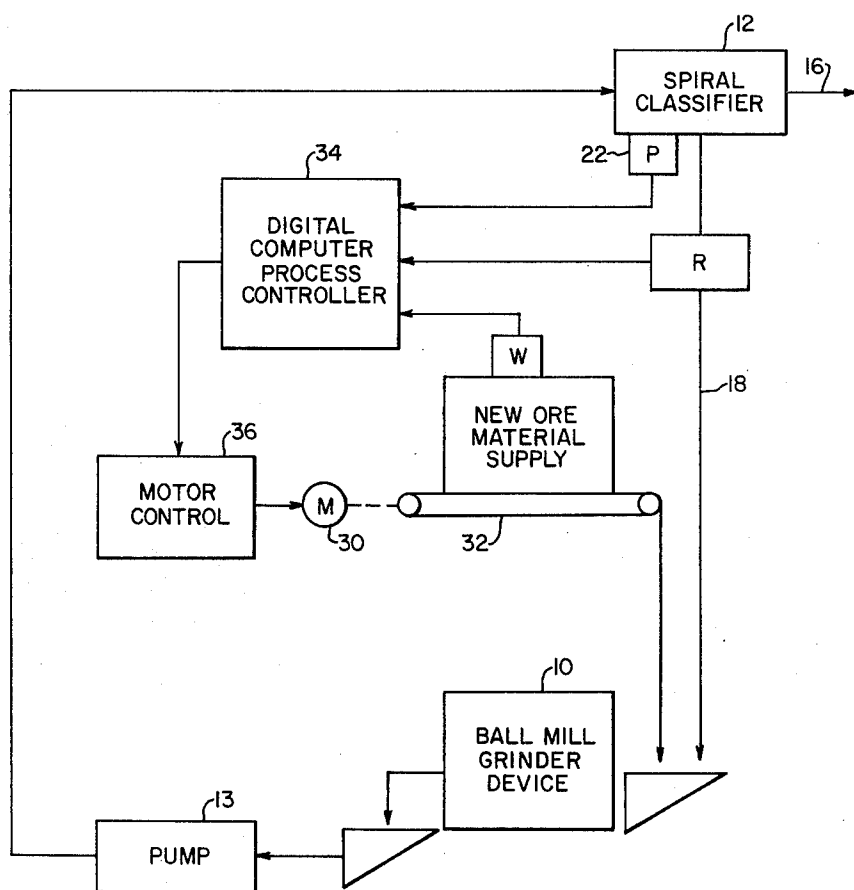
3,114,510	12/1963	McCarty et al.	241/34
3,145,935	8/1964	Wilson	241/97 X
3,248,061	4/1966	Franz	241/34 X
3,314,614	4/1967	Daniel et al.	241/34 X
3,397,844	8/1968	Whaley et al.	241/34 X
3,401,891	9/1968	Fleeman et al.	241/34
3,630,457	12/1971	Forman et al.	241/34

Primary Examiner—Joseph F. Ruggiero
Attorney, Agent, or Firm—R. G. Brodahl

[57] **ABSTRACT**

A control system and method are disclosed for controlling the operation of a ball mill grinder device operative in conjunction with a spiral ore particle size classifier operative in a closed circuit arrangement. The sum of the new ore material feed rate and the recycled ore material feed rate of the ball mill is regulated to be substantially equal to the desired maximum material flow rate capacity of the ball mill. The desired control of the ball mill is determined in relation to the motor power consumed by the spiral classifier as a function of the recycle rate integrated over the period of screen retention time, and divided by that time, to provide the effective mean value of the recycle rate. The instantaneous value of the recycle rate, for each determined iteration time, is stored in a memory table and referenced in relation to the material retention time of the spiral classifier to establish the present recycle rate going back to the ball mill from the spiral classifier.

17 Claims, 6 Drawing Figures



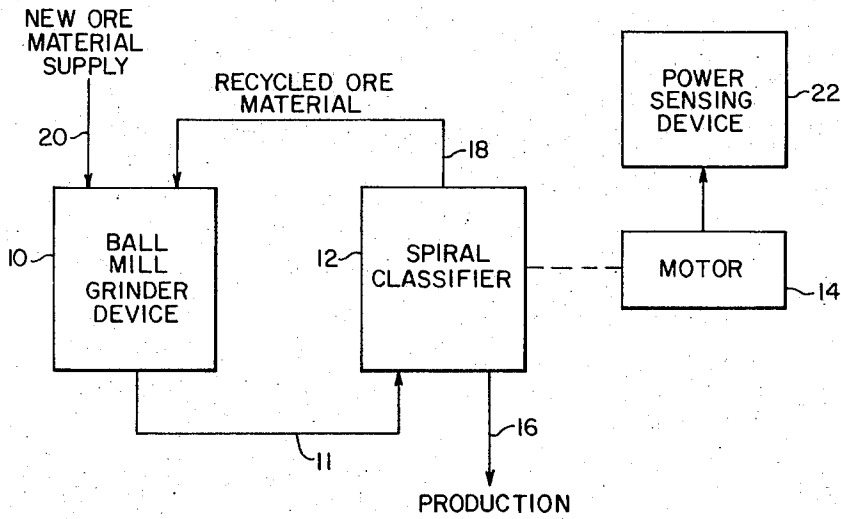


FIG. 1.

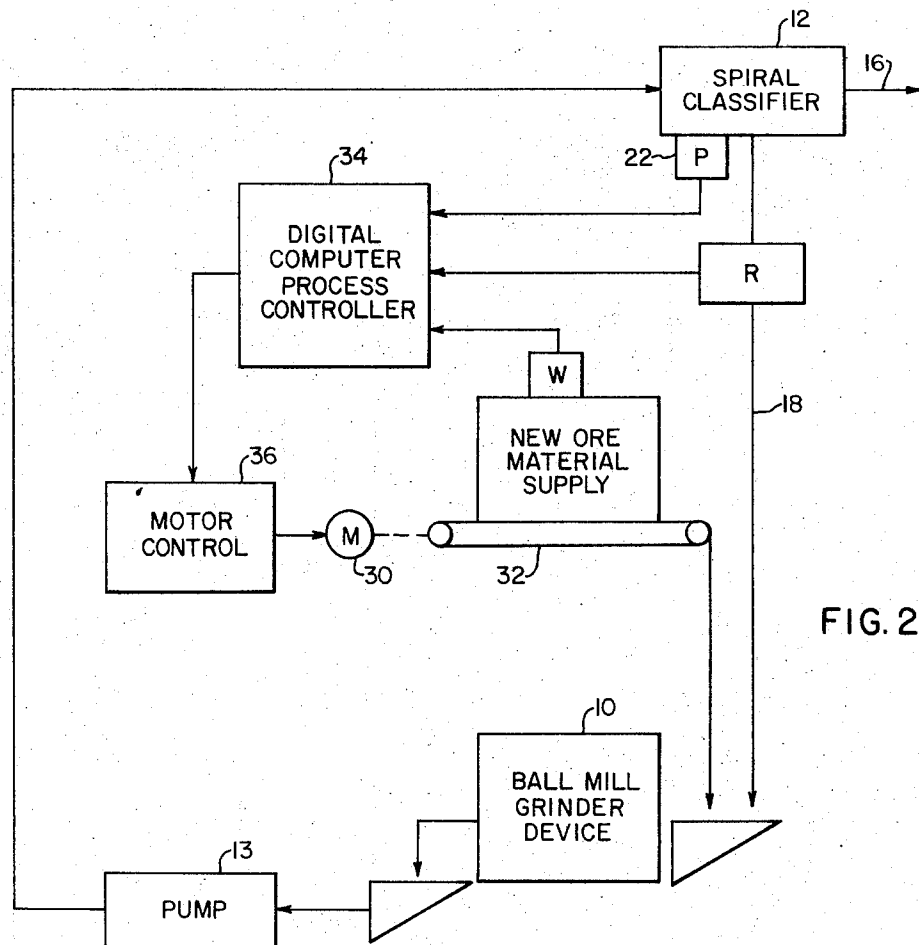


FIG. 2.

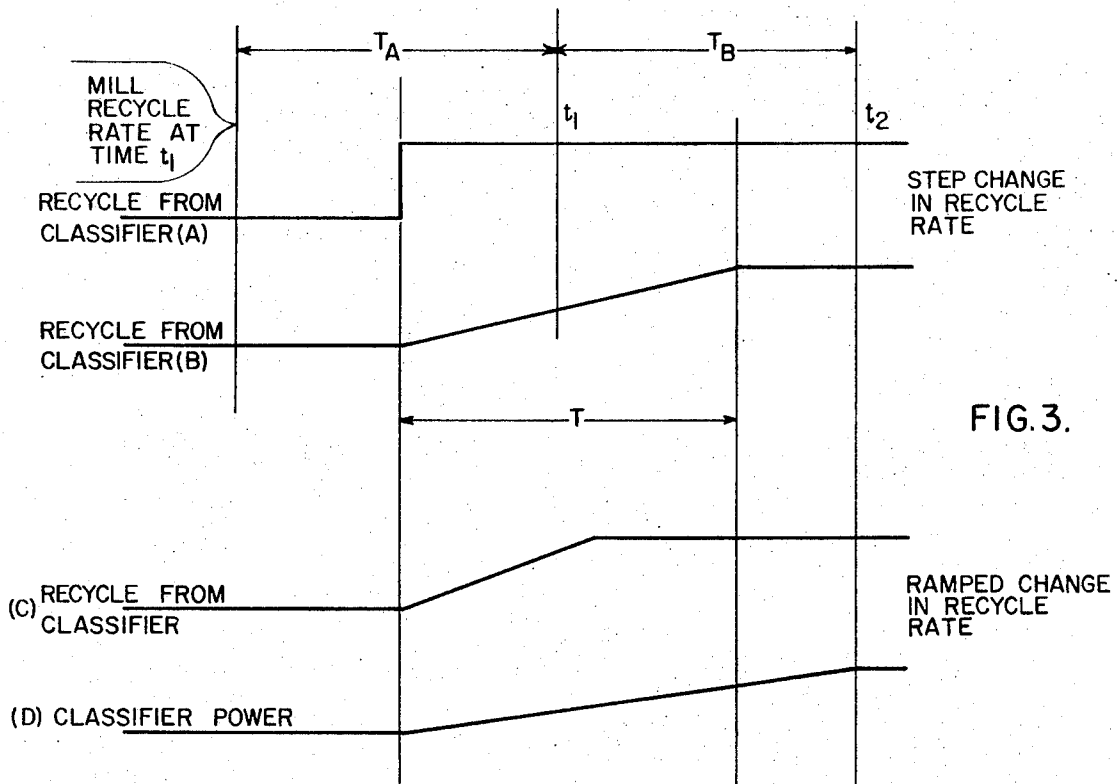


FIG. 3.

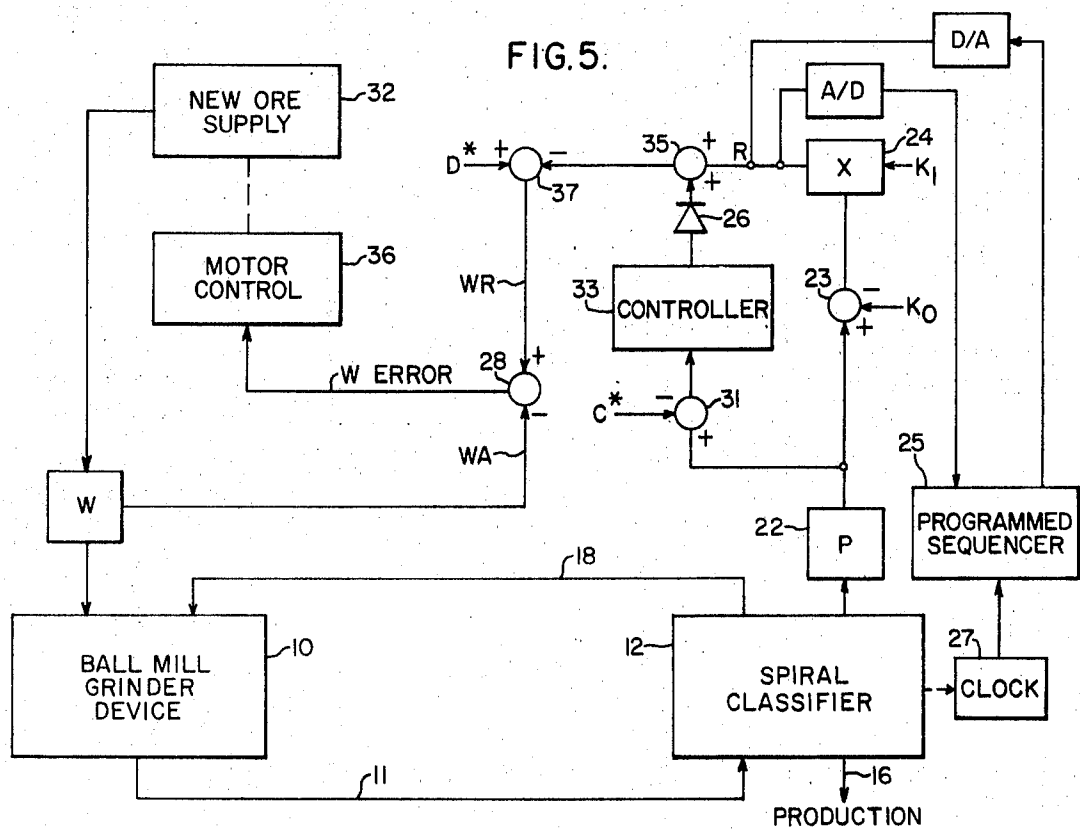


FIG. 5.

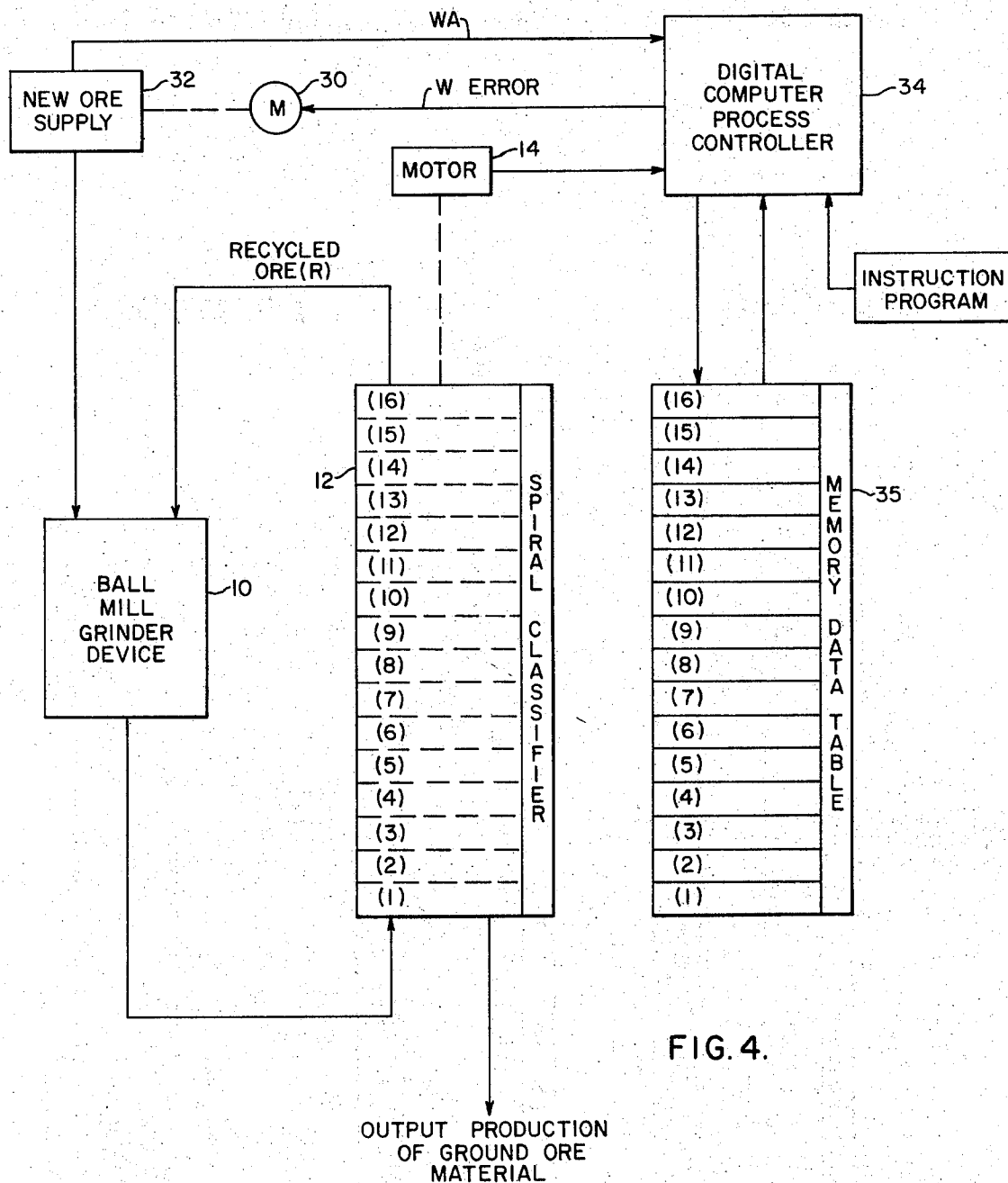
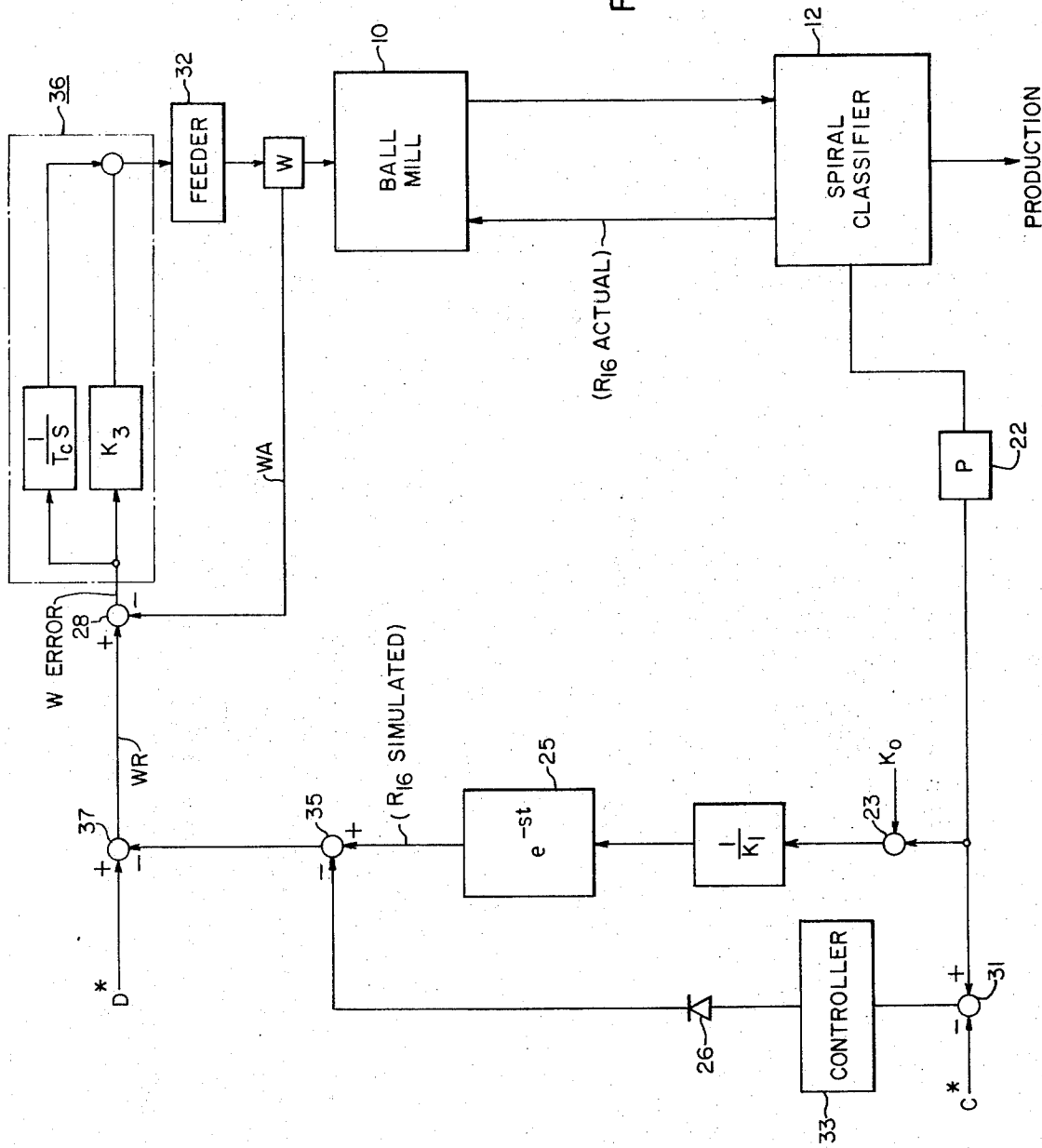


FIG. 4.

FIG. 6.



CONTROL SYSTEM AND METHOD FOR BALL MILL AND SPIRAL CLASSIFIER IN CLOSED CIRCUIT

BACKGROUND OF THE INVENTION

For the control of a grinding circuit including a spiral classifier apparatus, similar control problems are of concern with a ball mill grinding circuit including cyclones in the normal circuit. Each of these grinding circuits can be suitably controlled by regulating the sum of the new material feed rate and the recycle material feed rate, so that this sum is controlled to be substantially equal to the determined maximum material flow rate capacity of the ball mill itself. In this way, if the ore material hardness changes, or the ore material feed size distribution changes, these changes are reflected in the material recycle rate from the cyclone classifier and can be used to adjust the new material feed rate to maintain this sum substantially constant.

In the control of a cyclone ore particle size classifier, there is an almost instantaneous response between the ore material passing from the ball mill and into the cyclone classifier and then reporting to the underflow of the cyclone, but in the case of the spiral particle size classifier a time lag is present between the ground ore material leaving the ball mill discharge and reporting to the inlet of the spiral classifier and then being carried up the spiral classifier and recycled, in relation to oversize particles before this same material is recycled back to the ball mill inlet. This time delay means that in order to control the sum of the new ore material feed rate and the ore material recycle rate to be substantially constant, the control program must receive data taken from the operation of the spiral classifier and delay the consideration of this data in time until the recycled ore material is coming back into the ball mill or the signal used for that recycled ore material coming back into the ball mill truly reflects the present amount of the recycled ore material that is being returned to the ball mill. There is a further problem in that with a spiral particle size classifier, a screw device is used to move the ore material sands up an inclined trough container. The previous practice in some ball mill circuits has been to use the power drawn by the motor operative with this screw device as a measure of the amount of ore material sands being processed through the spiral classifier. This reflects the total amount of sands along the whole length of the classifier screw but the sands which are at the top of the classifier entered a retention time of 4 minutes earlier, assuming that 4 minutes is a typical retention time in the operation of a spiral classifier. Thusly, the sum total of the ore material load is thereby known, but the distribution of the ore material along the length of the spiral screw can vary, such that a substantial amount of ore material may be entering the spiral classifier at the present time but a lesser amount may have entered the classifier at some earlier time period and be recycled to the ball mill at the present time. It is known that most of the ore material particle size classification function occurs within the first spiral of the screw member, since the water is introduced into the first spiral portion of the classifier device. Therefore, the determination of the recycle rate R can be reasonably established in relation to the operation of this first spiral portion, and the power difference load on the classifier motor due to the ore material sands carried by the screw member can be deter-

mined by the sum or integration of all the recycled ore material units carried by the respective spirals of the screw member. For example, if the screw member has sixteen spirals and the retention time is four minutes, then a recycle rate calculation every one-quarter minute will provide the respective ore material units carried by the spirals of the screw member and the sum of these units will indicate the total ore material load on the classifier motor.

CROSS-REFERENCE TO RELATED APPLICATIONS

A related patent application Ser. No. 241,946 was filed Apr. 7, 1972 entitled "Control System And Method For A Reversed Ball Mill Grinding Circuit," by the same inventor and assigned to the same assignee.

SUMMARY OF THE PRESENT INVENTION

A general purpose digital computer control system is programmed for the desired control of a spiral classifier operating in conjunction with a ball mill grinder device in accordance with a determined control algorithm relationship between the classifier motor power P and the ore material recycle rate R from the classifier to the ball mill inlet under steady state conditions, as represented by the following control algorithm:

$$P = K_o + (1/K_1) (R_m) \quad (1)$$

where

P is the power drawn by the loaded spiral classifier motor,

K_o is a predetermined constant related to the power drawn by the spiral classifier motor when no load of ore material is present within the spiral classifier,

K_1 is a calibration factor to convert tons per hour into power,

R_m is a steady state value of ore material recycle rate over a typical retention time T .

Under changing conditions of operation of the ball mill grinder device circuit including a spiral classifier, this control algorithm converts to the following relationship:

$$P_t = K_o + \frac{1}{K_1 T} \int_{t-T}^t R \cdot dt \quad (2)$$

where:

P_t is the power consumed by the spiral classifier and is determined in relation to the recycle rate integrated over the period of screen retention time T and divided by that time T to give the effective mean value of the recycle rate R_m . The assumption is made that the power consumed by the spiral classifier motor is a linear function of the weight of the ore material being drawn up the screw regardless of how this total ore material weight is distributed along the length of the screw.

K_o represents the power drawn by the spiral classifier when there is no ore material load on the screw.

The digital computer control program is operative to infer R from P , with K_o and K_1 having been established previously by actual experiment with the ball mill grinder device operating in conjunction with the spiral

classifier. If the instantaneous value of R can be known for any point in time t , then the present recycle rate R_N can be found by referring to a memory data storage table containing values of the recycle rate R for each of predetermined iteration periods and vectoring down that data storage table to the value R_N inserted t minutes earlier.

BRIEF DESCRIPTION OF THE DRAWINGS

In FIG. 1 there is provided a block diagram of a ball mill grinder device operative with a spiral classifier.

In FIG. 2 there is schematically shown a digital computer process controller operative in accordance with the teachings of the present invention for controlling the operation of a motor operative such that the supply of new ore material is regulated in accordance with the recycle rate of oversize particle material from the spiral classifier such that the ball mill grinder device is operated at its desired maximum flow rate capacity.

In FIG. 3 there is provided a curve chart to illustrate a step change in recycle rate with the resulting variation of the classifier motor power and a ramped change in recycle rate with the resulting variation of classifier motor power.

In FIG. 4 there is provided an illustration of the memory data storage table maintained in conjunction with the iterative sampling of the actual ore material passing through the spiral classifier such that a determination of the amount of recycled ore passing back to the ball mill grinder device can be provided for the desired control of the ball mill grinder device in accordance with the teachings of the present invention.

In FIG. 5 there is provided an analog control system arrangement for a ball mill grinder device in accordance with the teachings of the present invention.

In FIG. 6 there is shown a transfer function block diagram to illustrate the teachings of the present invention.

DESCRIPTION OF A PREFERRED EMBODIMENT

The control of a ball mill grinder device circuit including a spiral particle size classifier can be provided in accordance with an established relationship between the spiral classifier motor power P and the ore material recycle rate R from the classifier to the inlet of the ball mill, which under steady state conditions is represented by the above control algorithm equation (1):

$$P = K_o \pm (1/K_1) (R_m)$$

(1)

Under changing conditions this process control algorithm converts to the equation (2):

$$Pt = K_o + \frac{1}{K_1 T} \int_{t-T}^t R \cdot dt$$

(2)

which establishes the power consumed by the spiral classifier at time t as the sum of the power required by the spiral classifier with no load of ore material passing through the classifier and the integral of the recycle rate over a period of screen retention time T divided by that time to give the effective mean value of the recycle rate R_m .

From the above control algorithm equation (1) the change in classifier load can be deduced from the following relationship:

$$\Delta R = R_1 - R_{N+1} = K_1 (P_1 - P_2) \quad (3)$$

where the subscripts represent the entries in a memory storage data table N items long for an iteration interval ΔT , and where the quantity $(N \Delta T)$ equals T . By rearranging the above equation (3), the following relationship can be obtained:

$$R_1 = K_1 (P_1 - P_2) + R_{N+1} \quad (4)$$

However, due to the possibility of accumulative errors, it is not desirable to rely upon equation (4) alone. The control algorithm must also reflect the factors of equation (2) so far as the present value of P is concerned. A ratio β of the present value of R_m computed from above equation (1) to the sum of R_1 through R_N can now be found such that equation (5) provides:

$$\beta = \frac{K_1 (P_1 - K_o)}{\frac{1}{N} \sum_{i=1}^N R_i} \quad (5)$$

where all of the stored values of R_i are now multiplied by β so as to bring the table into correspondence with the present spiral classifier motor load.

The general purpose digital computer system control program instruction listing provided in Appendix A sets forth (a) the initialization of the control algorithm operation to set up the ore material recycle rate numbers in the memory storage table and (b) the control algorithm manipulation of data in the memory storage table. The actual application program instruction listing for real time control of a ball mill grinding circuit including a spiral particle size classifier by a general purpose digital computer system, would include the additional functions such as data input and output programs and the like as well known to persons skilled in this art.

In lines 100-210 of the program listing, there is set up the actual load being fed to the classifier inlet at one-fourth minute intervals. Thus, between subscripts 1 and 20, the load is constant at 200 T/H; a step change occurs at subscript 21 to a load of 210 T/H which is held constant through subscript 40; followed by a ramped rise, etc. The effect of noise is simulated by the function DNORMI(0) in lines 120 and 210.

In lines 220-260 of the program listing, the program computes classifier power in accordance with equation (2) above. In this example, it has been assumed that $K_o = 0.0$ and $K_1 = 0.05$.

In line 310 there is computed R_1 in accordance with equation (4).

In line 340 there is reflected equation (5).

In Line 350 there is multiplied previous values of R by β .

The typical memory storage data table provided in Appendix B illustrates an operation of a ball mill

grinder device. Initially, data entry lines 1 through 20 correspond to a constant 200 tons/hour desired maximum material flow rate capacity for the ball mill, with the calculated power consumed by the spiral classifier motor being included in the first column. The second column is the actual ore material feed-in to the ball mill device from the new ore material supply. The third column is the computed feed-in which represents the product of the correction factor β times the actual feed-in. The fourth column represents the recycle rate R from the spiral classifier to the ball mill device, such that 16 iteration periods are provided between the data entry in the third computed feed-in column as compared to the fourth "recycle rate to the ball mill" column. In the print out there is shown the correspondence between actual and computed values and also how the numbers would be picked off the map so that the present recycle to the mill can be estimated from the feed rate 4 minutes and 16 program iterations earlier.

In accordance with the teachings of the present invention, an interpretation of the spiral classifier motor power provides a meaningful estimate to determine the ore material being recycled to the ball mill grinder device at the present time, even though this ore material entered the spiral classifier a typical retention time T of 4 minutes earlier. For this purpose, an integration is made of the amount of ore material entering during each iteration period within the retention time of 4 minutes, and the power drawn by the spiral classifier is related to that integrated amount. This integration of the ore material loading would be the same as though the mean ore material load for each iteration time period had been present during the whole of the 4-minute retention time T . There is an attenuation effect, even though there may be a step change in the material recycle rate from the classifier to the ball mill as shown by curve A in FIG. 3, between the mill recycle rate and the classifier motor power. If the amount of recycled ore material can be determined, there is no problem in effecting the desired control of the ball mill grinder device operation. The constraint for the operation of the spiral classifier is on the motor load.

The above equation (1) represents the desired control relationship to be provided between the motor power drawn by the spiral classifier motor and the effective mean recycle rate R_m , where K_0 is the power drawn with no material sands moving up the spiral of the classifier and R_m is the constant or steady state value of the material recycle rate back to the ball mill over a retention time T such as 4 minutes. K_1 is a calibration factor to convert tons/hour into power, such that $1/K_1$ is the provided gain on the control system. The retention time T is a variable and in a practical application would be determined in relation to the actual rotation of the classifier spiral which may be $2\frac{1}{2}$ revolutions per minute and in relation to the number of spirals along the length of the classifier to establish the actual retention time of a given unit portion of ore material passing through the classifier. An ideal data iteration interval would be one rotation of the classifier spiral, because then the motor power over one revolution would integrate out to give the mean power per cycle of the classifier spiral.

The memory data storage table provides typically 16 pieces of data for each retention time T . Thusly, P is the mean power over one revolution of the spiral and if the

recycle rate is changing, the equation (2) relationship applies where the power at time t is equal to $K_0 + 1/K_1$ times the integral of R between t and $t-T$, which represents the integral over the last N iterations of the recycle rate with respect to time. In this way, R is inferred from P , with p being measured with a hall effect amplifier or some other suitable well-known kilowatt transducer. The constant K_0 is measured experimentally when the spiral classifier is operating with no ore material load.

The memory data table shown in Appendix B includes N iterations where N is chosen as 16. The values of P in column 1 are converted to recycle rate R as shown in column 2 through the use of above equation (2). The column 3 corrected data is determined by multiplying the data in column 2 by the calculated conversion factor β as shown in above equation (5). The data shown in column 4 is the recycle rate to the ball mill, vectored down for the provided 16 iterations during a typical retention time T such that the column 4 indication is the ore material recycle rate leaving the spiral classifier and returning to the inlet of the ball mill grinding device.

The power at any time is utilized to establish the recycle rate R by the above equation (2) in relation to the integration of the recycle rate over the previous 4-minute retention time including 16 iterations of data. It should be understood that it is not critical how the ore material is distributed physically along the length of the spiral classifier, such that a larger amount of ore material can be present in the middle and smaller portions of ore material at the ends of the spiral classifier. The integration of this ore material will remain the same regardless of the ore material distribution. Thusly, between any two iterations, the difference in the ore material recycle rate between what is coming into the classifier R and what is leaving the spiral classifier and going to the ball mill R_1 can be determined from above equation (4) in relation to the change in power $(P_1 - P_2)$ times a constant K_1 . The latter relationship reflects the change in the recycle rate between what is coming in and what is going out of the spiral classifier. Thusly, in equation (4) there is set forth the recycle rate R_1 of ore material now going back into the ball mill grinding device, in relation to K_1 times the difference in power $(p_1 - p_2)$ plus what ore material is now entering the spiral classifier device R_{N+1} . The relationship of above equation (4) is rather sensitive in actual control operation, in that the quantity $(P_1 - P_2)$ can be a rather small number and there is a likelihood of error in the resulting control operation using above equation (4). Thusly, the correction factor β as determined in equation (5) in relation to the quantity K_1 times the present value of power P_1 minus the no load constant K_0 to represent the mean effective recycle rate now as the integration over all that was previously determined and divided by the summation of all the recycle rate values stored in the data table and shown in column two of Appendix B. If the correction factor β is now multiplied times the data values in the column two, the computed recycle ore material R_m is determined as a function of the current total power as a technique for correcting past errors. Thusly, β is the ratio of the present mean effect of recycle rate divided by the sum of the assumed recycle rates for the previous 16 iterations as determined by above equation (4). R_1 is the recycle rate at location 1 in the data table,

with the data table having 16 data storage locations. Thusly, there is placed in column two of the above illustrated Appendix B data table at location 1 the data for R_1 , which is the estimated recycle rate at the present time calculated according to above equation (4). There is already stored in column two the previous iteration data at table locations 2 through 16, with the data R_2 corresponding to the recycle rate one iteration earlier and calculated according to equation (4). While the data for recycle rate R_{16} stored in table location 16 was the recycle rate 16 iterations earlier, it should be realized that it has been multiplied successively by β for each iteration or for 16 recycle rate calculation occurrences. Thusly, every time a new data value for recycle rate is place in table location 1, there is a consideration of all the data in the other 15 table data storage locations, which perhaps do not equal R_m calculated according to equation (1) when they should equal R_m , and the correction factor β is utilized to modify all of these earlier calculated values of recycle rate as desired. Thusly, when the recycle rate R_1 is calculated at the present time and stored in data location 1 in column two of the storage table, which for purposes of example can be assumed to be 150 tons an hour, when this value of R_1 is modified by the correction factor β it may become 151.5 tons an hour such that the correction factor β adapts the information in column two as estimated by the operation of equation (4) into the real time value of the material recycle rate as represented by above equation (1). Thusly, equation (4) provides an estimate of the material recycle rate based upon a change in the spiral classifier motor power, and the sum of all the changes over the past 16 iterations as calculated should be equivalent to the real time ore material recycle rate, to provide the desired real time average recycle rate.

The desired maximum material flow rate capacity of the ball mill device is determined experimentally by running the ball mill with increasing amounts of new ore material supplied to the ball mill circuit until the ball mill chokes, and then reducing this flow rate slightly to allow a desired margin of operational tolerance. Once this desired maximum capacity is established, it does not change and the real time variable of the process operation is the ore hardness changes and the like which are reflected in the calculated recycle rate to the mill. Once the iterated recycle rate of ore material coming back to the ball mill is established as set forth in column 3 of Appendix B and transposed as set forth in column 4, the new ore material supply is controlled in accordance with the sum of the iterated recycle rate and the new feed rate being held substantially equal to the desired maximum capacity of the ball mill grinding device.

The above data table shown in Appendix B illustrates the operation of the control of the ball mill grinding device circuit in accordance with the teachings of the present invention for a first new ore material supply to the circuit of a constant 200 tons/hour, which is then increased at data lines 21 through 40 as a step function to a constant 210 tons/hour, and at data lines 41 through 60 this is increased at a ramp up to 220 tons/hour, and for data lines 61 through 70 is held constant at 220 tons/hour, and then for data lines 71 through 100 is ramped down to 205 tons/hour and for data lines 101 through 119 is held constant at 205 tons/hour. This data table example is provided for the purpose of illus-

trating the control system operation of the present invention.

The ball mill grinding device control system in accordance with the teachings of the present invention prevents overloading of the ball mill because the recycle rate is not allowed to become greater than desired, such that the ball mill is not permitted to choke and in effect it permits the ball mill circuit to operate much closer to its desired maximum ore material throughput.

In FIG. 1, there is shown a new ore material supply 20 operative with a ball mill grinder device 10 connected in circuit with a spiral particle size classifier 12, such that the ground ore material leaving the ball mill grinder device passes through a conduit 11 to the spiral classifier 12 and the resulting output production material having a particle size less than the provided cutoff of the spiral classifier leaves through conduit 16 as overflow production and the particle size material larger than the provided desired cutoff passes through conduit 18 as recycled ore material back to the ball mill grinder device 10. A motor 14 is operative to drive the spiral classifier 12, and a power sensing device 22 provides an output signal in accordance with the present load on the motor 14.

In FIG. 2 the ball mill grinder device 10 is shown operative with the spiral classifier 12, with a pump 13 being provided to pump the ore material slurry leaving the ball mill grinder device to the spiral classifier 12. The output production overflow leaves through the conduit 16, while the oversize recycled ore material passes through the conduit 18 back to the inlet of the ball mill grinder device. The new ore material supplied to the ball mill circuit is determined by the operation of a motor 30 operative with a conveyor 32 or the like, with a digital computer process controller 34 sensing the operation of the ball mill grinder circuit in accordance with the teachings of the present invention for determining the operation of the motor 30 through a suitable motor control 36 such that the sum of the recycle ore material feed rate R through the conduit 18 and the new material feed rate W determined by the operation of the motor 30 and the conveyor 32 is controlled by the digital computer process controller 34 to be equal to the predetermined desired maximum material flow rate capacity of the ball mill grinder device 10.

In FIG. 3, curve A illustrates a step change in the recycled material passing from the spiral classifier to the ball mill grinder device, and curve B illustrates the resulting change in the classifier motor load power P . Curve C illustrates a ramped change in the ore material recycle rate R from the spiral classifier to the ball mill grinding device and curve D illustrates the resulting change in the classifier motor load power P .

In FIG. 4, there is schematically illustrated the data table stored in the memory of the digital computer process controller 34, which data table corresponds to column 4 of Appendix B. As the ground ore material passes from the ball mill grinder device 10, it enters the spiral classifier 12 at the section indicated as "1" for the first rotation or iteration of the spiral classifier, after which it passes to the section 2 and then successively through the 16 physical sections of the spiral classifier corresponding to spirals of the screw driven by the motor 14 and operative to move the ore material through the spiral classifier 12. In the memory data table 35, the calculated ore material recycle rate as shown in column 3 of Appendix B, which is modified

by the correction factor β to adjust the estimated recycle rate as shown in column 2 to the real time recycle rate as shown in column 3, is entered into the data table section 1 and is succeedingly moved through the data table such that the real time recycle rate in data table section 16 corresponds to the actual material in the spiral classifier section 16 that will be recycled to the inlet of the ball mill grinder device during the next iteration period. The digital computer process controller 34 utilizes this data from the memory data table 35 in conjunction with the sensed supply of new ore material for the ball mill grinder device such that the sum of the new ore material W plus the actual recycled ore material R to the ball mill grinder device is made equal to the predetermined and desired maximum flow rate capacity of the ball mill grinder device.

In FIG. 5 there is shown an analog control system operative with a ball mill grinder device 10 in a closed circuit arrangement with a spiral classifier 12 which spiral classifier is driven by motor 14. The motor power P , as sensed by the power sensing device 22, is related to the total amount of ore material supplied to the spiral classifier 12. The quantity K_0 is related to the amount of power required to operate the classifier 12 when there is no ore material passing through the classifier 12. The output of the summing junction 23 indicates the difference power required for moving the load of ore material through the classifier 12. At multiplier 24 the product of the factor K_1 with the difference power provides an indication of the amount of recycle material R actually so moved by that difference power. The analog signal R is converted into a digital signal and entered into the programmed sequencer 25 operative with a clock 27, which may include a contact switch responsive to revolutions of the spiral within the spiral classifier. The programmed sequencer 25 functions to retain the iterated recycle rates for a desired retention time and then outputs a digital signal in accordance with the present ore material recycle rate from the spiral classifier 12 to the ball mill grinder device 10. This digital signal is converted to analog and supplied to summing junction 35.

In relation to the principal constraint on the grinding circuit being the ball mill grinder device throughput, that is, the sum of the new feed rate plus the recycle rate, this constraint is almost independent of mill feed size distribution and ore grindability and is a stabilizing influence if controlled substantially constant in that the retention time or the retention time distribution thereby also remains substantially constant. For the analog control circuit arrangement as shown in FIG. 5, the quantity R is the ore material recycle rate from the spiral classifier to the ball mill grinder device. The quantity P is the classifier motor power as sensed by the device 22. W is the new ore material feed rate from the new ore supply 32 as determined by a motor control 36. The quantity D is the desired total ball mill grinder device load and the quantity C is the maximum allowable power for the motor of the spiral classifier 12. The relationship of the ore material recycle rate R to the classifier motor power P under steady state conditions as shown by above control algorithm equation (1) can be represented by the following:

$$R = K_1 (P - K_0).$$

(6)

To hold the grinding ball mill device throughput substantially constant under normal conditions, the following relationship can be provided:

$$W = D - R.$$

(7)

Should the classifier motor power P tend to exceed the maximum allowable motor power C , the new ore feed rate W should be reduced in an effort to cause the classifier motor P to assume the same value as the maximum allowable power C . Thusly, control equation (7) can be rewritten as follows:

$$W = D - R - K_2 (p - C) dt$$

(8)

The integral term of the above equation (8) is inhibited from becoming negative, so that it would be inoperative as soon as the integral term had dropped to zero, in reference to the control circuit arrangement shown in FIG. 5 by the diode 26 which functions to inhibit the integral term from becoming negative.

The control arrangement shown in FIG. 5 is operative in accordance with above control equation (8) to provide a reference value W_R for the new ore feed rate which is compared at summing junction 28 with the sensed actual value W_A of the new ore feed rate from the supply 32 to the ball mill grinder device 10. The junction 31 provides the difference relationship $(P - C)$ and the controller 33 provides the desired integral quantity K_2 times the integral of $(p - C)$ in relation to time dt . The summing junction 35 provides the quantity $R + K_2$ times the integral of $(p - C) dt$, and the summing junction 37 provides the relationship in accordance with the above control equation (8). The reference value W_R of the new ore material feed rate for controlling the operation of the ball mill grinder device circuit including the spiral classifier is thereby provided.

In FIG. 6 there is shown a transfer function block diagram to illustrate the teachings of the present invention in regard to the functional relationships between the provided control parameters and operation and the controlled ore material grinding process. The block diagram illustrates the transfer functions which are time dependent and also the summing nodes or multipliers where the effects are not time dependent. Where the time variable is considered, a Laplace operator is provided. A desired set point D for the total load on the ball mill is compared at summing node 37 in accordance with control equation (8) to provide an ore material feed rate reference signal W_R . At summing node 28 the actual feed rate W_A is compared to provide a feed rate error signal as the set point for a feed controller 36. The latter feed controller 36 has both a gain K_3 and a reset function represented by $1/T_c S$ with S being the Laplace operator. The gain and the reset are summed and the output controls the new ore supply 32 for controlling the feed rate of the ore material going to the ball mill 10. The actual feed rate represented by W_A comes back as a negative feedback. The controlled process includes the mill and the spiral classifier in series. The operation of the spiral classifier 12 is reflected in the power signal P . At summing node 23, the no load power K_0 is subtracted and then multiplied by $1/K_1$ to transform power into a signal reflecting the instant-

neous recycle rate. The transfer function 25 represents a distance velocity, where e^{-st} is the Laplace form of the distance velocity lag, so the output is now related to the input but displaced in time, which is what this transfer function does. The summing node 31 is provided as an override to prevent overloading of the spiral classifier motor. The motor power P is compared with the maximum allowable power C and should this resultant become positive as would happen if power became excessive, the output would start reducing the rate of feed to limit the motor power to some maximum value. The summing nodes can be operational amplifiers or they can just be resistors in which the voltages are subtracted. The distance velocity lag is provided by taking the analog input signals and converting them to a digital form and simulating the distance velocity lag by use of the memory storage table which is being continuously updated, and the output has to be converted back to analog form to be operative with the analog controller. Alternatively, as shown in FIG. 4, this whole control arrangement can be implemented digitally, as well known to persons skilled in this art.

APPENDIX A

```

SCREEN      04/10/72
100 DIMENSION P(200),W(200),X(200)
110 DO 1 I=1,20; W(I)=200.0
120 W(I)=W(I)+0.01*DNORM1(0)
130* DNORM1(0) INTRODUCES "NOISE" ON THE
WEIGHT SIGNAL
140 P(I)=W(I)/20.0
150* P(I) IS THE POWER IN KILOWATTS
160 I X(I)=P(I)*20.0
170* STEP AND RAMP CHANGES IN INLET RE-
CYCLE RATE TO SCREEN
180 DO 2 I=21,40; 2 W(I)=210.0; DO 3 I=41,60; 3
W(I)=W(I)-1)+0.5
190 DO 4 I=61,70; 4 W(I)=W(I)-1)+0.0; DO 5
I=71,100; 5 W(I)=
200 &W(I-1)-0.5; DO 6 I=101,130; 6 W(I)=W(I-
1)+0.0
210 DO 50 I=21,130; 50 W(I)=W(I)+0.01*D-
NORM1(0)
220* COMPUTE POWER DURING CLASSIFIER
LOAD CHANGES
230 DO 9 I=20,130; N=I-15; P(I)=0.0
240 DO 7 J=N,I
250 7 P(I)=P(I)+0.05*W(J)/16.0
260 9 CONTINUE
270*
280 PRINT,"ENTER NO. RUNS"; INPUT, ITGT
290 N1=4; n2=1
300 I=20; 8 IF(I-ITGT-19) 10,1000,1000; 10 I=I+1
310 X(I)=20.0*16.0*(P(I)-P(I-1))+X(I-16)
320 TOT=0.0
330 N1=I-15
340 DO 11 J=N1,I; 11 TOT=TOT+X(J)*0.0625;
FACT=20.0*P(I)/TOT
350 DO 12 J=N1,I; 12 X(J)=FACT*X(J); GO TO 8
360 1000 DO 13 J=1,20; 13 PRINT
300,J,P(J),W(J),X(J)
370 DO 14 J=21,I; 14 PRINT
310,J,P(J),W(J),X(J),X(J-16)
380 300 FORMAT(1H,16,5X,3F15.7)
390 310 FORMAT(1H,16,5X,4F15.7)
400 STOP: END

```

APPENDIX B

Screen 17:17EST 04/10/72

Enter No. runs? 100	(Power)	(Actual feed)	(Computed feed)	(Recycle rate)
1	10.0005010	200.0100327	200.0100327	
2	10.0004061	200.0081234	200.0081234	
3	10.0005432	200.0108643	200.0108643	
4	9.9983369	199.9967384	199.9967384	
5	10.0005020	200.0100403	200.0100403	
6	10.0004246	200.0084915	200.0084806	
7	9.9980349	199.9926968	199.9926968	
8	10.0007346	200.0140004	200.0146885	
9	9.9971000	199.9941908	199.9941908	
10	9.9970647	199.9952927	199.9952908	
11	10.0000163	200.0003202	200.0003223	
12	10.0000002	200.0130032	200.0130013	
13	10.0003437	200.0008741	200.0008684	
14	9.9980350	199.9987125	199.9987008	
15	10.0005491	200.0100806	200.0100768	
16	9.9983412	199.9863240	199.9868202	
17	10.0005314	200.0106277	200.0106077	
18	10.0002307	200.0046139	200.0046101	
19	9.9904873	199.9897461	199.9897461	
20	10.0001305	200.0040665	200.0040664	
21	10.0313008	200.0874191	200.0874191	200.0100403
22	10.0625156	200.9943733	200.9943371	200.0084806
23	10.0037237	200.9792404	200.9792690	199.9926968
24	10.1249714	210.0139618	210.0139637	200.0146885
25	10.1562454	210.0018673	210.0018673	199.9941998
26	10.1874539	209.9820290	209.9820156	199.9952908
27	10.2186816	209.9932276	209.9931889	200.0003223
28	10.2498863	209.9990826	209.9991093	200.0130013
29	10.2811724	210.0184078	210.0184307	200.0086884
30	10.3124092	209.9944324	209.9944725	199.9970668
31	10.3436041	209.9933643	209.9933529	200.0100768
32	10.3748019	209.9980433	209.9980128	199.9868202
33	10.4061338	210.0080318	210.0080209	200.0106277
34	10.4373189	209.9838715	209.9838600	200.0046101
35	10.4686154	210.0046291	210.0046177	199.9897461
36	10.4908475	209.9983521	209.9983444	200.0040664
37	10.4908546	209.9896526	209.9896669	200.0874191
38	10.4908617	209.9966469	209.9966297	200.9943371
39	10.4908928	209.9892216	209.9892216	200.9792690
40	10.4908850	210.0114288	210.0114460	210.0139637
41	10.5014780	210.0116310	210.0116196	210.0018673
42	10.5040446	210.9953594	210.9953480	209.9820156
43	10.5094002	211.5150204	211.5149860	209.9931889
44	10.5150078	211.9855099	211.9855328	209.9991093
45	10.5230778	212.5048618	212.5048103	210.0184307
46	10.5327526	212.9943848	212.9944286	209.9944725
47	10.5437430	213.5102291	213.5102806	209.9933529
48	10.5562309	213.9950600	213.9950409	209.9980128
49	10.5702715	214.5010452	214.5010204	210.0080299
50	10.5859348	214.9961224	214.9961033	209.9838600
51	10.6031322	215.5077953	215.5078201	210.0046177
52	10.6218996	216.0038986	216.0038986	209.9983444
53	10.6422712	216.5085545	216.5085640	209.9896669
54	10.6641511	216.9982033	216.9982014	209.9966297
55	10.6876519	217.5095139	217.5094776	209.9892216
56	10.7125945	217.9930916	217.9930935	210.0114460
57	10.7376291	218.5226898	218.5226784	210.0116196
58	10.7626255	218.9942074	218.9941998	210.9953480
59	10.7875900	219.5036716	219.5036526	211.5149860
60	10.8125924	219.9862347	219.9862347	211.9855328
61	10.8360926	220.0249310	220.0248795	212.5048103
62	10.8579936	220.0027256	220.0027504	212.9944286
63	10.8782332	219.9869194	219.9869480	213.5102806
64	10.8969729	219.9917793	219.9917893	213.9950409
65	10.9141582	220.0003624	220.0003262	214.5010204
66	10.9297044	219.9996891	219.9996891	214.9961033
67	10.9438490	220.0052738	220.0052662	215.5078201
68	10.9563342	219.9991589	219.9991798	216.0038986
69	10.9672168	219.9900611	219.9910030	216.5085640
70	10.9765522	219.9855499	219.9855251	216.9982014
71	10.9827261	219.4851017	219.4851131	217.5094776
72	10.9858505	218.9958038	218.9957809	217.9930935
73	10.9857829	218.4981632	218.4981499	218.5226784
74	10.9826536	217.9928436	217.9928308	218.9941998
75	10.9764458	217.5171700	217.5171471	219.5036526
76	10.9671230	217.0020335	217.0030041	219.9862881
77	10.9560040	216.4956799	216.4955940	220.0248795
78	10.9435802	216.0012035	216.0012150	220.0027504
79	10.9295356	215.4897785	215.4897095	219.9860480
80	10.9138495	214.9722252	214.9721737	219.9917303
81	10.8967249	214.5205116	214.5204792	220.0003262
82	10.8779500	213.9916687	213.9916035	219.9996891
83	10.8576322	213.5035801	213.5035782	220.0052662
84	10.8357254	212.9890404	212.9890289	219.9991798
85	10.8128068	212.4969073	212.4970341	219.9910030
86	10.7878192	211.9895115	211.9895020	219.9855251
87	10.7623033	211.4992332	211.4992332	219.4851131
88	10.7373848	211.0027084	211.0026509	218.9957809
89	10.7124044	210.5044250	210.5044098	218.4981499
90	10.6874820	210.0176544	210.0176849	217.9928308
91	10.6623797	209.4844265	209.4844284	217.5171471
92	10.6374177	209.0150471	209.0151443	217.0030041
93	10.6124035	208.4911423	208.4910622	216.4955940
94	10.5874583	208.0187397	208.0187283	216.0012150
95	10.5624727	207.4943081	207.4944267	215.4897095
96	10.5375447	206.9952660	206.9952240	214.9721737
97	10.5124710	206.4960387	206.4968700	214.5204792
98	10.4875556	206.0186977	206.0187855	213.9910035
99	10.4625497	205.5016937	205.5016747	213.5035782
100	10.4375850	205.0003338	205.0003281	212.9890289

What is claimed is:

1. In a control system for an ore grinding circuit including at least one particle size spiral classifier operative with a ball mill grinding device, the combination of means for sensing the motor power of said classifier in relation to the ore material passing through said spiral classifier for each of a plurality of iteration periods related to the function operation of said spiral classifier, means for sensing the actual supply of new ore material to said ball mill grinding device, stored program control computer means for determining the recycle rate of ore material from said spiral classifier to said ball mill grinding device in relation to said motor power for at least a predetermined one of said iteration periods, and means for controlling the desired supply of new ore material to said ball mill grinding device for said one iteration period in accordance with a predetermined relationship including said actual supply of new ore material and said recycle rate of ore material.

2. The control system of claim 1, with the determination of the recycle rate being in accordance with the relationship:

$$P_t = K_0 + \frac{1}{K_1 T} \int_{t-T}^t R \cdot dt$$

where P_t is the motor power of the spiral classifier at time t , K_0 is the power required by the spiral classifier with no load of ore material passing through the classifier and the integral of the recycle rate R over the period of ore material retention time T including said plurality of said iteration periods sets forth the motor power in relation to the ore material recycled from said classifier to said ball mill grinding device.

3. The control system of claim 1, with said desired supply of new ore material to said ball mill grinding device being controlled in accordance with the relationship:

$$W_{error} = W_R - W_A$$

where W_R is determined in relation to a comparison of the desired total load of the ball mill grinder device with the ore material recycle rate and where W_A is the actual supply of new ore material.

4. The control system of claim 1, with said stored program control computer means for determining the recycle rate being responsive to the operation of said classifier such that a recycle rate is established for each of said plurality of iteration periods related to the functional operation of said classifier, and with said sensed motor power of the classifier being representative of the sum of all the determined recycle rates during a predetermined ore material retention period including said plurality of iteration periods.

5. A control system for an ore material grinding circuit including a spiral classifier operative with an ore material grinding device, said control system including means for sensing the motor power of said classifier in relation to each of a plurality of iteration periods

related to the functional operation of said classifier,

means for sensing the actual supply of ore material to said grinding device,

stored program control computer means for determining the recycle rate of the ore material returning to said grinding device for each of said iteration periods in relation to said motor power of said classifier and for determining a desired supply of ore material to said grinding device for each of said iteration periods in relation to said recycle rate and said actual supply of ore material, and

means for controlling the supply of ore material to said grinding device for each of said iteration periods in accordance with said desired supply of ore material.

6. The control system of claim 5, with said stored program control computer means for determining the recycle rate being operative to determine a recycle rate for each of said plurality of iteration periods related to the functional operation of said classifier such that said motor power is related to the sum of all the recycle rates during a predetermined ore material retention time period including said plurality of iteration periods for said classifier.

7. A method for controlling an ore material grinding circuit including at least one spiral classifier operative with a ball mill grinding device, said method including the steps of

sensing the motor power of said classifier in relation to the ore material passing through said classifier for each of a plurality of iteration periods related to the functional operation of said classifier,

sensing the actual supply of ore material passing to said ball mill grinding device,

establishing the present recycle rate of ore material from said classifier to said ball mill grinding device for each of said iteration periods in relation to said motor power, and

providing a desired ore material feed to said grinding device for each of said iteration periods in accordance with a desired relationship between the actual supply of ore material and said recycle rate of ore material.

8. The method of claim 7, with the step of establishing the present recycle rate of ore material being in consideration of a predetermined relationship with the recycle rate established for each of said plurality of iteration periods related to the functional operation of said classifier.

9. The method of claim 8, with the established recycle rate for each iteration period being updated such that said motor power is related to the sum of all the updated recycle rates.

10. In apparatus for controlling a ball mill grinder device operative with a spiral particle size classifier, the combination of

means for sensing the motor power of said classifier for each of a predetermined number of iteration intervals related to the operation of said classifier with ore material passing through said classifier,

stored program control computer means for determining an ore material recycle rate from said classifier to said ball mill grinder device for each of said iteration intervals, for determining a mean recycle

rate in relation to the determined recycle rates for all of said iteration intervals, for determining a present recycle rate in relation to said motor power for the present iteration interval, and for modifying said determined recycle rates in accordance with a predetermined relationship including said mean recycle rate and said present recycle rate, and

means for controlling the new material feed rate to said ball mill grinder device in accordance with a predetermined one of said determined recycle rates.

11. The apparatus of claim 10, with said stored program control computer means determining said ore material recycle rate for each of said iteration periods in relation to a predetermined difference relationship between said sensed motor powers of said classifier.

12. The apparatus of claim 10, with said stored program control computer means determining said means recycle rate in relation to the sum of said determined recycle rates for all of said iteration intervals divided by said number of iteration intervals.

13. The apparatus of claim 10, with said stored program control computer means modifying said determined recycle rates in accordance with a predetermined ratio relationship between said mean recycle rate and said present recycle rate.

14. The apparatus of claim 10, with said stored program control computer means determining an ore material recycle rate from said classifier to said ball mill grinder device for each of said iteration intervals in accordance with the sensed change of motor power between successive iteration intervals.

15. The apparatus of claim 10, with said means for

controlling the new material feed rate to said ball mill grinder device being responsive to the determined present recycle rate of the ore material presently being recycled from said classifier to said ball mill grinder device.

16. In a control system for an ore grinding circuit including at least one particle size spiral classifier operative with a ball mill grinding device, the combination of means for sensing the motor power of said classifier in relation to the ore material passing through said spiral classifier for each of a plurality of iteration periods related to the functional operations of said spiral classifier,

means for sensing the actual supply of new ore material to said ball mill grinding device,

means for determining the recycle rate of ore material from said spiral classifier to said ball mill grinding device in relation to said motor power for each of said plurality of iteration periods, and

means for controlling the desired supply of new ore material to said ball mill grinding device for each of the iteration periods in accordance with a predetermined relationship including said actual supply of new ore material and said recycle rate of ore material.

17. The control system of claim 16, with said recycle rate established for each of said plurality of iteration periods being related to the functional operation of said classifier, and with said sensed motor power of the classifier being related to the sum of the respective determined recycle rates for said plurality of iteration periods.

* * * * *

35

40

45

50

55

60

65