

METHOD OF IMPROVING THROUGHPUT EFFICIENCY OF A ROTARY
DRUM MILL

The monitoring of a ball grinding mill or equivalent through electrical signals derived from the mill, in operation, has long been known. U.S. Patents 2,405,059; 2,766,941; 3,944,146; and 4,026,479 are
5 representative of typical monitoring systems.

Each of these systems depends upon sound signals derived from the mill operation. However, sound signals are neither pure nor primary signals, and their use leads to complex means for analysis and selection of different
10 operating characteristics. It is easily recognizable that a sound frequency, magnitude or characteristic pattern will change considerably with changes in loading, speed, material constituency, material particle size and other characteristics of the material. Also, in the mill
15 environment there are extraneous sounds which will affect such systems. Therefore for operation where significant ranges of materials and different ball mill conditions exist, a sound-operated system tends to be restricted to sensing a particular limited condition in a particular
20 mill to which it is custom tailored. It is therefore desirable to establish signals which are more universally significant and less susceptible to error from extraneous causes.

Furthermore, the sound-derived signals which are tailored to specific mill conditions are significantly altered by the physical nature of the materials being processed. Thus, for example, if a chemical additive to the raw materials affects the physical behaviour of the materials enough to improve the throughput efficiency of the mill, it also affects the sound. Thus, preselected patterns of sound signals may not properly detect material differences in throughput efficiency which should be monitored and controlled.

There are also other shortcomings of the prior art systems and methods, because the nature of the mill operation is not understood or has not been adopted as an integral part of the monitoring and control methods. Thus, for example, a number of interrelated variables may affect efficiency, such as the amount of charge of materials in the mill, the charge characteristics including the chemical additives used, and the ball grinding efficiency. Nevertheless, most systems and methods are responsive only to single control factors such as the rate of flow of materials through the mill, without regard to the grinding efficiency which could change drastically in characteristic depending upon other mill conditions. It is therefore desirable to employ control signals which are representative of complex interactions in the mill and yet are indicative of the true throughput efficiency of a uniform product.

Also it is desirable to have methods and signals available for both instantaneous on-line analysis, and long term analysis, of mill conditions. Few control methods or systems afford a compatible dual capability
5 of this sort.

Particularly for use under semi-automatic operation, with operator intervention or operator analysis of mill conditions in set up maintenance or control functions, it becomes necessary to communicate mill
10 conditions in a way that cannot be misinterpreted, or misunderstood, or overlooked. In this respect any signals or displays which make an operator depend upon the visual sensing of a particular value of a variable signal magnitude or meter reading, tend to cause operator error,
15 particularly where operators may not have significant mill operation analysis skills.

Accordingly, it is a general object of this invention to improve the prior art methods of operational control of grinding mills.

20 Accordingly, one aspect of the present invention provides a method of monitoring the operating conditions of a rotary drum type grinding mill driven by an electrical motor to grind raw materials comprising: operating the mill by means of said motor over a range of power
25 magnitudes in the presence of raw material load magnitudes which are above and below a desired raw material load

magnitude; deriving a motor power signal intermediate in said range; and controlling the raw material load magnitude in said mill in response to the derived motor power signal to maintain the motor power signal
5 substantially at the desired intermediate value which corresponds to the desired raw material load magnitude.

Another aspect of the invention provides a method of operating and monitoring an electric motor-operated rotary drum type mill, comprising:
10 establishing a desired high operating efficiency condition with a known raw material load magnitude operating at a known motor power; operating the electrical drive motor with a partial mill change at said established operating condition on an intermediate
15 portion of the motor power curve wherein the motor power decreases and increases with raw material load magnitude; deriving from the electrical power supplied to the motor a motor power signal over a range, which range includes the power at positions on either side of
20 said desired operating condition, in an intermediate position on said range; and providing control signals, responsive to the magnitude of said power signal indicative of the need for corrective action when material load conditions are below or above that of said
25 desired operating condition.

It has therefore been established in accordance with the present invention that reliable, comprehensive and convenient electrical control signals may be derived from monitoring solely the power changes 5 of an electric drive motor rotating the drum of the ball mill. Thus, the desired mill operating condition is established by the criterion of running at a constant speed with a synchronous motor while effectively grinding a desired charge, and the motor is operated in 10 that condition at an intermediate point on a variably detectable range of the power curve.

This set of conditions permits the mill to be monitored and controlled simply, as a function of the amplitude of motor power signals which are easily detected and processed, and yet which carry comprehensive mill operational characteristics including the amount of properly ground output materials used, the amount of raw material feed desirable, the load magnitude of raw materials inside the mill drum, the nature of operation of the balls (or rods), and the effect or optimum usage of chemical additives capable of increasing the mill efficiency.

The motor power signal magnitude is then processed to produce control signals for purposes of operating displays and control functions, preferably in a combination of signal magnitudes showing undershoot and overshoot of the desired mill operating condition, and enabling control either by semi-automatic operator intervention or fully automated feed of materials and chemicals to attain optimum efficiency both instantaneously and over the long term.

For long term historical operation to analyse and monitor mill performance, the instantaneous real-time signal is stored and recalled when desired.

A set of pictorial representations of actual mill conditions enabling a semi-skilled operator to understand the nature of the mill condition without

analysis or interpolation is presented in response to the motor load signals.

Thus, the present invention provides a comprehensive and reliable mill analysis and understanding from a simply derived and processed signal, namely the supply power to the motor. This invention provides a novel manner of knowing, on the basis of motor power, whether the raw material load magnitude in a mill is too great or too small, a heretofore unknown mode of operation as acknowledged by the aforesaid U.S. Patent No. 2766941.

In order that the present invention may more readily be understood the following description is given, merely by way of example, with reference to the accompanying drawings, in which:-

Figure 1 is a block system diagram of a mill control system embodying the invention; and

Figure 2 is a graph displaying mill operating conditions used in accordance with this invention, relating typical selected operational signal magnitudes to typical pictorial representations of the corresponding mill operating conditions.

As may be seen in Figure 1, a ball mill generally comprises a rotary drum 10, a separator 11, a feed line 12 to the separator and a recirculation line 13 for reintroducing coarse particles from feed line 12 and separator 11 back into the rotary drum 10. The output

grinding products passed by separator 11 are withdrawn by way of output line 14.

The rotary drum 10 is driven by the shaft 15 of an electric motor 16 having electrical supply conductors 17.

5 Typically the drum is rotated at a known constant speed ascertained by gearing (not shown) and synchronous motor speed. Such motors will draw the necessary current from conductor 17 (which presents constant input voltage) to operate at constant speed under various load conditions.

10 Thus, changes of line current will represent changes in the motor load. This parameter (current) is easily detected from an alternating current line (as represented by the ~ symbol) by means of an a-c coupled current transformer 18 about the conductor 17 so that a signal proportional to the

15 motor power is conventionally produced in a suitable detector 19. This is the sole detected signal necessary to produce a comprehensive analysis of mill conditions.

In order to understand the invention better, it is desirable to consider some of the characteristics of

20 mill operation. For this purpose reference will also be made to Figure 2, where there are two graphs having as common abscissa the load magnitude of the raw material in the rotary drum 10 driven by the motor 16 related to the charge of raw materials introduced into the drum 10 at

25 input 20 from suitable raw material feed means 21.

Similarly chemical additives may be introduced by feed means 22 to affect the power loading on the motor

indirectly, since the corresponding volumes and weights are small compared to those of the raw materials, such as clinkers from which cement is to be ground. In considering the load, therefore, the amount of recirculated raw materials along line 13 and the drum input 20 is then also a factor. It is in this respect that the chemical additives at 22 affect the loading, since they are of a type that will improve the output efficiency of ground materials at line 14. Typical chemicals used for such purposes are set forth in U.S. Patent 3,607,326.

Now consider the ordinate of Figure 2, which displays two scales representative of pertinent performance characteristics, namely for the upper graph the motor current I (proportional to motor power at constant supply voltage) and for the lower graph the grinding efficiency (Eff) on the raw materials, this latter being a function of the grinding medium, of the density of the raw materials, and of the flow pattern through the rotary drum. For better understanding of the nature of these parameters, reference is made to the simulated pictorial representations A to E. These views represent diagrammatically a transverse cross section of a drum 10 while it is rotating with grinding medium balls and raw material load, to show the materials 2 and balls 31 at various volumetric charge loadings of the

drum from underload A to overload E. The loading condition C may be considered as the desired condition. It relates to a maximum grinding efficiency at point C on the lower curve Eff and to a chosen current operation datum C on the upper current curve, I.

Referring to the lower, grinding efficiency curve, Eff, clearly for raw material load magnitudes which are either greater or less than the load magnitude for condition C, for example at points A, B, D, E, the grinding efficiency is reduced. However, the current characteristic I changes in magnitude over the entire range of points A, B, C, D, E. Thus, the current I characteristic provides a detectable control signal that can indicate whether various mill charge loads are too great or too small, thereby to permit monitoring and correction to an optimum operation characteristic.

Typically the motor current curve I will, over a measurable current range shown, decrease from an underloaded condition A to an overloaded condition E, typified by profiles of internal mill conditions. These profiles may be considered an average or integrated combination of the drum profile conditions at axial stations from one end to the other of the drum, since, as may be seen pictorially at 49 in Figure 1, the left hand input end of the drum may have a tunnel (shown as 48 in the display 49 of Figure 1, but also illustrated

in the entrance overloaded condition represented in Figure 2E). This tunnel results from overloading with input raw materials such as is shown in profile E, while the right hand end of the drum may conversely have a profile more like that of profile A, the average condition providing the preferred operating condition then being somewhat as C. These profiles A to E will be easily understood by unskilled or semi-skilled plant operators to indicate underloaded to overloaded conditions in the drum.

The pictorial drum representations depict rotation clockwise of the drum so that, as the load changes, the grinding medium balls and the hatched charge of raw material are centrifugally and frictionally carried in patterns such as indicated.

Higher motor current results when the raw material load A is lighter and lower motor current when the load E is heavier where the tunnelling effect is evident. It can be reasoned that if the balls in an overloaded condition E drop on a thicker cushioned layer of raw materials then the grinding efficiency will be less than the condition C where a ball drop will impact a thinner layer of material. Also, in the underloaded condition A the efficiency is low because the balls are hitting balls rather than raw materials.

It is evident then that both the nature of the flow pattern through the rotating drum and the mill grinding efficiency are indicatable simply in terms of the parameter of motor horsepower or current. Also, a pictorial display of the mill conditions A to E will show an operator on premises a signal giving him a full understanding of the conditions so that he may calibrate automatic feed conditions or semi-automatically control feed rates. Conversely a load current reading such as might be displayed on meter 40 would not have a similar impact and could readily be overlooked because of attention necessary to monitor a continuously variable instantaneous reading and not flag critical conditions that require operator attention and understanding. These operational characteristics are described for example in the Cement Data Book, Walter H. Duda, Bauverlag, Wiesbaden, and in particular Chapter 5, pages 94 to 104.

It is not a trivial feature that this invention, because of its universal nature and the use of a single easily derived signal, namely motor current, can readily be adapted, and instrumentation can be added to existing ball mills, without change or custom installation other than possible internal instrument calibration.

The processing of the detected motor load current (19) is quite simple to provide all the necessary operator and control signal information as seen in Figure 1.

The output current reading 41 may be displayed as a current or power reading on meter 40 for an instantaneous reading. However, as above stated this has little impact on delivering the meaning to a relatively unskilled operator. Thus, a schedule of selected critical conditions requiring operator action, such as the aforesaid conditions A to E, can be selected for control purposes by simply monitoring the current amplitudes at selector 42 to select the corresponding current values A to E on the ordinate of Figure 1, for example. At any one of these conditions control (as suggested by block 43) can be triggered either semi-automatically by operator intervention, or fully automatically, to alter parameters such as raw material or additive feed rates.

The principal display 44 is pictorial, that is, actual pictures or diagrammatic views such as shown in Figure 2 are shown in video form, preferably along with the instantaneous real time reference signal at 45 as derived from a system clock 46.

This method of operation is also adaptable to storage and recall of mill operating conditions by means of any suitable analogue or digital recorder. The segregated amplitude signals at leads 50 are in effect digitalized signals that may be coded and stored in digital form. In this embodiment the analogue current signals (41) may be stored on for example a tape recorder

51, along with a periodic time indication, or at a series of time intervals sampled by the signals of clock 46. For example, starting at mill startup time on a working shift of eight hours, the mill operation may be sampled and stored every fifteen minutes throughout the shift for recall and readback, thereby implicitly carrying a time indicia. A digital system can, of course, store clock time for every sample, and thus the output on leads 50 could be stored therewith.

10 It is clear therefore that whenever deviations from expected mill throughput occur, the recordability of the signal is important to provide a historical review. Thus, the cause may be analysed and corrected, even without full time operator attendance and attention.

15 It is possible to derive a further flow pattern display such as lamp bank 47 which has an optimum central position so that under preferred operating conditions the internal flow pattern within simulated drum 49 will permit tunnelling 48 to proceed only to a predetermined distance
20 along the length of the drum. As indicated above, the tunnelling of Fig. 2E is identified by reduced current from the desired operation current (condition C). Thus, the lights are lighted from left to right as a function of current to show flow tunnel 48 length conditions inside
25 the drum 49 on the lamp array 47 as derived from the signals available 50. Thus, both the loading conditions

44 and flow conditions 47 are pictorially representable solely from the magnitude of the input motor current basic signal.

However, one other factor affects tunnelling 48, namely: raw material density. The fluffier or less dense the raw materials, the more fully (volume) loaded the drum is, as represented by the displays 44 (Fig. 2A to 2E). Thus, the central idealized flow lamp in bank 47 may not coincide with the preferred loading pattern Fig. 2C but may rather match Fig. 2B or Fig. 2D if the raw materials are more or less dense. Therefore, it may be desirable to shift the lamp lighting sequence of flow picture 47 to the right or left as a function of an input material density signal indicated at 52.

In controlling the mill it is important to correct for overloading and to revert back to more efficient operation. This is a critical condition regarding chemical additives. The feeds of raw materials and chemical additives then need to be adjusted to assure the same proportions of chemicals to raw materials, particularly during the period of reversion from overloading to normal operation. The ratio of chemical additives to raw materials may be selected especially to aid the system to return to an equilibrium condition at the desired operating condition.

Therefore, the present invention provides improved and useful methods of operation and operational

analysis of grinding mill performance with procedures and steps which are simple, effective, and simply understood.

The invention thus provides methods of operation, and analysis of operation, of a grinding mill
5 of the electric motor-operated rotary drum type, particularly those for producing cement. Mill output efficiency is improved and optimum feed of raw materials and chemical additives is permitted.

The method described above is also described
10 and claimed in our Patent Application No. 8333536 which has been filed as a Divisional of the present application.

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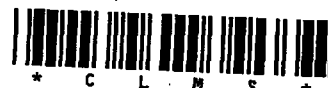


CLAIMS

1. A method of monitoring the operating conditions of a rotary drum type grinding mill driven by an electrical motor to grind raw materials, comprising: operating the mill by means of said motor over a range of power magnitudes in the presence of raw material load magnitudes which are above and below a desired raw material load magnitude; deriving a motor power signal intermediate in said range; and controlling the raw material load magnitude in said mill in response to the derived motor power signal to maintain the motor power signal substantially at the desired intermediate value which corresponds to the desired raw material load magnitude.

2. A method according to claim 1, including the step of reproducing different pictorial representations of internal mill conditions in response to a plurality of respective predetermined power magnitudes within said range.

3. A method of operating and monitoring an electric motor-operated rotary drum type mill, comprising: establishing a desired high operating efficiency condition with a known raw material load magnitude operating at a known motor power; operating the electrical drive motor with a partial mill charge at said established operating condition on an intermediate portion of the motor power curve wherein the motor power decreases and increases with raw material load magnitude; deriving from the electrical power supplied to the motor a motor power signal over a range, which range includes the power at positions on either side of



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said desired operating condition, in an intermediate position on said range; and providing control signals, responsive to the magnitude of said power signal indicative, of the need for corrective action when material load conditions are below or above that of said desired operating condition.

4. A method according to claim 3, including the step of displaying pictorial representations of the mill operating conditions, in response to the control signal.

5. A method according to claim 4, wherein the pictorial representations are typical patterns of grinding media and material charge within the drum.

6. A method according to claim 3, including the step of providing the indications of the need for corrective action in the form of a visual display enabling operators to take corrective action in restoring the load conditions to the desired condition.

7. A method according to claim 6, wherein the visual display indicates flow conditions through the mill.

8. A method according to claim 6, wherein the visual display indicates the status of the load within the rotating drum.

9. A method according to any one of claims 6 to 8, wherein signals representative of the control signals of different magnitudes at periodic intervals during mill



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operating identified by clock time are sampled and stored, the stored signals are recalled, and the pictorial representations of the mill operating conditions are displayed in response to the recalled signals.

10. A method according to any one of claims 3 to 9, including the steps of storing the motor power signals derived at periodic sample times during operation of the mill, and playing back a history of mill operation from the stored signals.

11. A method according to any one of claims 3 to 10, including the step of determining a motor power condition at which grinding efficiency is maximized, and maintaining said desired operating condition substantially at that motor power condition.

12. A method according to any one of claims 3 to 11, wherein the mill is operated with a synchronous motor exhibiting said power curve.

13. A method according to any one of claims 3 to 12, wherein the mill is operated during said method steps at a constant motor speed.

14. A method according to any one of claims 3 to 13, wherein raw materials to be ground are added to the mill charge, chemicals affecting the physical behaviour of the ground materials are added in a manner increasing the output efficiency of mill, and a continuous indication

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of the mill load conditions as affected by the addition of chemicals and materials to the mill charge is established from said signal.

15. A method according to claim 14, wherein the mill output efficiency is improved by the additional steps of controlling the addition of raw materials and chemicals in proportion one to the other, thereby maintaining said signal substantially at said desired operating condition.



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