

Oct. 16, 1956

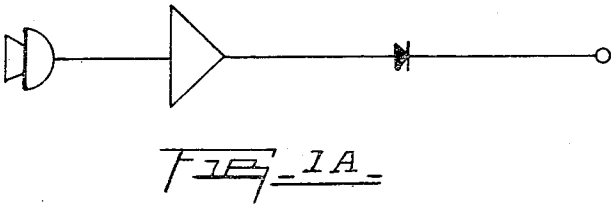
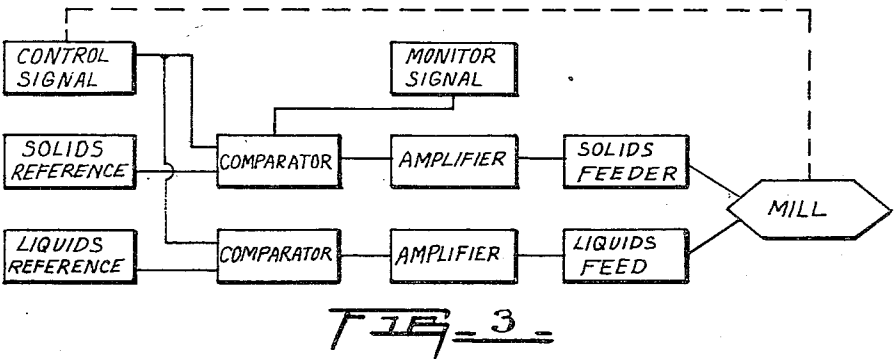
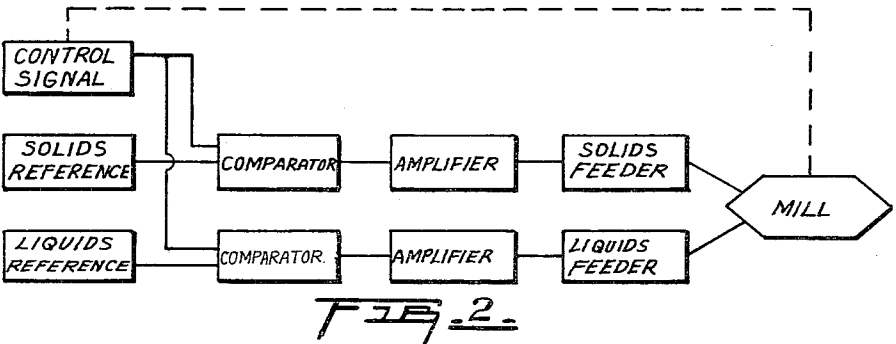
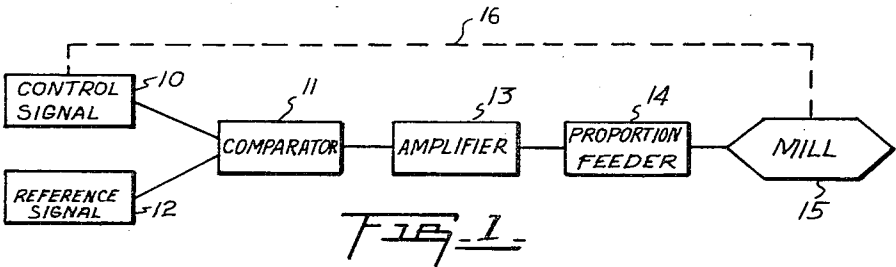
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2,766,940

BALL MILL FEED CONTROL

Filed April 5, 1954

4 Sheets-Sheet 1



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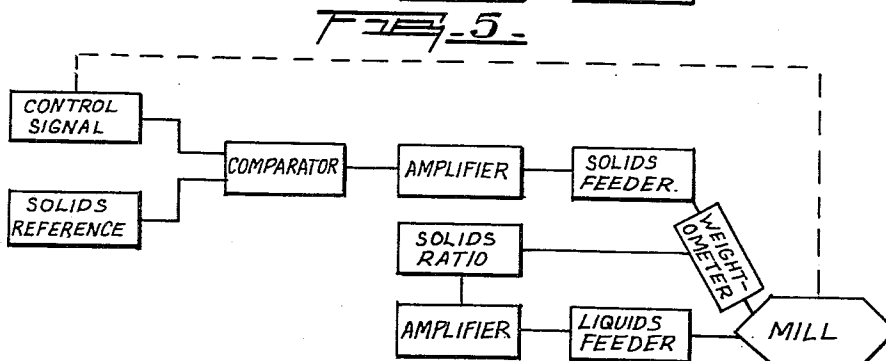
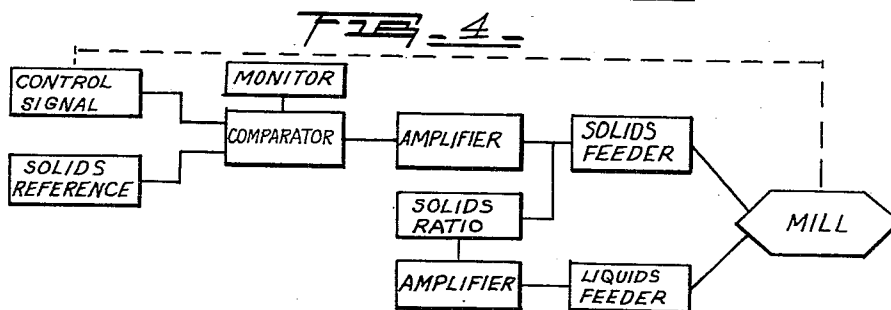
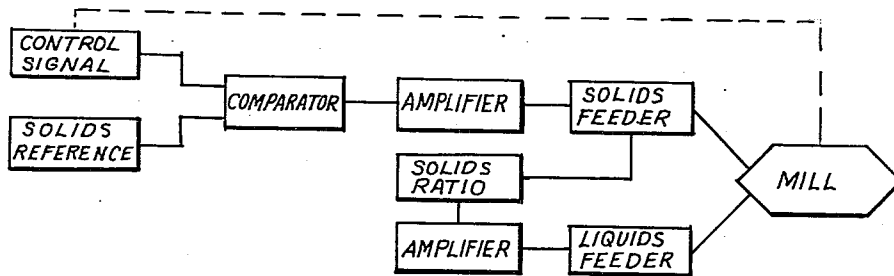
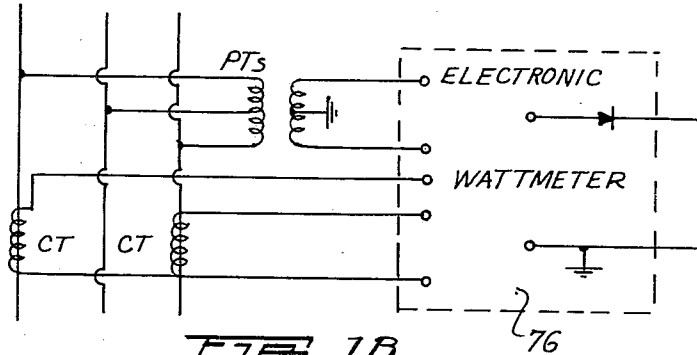
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BALL MILL FEED CONTROL

Filed April 5, 1954

4 Sheets-Sheet 2



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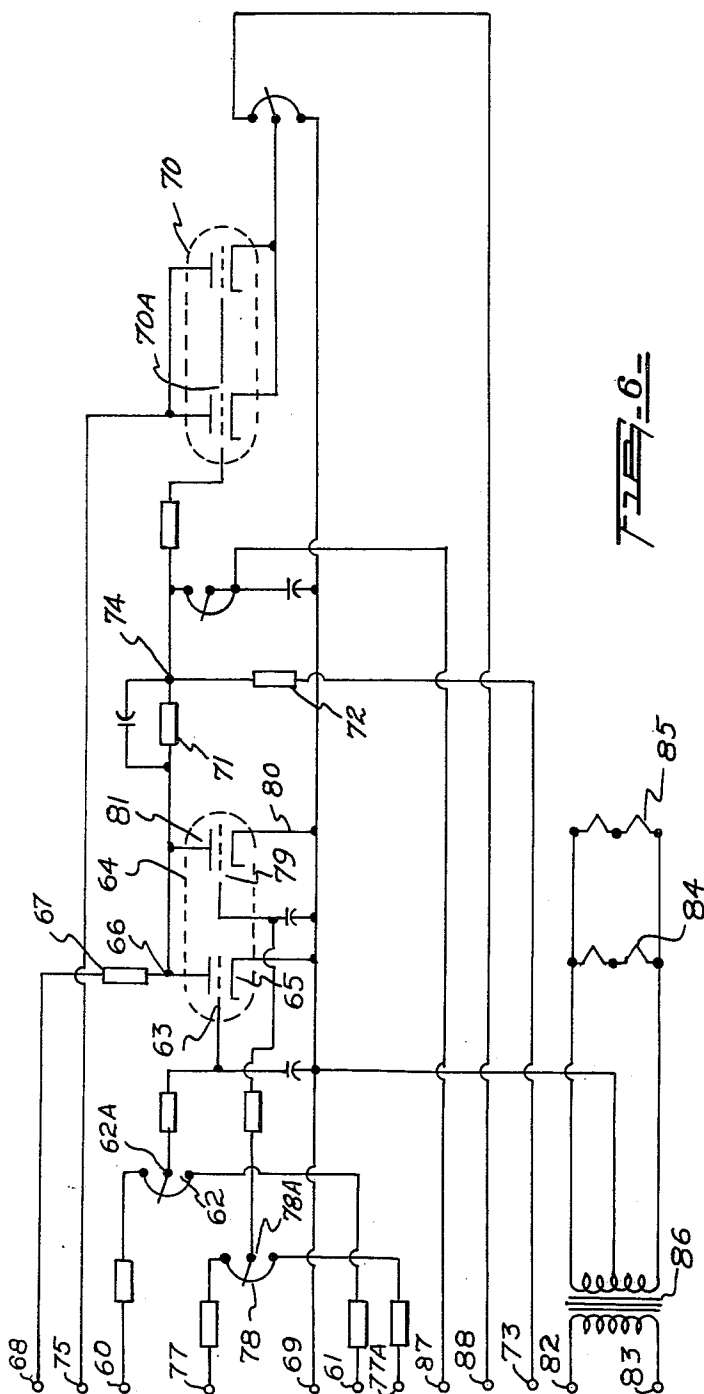
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Filed April 5, 1954

4 Sheets-Sheet 4

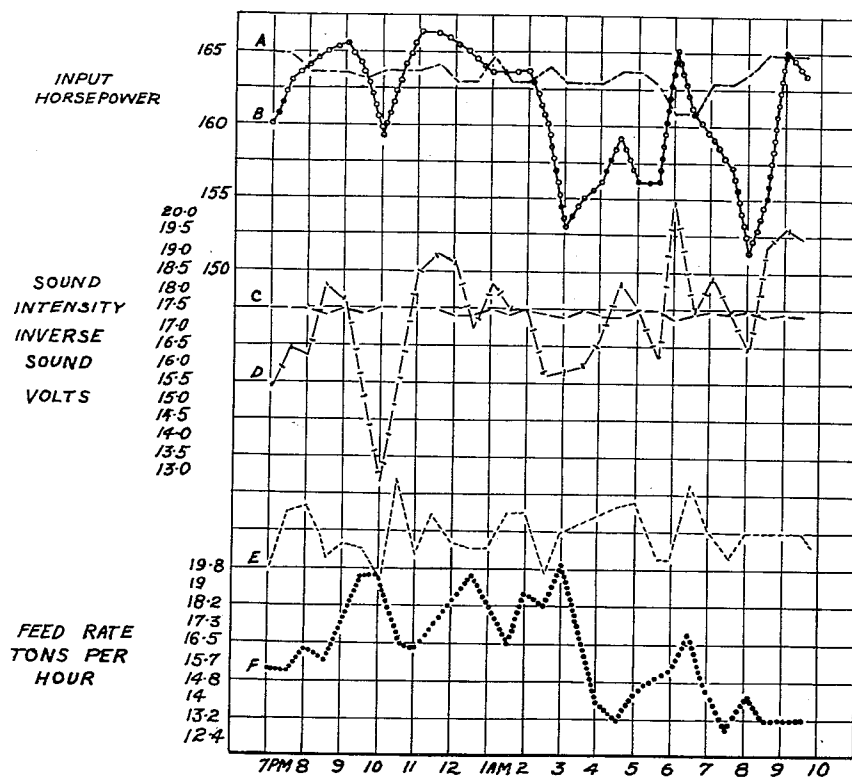


Fig. 7.

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## BALL MILL FEED CONTROL

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16 Claims. (Cl. 241—21)

This invention relates to an automatic feed control for wet grinding mills such as ball mills, rod mills, tube mills, and the like.

As is well known in the grinding art, the efficiency of the grinding operation is critically affected, firstly by the rate of feed of fresh ore to the mill, and secondly by the proportion of liquids to solids maintained within the mill. At any given rate of feed, the grinding efficiency is basically determined by the latter factor. The situation is further complicated by the fact that the quantity of water required per given quantity of ore fed to the mill to produce optimum grinding conditions varies considerably depending upon the particle size distribution of the feed and its physical characteristics such as rate of breakdown and etc., the object of the mill operator being primarily to maintain an optimum "viscosity" of ore pulp within the mill.

It has long been recognized that the sound given off by a mill is an indication of the grinding conditions within the mill, and the skilled operator, in accordance with general practice existing in most mills today, will manually vary the rate of introduction of water in accordance with his assessment of conditions within the mill as indicated by the sound which is given off. Further, as an added check, it is usual to sample the mill product periodically to determine the actual solids liquid ratio or pulp density at the outlet end of the mill and to make any further adjustments to the water introduced which are indicated as a result of such sampling. It has further been recognized that some indication of the grinding conditions can be obtained by measuring the power consumed by the mill motor, there being a family of characteristic curves of power versus mill capacity for each mill so that if the proportionate rate of feed of liquids and solids is fixed, the grinding efficiency of the mill can be determined over a limited range of operating conditions by reference to the appropriate characteristic curve.

There have, in the past, been a number of proposals based on the above observations for controlling the feed to wet grinding mills automatically by means of an electrical signal produced by sound emanating from the mill or by power consumed in the mill motor. However, to date, none of these proposals has been capable of producing an increase in efficiency of operation sufficient to justify acceptance and use on any substantial scale. The reason for the general failure of these prior proposals to gain substantial acceptance in the art is that all such systems heretofore proposed have basically been subject to the same disadvantages as are inherent in the skilled operator, namely they tend to produce proportionate rates of liquid and solid feed which oscillate or "hunt" about the point of optimum efficiency, so that throughout most of the period of operation, conditions of operation are not at an optimum. Such conditions have been accepted in the art principally, I believe, because it has not before been fully appreciated just how much loss in capacity results from a relatively small departure from optimum conditions, nor to what extent the problem of slimes

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production can be reduced by preventing such conditions of continual hunt back and forth past optimum, which are the inevitable result of manual operation or operation with automatic control systems of the type heretofore proposed.

I have now found that most surprising increases in efficiency of operation can be produced if the relative proportions of solids and liquid feed are controlled in a manner which provides for a variation in the rate of feed of at least one of the feed components which is proportional to the amount by which a control signal such as one based on sound or another criterion of operation conditions within the mill departs from a predetermined similar datum signal corresponding to desired or optimum conditions. I have found, for instance, that in the operation of wet ball mills a control system operating on the above basis is capable of producing an increase in capacity as high as 33% compared with manual control by a skilled operator while at the same time producing an increase in metallurgical efficiency by reason of a substantial reduction in the relative quantity of slimes produced, which primarily are caused by overloads in the comminution unit.

Broadly speaking, the method of the present invention consists in continuously producing an electrical signal which is functional to, that is which varies with an operating condition within the mill; continuously producing a similar datum signal which corresponds to a desired relative feed rate of a selected feed component to the mill; comparing said two signals to produce a difference signal, and then varying the feed rate of the selected feed component in accordance with the sense and magnitude of the difference signal thus produced.

In some instances, it may be desirable and is preferable according to the invention to monitor the system of control to prevent certain fixed conditions of the milling system from being exceeded. For instance, it may be desirable when using sound as a control signal to control rate of ore feed to monitor the control system to prevent overloading of the mill motor in the event that the system calls for a rate of feed which would create such overload. Similarly, where it is the liquid feed which is being so controlled, it will in some cases be desirable to make sure that the amount of water called for does not exceed the capacity of the system. In both cases, additional factors may come into consideration such as the capacity of the metallurgical circuits either in advance of or beyond the mill. This is an important consideration where the control of the present invention is installed in existing plants where the plant has been built to a scale commensurate with the previously existing capacity of the grinding section.

In the control of primary ball mills where it will normally be desired to feed the ore to the mill at the maximum possible rate consistent with optimum efficiency, it will be desirable to control both the rate of feed of ore and the rate of feed of water. This is done according to the present invention by controlling the ore feed by the use of a difference signal obtained by comparing the sound level signal with an "ore" reference signal and varying the rate of feed of the ore in accordance with the sense and magnitude of such difference signal, while at the same time the sound level signal is independently compared with a "water" reference signal, and the flow of liquid to the mill is varied in accordance with the sense and magnitude of the latter difference signal. In secondary ball mills, however, where the quantity of the feed to the mill depends upon the amount of product produced by the mill immediately above it in the milling circuit, the amount of ore fed to the mill is not normally subject to effective control, and consequently it is only necessary to control the liquids fed into the mill in such

a manner as to produce a viscosity consistent with optimum grinding efficiency.

It will be appreciated that it may in some cases be desirable to maintain, insofar as is possible, a constant predetermined rate of production from the primary grinding mill and in other cases, it may be practical to eliminate the need for independent control of the rate of liquid feed and directly proportion it to the amount of ore actually fed to the mill. Thus, in the latter case according to the invention, the amount of ore fed to the mill will be varied in accordance with the sense and magnitude of a difference signal obtained by comparing an electrical signal functional to an operating condition within the mill with a predetermined datum signal corresponding to desired conditions, and the feed of liquid will be controlled by a suitable device which feeds a predetermined quantity of liquid per unit weight of ore which is actually fed to the mill and thus maintains a relatively constant pulp density. In the former case, it will be practical simply to set the ore feeding means to feed at a predetermined desired rate, and then simply to vary the feed of liquid to the mill to maintain a desired viscosity in the same manner as above described for the control of secondary grinding mills. In either of these cases, it may be desirable to monitor the system on the basis of power consumed in the mill motor to prevent conditions of overload in the motor occurring or to prevent any fixed condition in the milling circuit or ancillary equipment from being exceeded.

The invention and its operation will be understood more fully from a consideration of the following detailed specification taken in conjunction with the accompanying drawings wherein—

Figure 1 is a block diagram illustrating the general arrangement of control circuit components in the case where only one feed component is controlled;

Figure 1A is a detail schematic of a typical "sound" signal source;

Figure 1B is a detail schematic of a typical "power" signal source;

Figure 2 is a block diagram illustrating a suitable arrangement of circuit components in the case where both feed components are controlled;

Figure 3 is a block diagram similar to Figure 2 but illustrating a modified control system in which the solids feed is monitored;

Figure 4 is a block diagram illustrating a further arrangement of circuit components providing for the control of ore feed in accordance with the present invention and proportioning of the liquid feed in fixed relation to the ore fed to the mill;

Figure 5 illustrates an alternative arrangement of the circuit components illustrated in Figure 4 wherein provision is made for the monitoring of the system on the basis of power consumed in the mill motor;

Figure 5A illustrates an alternative system to that shown in Figure 4 wherein the liquid feed is proportioned directly to the solids feed delivered to the mill.

Figure 6 is a circuit diagram illustrating suitable electrical connections for the monitoring system indicated in the block diagram shown in Figure 5;

Figure 7 is a comparative graph showing the variation of sound level, power consumption, or feed rate which occurs during a typical operating period with manual control by a skilled operator on the one hand, and automatic control according to the present invention on the other hand.

Referring now more particularly to the drawings, in its simplest form the method of the invention is illustrated by the block diagram shown in Figure 1 where a control signal functional to an operating condition within the mill is continuously produced by suitable means represented by box 10 and continuously compared by suitable means in box 11 to a continuously produced similar reference signal generated by appropriate means represented by box

12. The result of the comparison of these two signals is a difference signal which is then amplified in the amplifier represented by the box 13, and the amplified signal thus produced will control the operation of a proportioning feeder represented by box 14, and the rate at which the proportioning feeder 14 delivers material (solid or liquid as the case may be) to the mill 15 is either raised or lowered a proportionate amount depending upon the sense and magnitude of the difference signal.

As previously mentioned, either or both feed components may be controlled in accordance with the present invention depending upon the circumstances existing. In wet grinding systems, there are two feed components, one containing the ore which is to be reduced and the other being a liquid which is fed to the mill simultaneously to produce a suitable mixture of ore and liquid for the grinding media to work upon. In the present specification and claims, I refer to "liquid feed" and "solids feed" as the two feed components fed to the mill. It will be appreciated, of course, that in many cases the solids will be wet or will consist of a relatively thick ore pulp containing in many instances various conditioning agents in accordance with the conventional practice being followed in the particular mill concerned. At the same time, of course, the liquid which is fed to the mill, while it will usually consist essentially of water, may also contain the usual feed conditioning agents in solution in accordance with conventional practice. One of the commonest practices in this respect is the introduction of spent cyanide solution from the cyaniding plant as the liquid feed in the recovery of gold.

As indicated diagrammatically by the dotted line 16, the control signal produced in box 10 is functionally related to the conditions of operation of the mill 15. This signal may be derived from any manifestation of the operating mill which is subject to continuous sensing during operation. The most well known of such manifestations is the sound given off by the mill which has long been recognized by mill operators as having a direct functional relationship to the conditions existing within the mill. Moreover, the sound readily lends itself to continuous sensing by means of well-known electrical devices. I accordingly prefer to derive the control signal from the sound which is given off by the mill during operation, but it should be borne in mind that vibration other than sonic vibration can also be used equally as effectively. In the case of sound, the sound intensity may be converted into a proportional electrical signal simply by means of a dynamic microphone placed in a convenient location adjacent the mill. The circuit can be arranged to provide a control signal which is functional to, that is, which varies with, the entire volume of sound, or alternatively, it may be made proportional to the intensity of sound emitted by the mill within certain frequency ranges. The latter may be accomplished with conventional filters and is in most cases preferred inasmuch as a certain amount of the sound given off by a mill is purely mechanical in origin and bears no relation to the grinding conditions existing within it. If vibration other than sonic vibration is to be used in deriving the control signal, a vibration pickup may be affixed to a convenient portion of the mill, such for instance as a trunnion support, and the electrical signal which is produced may be proportional to the entire range of vibrations thus picked up, or as in the case of sound, to only the vibrations within a certain selected frequency range.

When taken by itself, the power input to the mill motor does not necessarily bear a functional relationship to the conditions within the mill. However, for conditions of constant "viscosity" within the mill or in coarse grinding operations for conditions of constant "pulp density" within the mill, the power input to the mill motor is functional to or varies with the charge load in the mill at any given time. Accordingly, if the type of solids fed to the mill lends itself to control

of "pulp density" by predetermined proportionate feeding of liquids and solids, a control signal proportional to the power input to the mill motor may be used. In addition, of course, if the "viscosity" of the pulp within the mill is maintained reasonably constant by independent means, a control signal derived from the power input to the mill motor may be used to control the rate of feed of the solids feed component. It will be understood, however, from what has been said above that a control signal derived from the power input to the mill motor will not be satisfactory for purposes of controlling the liquid feed component because in that case the "viscosity" or "pulp density" ceases to be a constant and the power derived signal loses its character as a signal functional to the operating conditions in the mill.

The control signal and the reference signal may be compared in any conventional manner which will result in an output of the comparator 11 equal in magnitude and having a sense corresponding to the difference between the control signal and the reference signal at any given instant. The amplifier 13 may be of any suitable type which is capable of converting the relatively weak difference signal which it receives into a signal effective to control the power input to the proportioning feeder. In terms of the method of the present invention, of course, the amplifier is merely part of the means used for varying the rate of feed of the feed component being controlled in accordance with the sense and magnitude of the difference signal produced by the comparator 11.

As mentioned earlier, the principal object of an operator conducting a wet grinding operation is to maintain the "viscosity" of the charge (i. e. the resistance to flow of the pulp in the mill) at such a value as will enable the most efficient grinding of the solids feed. Viscosity is primarily determined by "pulp density" (that is to say the proportion of liquids to solids present in the mill). "Viscosity" is also affected to a considerable extent by the particle size of the solids. For instance, a very finely divided solid material at a given "pulp density" will have a considerably greater "viscosity" than a coarse material at the same "pulp density." To some extent also the physical character of the solids present can affect "viscosity." For instance, a porous material will generally produce a higher viscosity for any given state of subdivision and pulp density than will a hard, granular material. It will be apparent from this that in fine grinding operations the "viscosity" must be directly controlled if optimum efficiency is to be achieved because in fine grinding operations the "viscosity" bears little direct relationship to the "pulp density." On the other hand, in coarse grinding operations, the "viscosity" is basically proportional to the "pulp density" and can be controlled satisfactorily in most cases simply by controlling the "pulp density," i. e. by feeding solids and liquids to the mill in predetermined proportion.

Bearing the above considerations in mind, it will be appreciated that there are various manners in which the present invention may be applied to the control of wet grinding mills. In the case of the secondary mill where the solids feed is normally the product of the primary grinding mill, the method of control illustrated by the block diagram in Figure 1 will be satisfactory, the control signal being derived from the sound given off from the mill and being used to control the liquids feed. For the control of primary mills, however, it is generally desired to utilize the maximum productive capacity of the mill and therefore it is preferred to apply the method of the invention in one of the various forms illustrated by the block diagrams shown in Figures 2-5A inclusive.

Referring to Figure 2, it will be observed that in essence there are two complete systems similar to that illustrated in Figure 1, one controlling the solids feed by reference to a "solids" reference signal and the other controlling the liquids feed independently by reference to a "liquid" reference signal. The liquids feed con-

trol will operate to maintain conditions of optimum viscosity within the mill, while the solids feed will maintain the feed of solids at a rate which corresponds to the maximum capacity of the mill under any one set of feed conditions. In this case, the solids reference signal will correspond to the feed rate required for maximum production of the mill while the liquid reference signal will correspond with the rate of feed of liquid which maintains optimum "viscosity" when the mill is operating at maximum production.

There is a danger that the mill motor may become overloaded due to variability in the condition of the solids feed material, and it is, therefore, desirable to monitor the rate of solids feed in a manner which will prevent the rate of solids feed from being increased whenever the power drawn by the mill motor reaches a value corresponding to the maximum rated power load for the motor. There are several ways of accomplishing this, but in general, it has been found desirable to apply the monitoring factor in the comparator. A suitable manner of effecting monitoring in the above manner is illustrated in the circuit diagrams shown in Figure 6, and will be discussed later. In fine grinding operations where it is desirable to have independent control of "viscosity" the monitoring signal will normally be applied to the solids feed control system, permitting the liquids feed control system to maintain optimum "viscosity" throughout the operation. However, in coarse grinding operations, where the operation of the mill may effectively be controlled on the basis of "pulp density," a system such as that illustrated in Figure 4 may be used with advantage. In this system, the feed of solids is controlled in similar manner to that in the system illustrated in Figure 3, but the amplified signal from the comparator of the solids feed control system is fed to the comparator of the liquids feed control system wherein it is compared with the liquids reference signal to feed liquids to the mill in predetermined proportion to the amount of solids fed to the mill, and thus maintain a constant pulp density.

In the system illustrated in Figure 3, it will be appreciated that the control signal may either be a signal derived from sound or vibration emanating from the mill or may alternatively be a signal derived from the power load on the mill motor. The monitoring signal will be a signal derived from the power drawn by the mill motor in the case where the control signal is derived from sound or vibration and vice versa.

If the mill is to be controlled on the basis of pulp density, it may be desirable to take off the liquids feed control signal at a later stage in the system, i. e. from the ore feeder as illustrated in Figure 4, or from the final output of the amplifier as illustrated in Figure 5. In the case illustrated in Figure 5A, a signal derived directly from the actual amount of solids which is fed into the mill is used. The systems illustrated in Figures 4 and 5 simply involve rearrangements of the electrical circuits, each having its own particular advantage in particular instances, while the system illustrated in Figure 5A involves the presence in the system of a weightometer which actually measures the amount of solids which is fed by the solids feeder, and translates the rate of solids feed into an electrical signal which can then be used to control the liquids feeder control system. The latter system has the principal advantage in that it is not subject to errors which may arise through any malfunctioning or faulty calibration of the solids feeder or in changes in feed rate at any one setting, particularly in volumetric feeders and where ore conditions of feed to it may be constantly changing in size or flowability due to moisture content, and, therefore, it will basically give more accurate control of "pulp density" than will any of the other systems previously discussed. The preferred solids feeding arrangement for use in connection with the method illustrated in Figure 5A is a variable speed belt which

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draws from the feed bins on the basis of a constant belt loading per unit length so that the actual rate of feed of solids to the mill is usually directly proportional to the speed of the belt. In such an arrangement, the electrical signal used to control the liquids feed can be derived in a simple manner, e. g. by a tachometer-generator, or by measuring the voltage drop across the motor windings, where the motor used to drive the belt is a D. C. motor.

#### CONTROL SIGNAL

As previously mentioned, the control signal may be derived from the sound emanating from the mill, from vibrations emanating from the mill other than sonic frequencies, or in certain instances from the power consumed by the mill motor. If the control signal is to be proportional to the sound emanating from the mill, the circuit components represented by the box 10 in Figure 1 will consist essentially of a dynamic microphone, an amplifier and a rectifier (as indicated in Figure 1A). If it is desired that the signal thus produced be proportional to the sound emitted within only a limited frequency band, the circuit can include a band pass filter, or the elements of the sound pickup system can be selected so that they are very sensitive to the sound frequencies which it is desired to utilize and relatively insensitive to sound frequencies outside the selected range. For instance, it has been found that audible frequencies emitted from a primary ball mill which are above 2,000 cycles per second vary in intensity in close relationship to the actual conditions within the mill whereas frequencies substantially below 2,000 cycles per second are not very satisfactory as a source of a control signal for purposes of the present invention because an appreciable proportion of the intensity of sound within these low frequencies can be attributed to extraneous causes such as the mechanical noise of the mill and power transfer system.

If the control signal is to be derived from vibrations other than sonic emitted by the mill during operation, apart from the type of pickup used, the circuit components required will be essentially the same as they will be when sound is used. In this case, however, the selection of a predetermined frequency band will more conveniently take place essentially within the circuit rather than as a result of selection of pickup components of selected characteristics.

Where electromagnetic pulse type feeders are employed and the control of the feed rate is effected by a phase shift in a saturable core reactor controlling thyatron power output tubes associated with the feeder, it will be convenient to invert the voltage of the control signal when it is derived from sound or vibration since the amount of phase shift effected, and hence the amount of power which is passed to the feeders, is proportional to the voltage applied to the saturable core reactor. (This is apparent from the fact that the sound or vibration produced by the mill will in general be less for high rates of feed than for low rates of feed when operating under ideal conditions.)

If the control signal is to be derived from the power consumed by the mill motor, the circuit components necessary to produce the control signal will consist essentially of a Watt-meter circuit applied across the power input lines to the mill motor and producing a voltage proportional to the motor input and a rectifier. A suitable system is illustrated in Figure 1B which shows an electronic Watt-meter connected in the power lines to the mill motor from which is produced as output a rectified voltage proportional to the power input to the mill motor.

#### REFERENCE SIGNAL

The circuit components represented by the box 12 in Figure 1 consist essentially of a means for providing a regulated voltage which can be adjusted to a predetermined desired value and a rectifier. For instance, it may be convenient to use a voltage regulator which receives as input the standard 115 volts line voltage and produces as out-

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put a regulated voltage of say 210 volts, a rectifier, and a potentiometer which may be set at a desired value to give as final output a desired rectified voltage which may be used as a reference signal.

#### COMPARATOR

The circuit components represented by the comparator box 11 may be of any conventional type. For instance, the comparator may consist of a simple bridge circuit, or alternatively an electronic grid which may or may not, depending upon the circumstances, be connected so as to form an integral grid system with components of the amplifier. The only important feature of the comparator circuit is that it must produce as output a signal which is proportional to the difference between the reference signal and the control signal and which has a sense which is opposite for opposite values of the algebraic sum of the control signal and the reference signal.

#### AMPLIFIER

Any suitable amplifier may be used which will fulfil the functions required in the particular application, the function of the amplifier simply being to amplify the signal produced by the comparator to a sufficient extent so that it may effect control of the particular type of feeder being used. The amplifier may, and in the preferred instance is, integrally associated with the comparator grid system.

#### PROPORTIONING FEEDER

There are various types of proportioning feeders which are available on the market, perhaps the commonest type being the electromagnetic pulse type feeder of which a typical example is the type manufactured by the Syntro Company of Homer City, Pennsylvania, United States of America. This type of feeder feeds solids from the bottom of a bin along a plate which is vibrated by a magnetic pulse with an amplitude which varies as the amount of power fed to the feeder is varied. The amount of material fed is proportional to the amplitude of the vibration of the feeder plate. Another suitable type of proportioning feeder consists of a variable speed conveyor belt arranged beneath the feed bin in such a way that, as the belt moves, a relatively constant load of ore per foot of belt is fed from the bin. In this type of feeder, the rate of feed to the mill is proportional to the speed of the belt.

Where it is the liquid feed component which is being controlled, the proportioning feeder may take the form of a motor operated valve in the liquid supply line. Such valves are generally controlled by the position of a potentiometer arm and open to a position corresponding to the voltage applied for any given position of said arm. Such valves may be used in accordance with the present invention by automatically actuating the potentiometer to correspond to the output voltage of the amplifier. This may be accomplished by a simple circuit arrangement which compares the potentiometer voltage with the control signal from the amplifier and operates the valve motor in an appropriate direction until the potentiometer voltage and the control signal voltage are equal. Other methods of accomplishing a similar function will be obvious to those skilled in the art.

#### MONITORING SIGNAL

As indicated previously, the monitoring signal may either be a power derived signal or a sound derived signal, depending upon the source of the control signal. The monitoring signal is applied to the system in a manner which prevents the system from creating conditions wherein a particular fixed condition of the milling plant is exceeded. The commonest fixed condition in connection with which it may be desired to affect monitoring is the rated power load of the mill motor. However, certain other fixed conditions such as the capacity of the follow-up metallurgical circuit of the ultimate capacity of the feed supply circuit may also impose limitations on the operation of the mill, and render monitoring desirable.

The commonest instance where monitoring will be re-

quired will be in connection with the rated power of the mill motor, and in this connection a convenient means of applying the monitoring to the control system is illustrated in Figure 6 which will be described in detail below.

The normal controlling signal is received at terminal 60, is compared with the reference signal received at terminal 61 across a potentiometer 62, the centre tap 62A of which is connected to the grid 63 of the first half of tube 64. The potential of this grid with respect to the cathode 65 determines the plate current of this half of the tube and hence the potential of point 66, since there is an IR drop across resistor 67 proportional to the plate current. Under normal operating conditions, point 66 will be 50 volts negative with respect to terminal 68 and approximately 50 volts positive with respect to terminal 69. Since 50 volts can not be put on the grid 70A of tube 70, this voltage is dropped across resistor 71 and approximately 100 volts dropped across resistor 72 between points 73 and 74.

Under such conditions, tube 70 passes sufficient current through terminal 75 to the D. C. winding of a saturable core reactor (not shown) connected between 75 and 68 so as to control the output of that reactor to the thyatron tubes.

The monitoring signal from Watt meter 76 (see Figure 1B) is received at terminal 77 and is compared in rheostat 78 with an arbitrary reference which is received at terminal 77A, the centre point 78A of rheostat 78 picks up the difference and is connected to the grid 79 of the second half of tube 64. Since the cathode 80 of the second half of tube 64 is connected to 69 under normal conditions, the grid 79 will be negative with respect to cathode 80 and no current will flow, but as soon as the monitoring signal voltage increases or becomes positive with respect to terminal 69 and hence to the cathode 80 of the second half of tube 64, current flows from the plate 81 through the second half of the tube. This increased current flow increases the voltage drop across resistor 67 in effect making point 66 more negative, and hence making the grid 70A of tube 70 more negative. This reduces the plate current to terminal 75 hence to the D. C. winding of the saturable core reactor so that the output of the reactor is reduced in proportion to the reduced current through tube 70.

Terminals 82 and 83 are connected across the normal 115 v. A. C. supply and provide heating current through transformer 86 to the elements 84 and 85 of the tubes 64 and 70 respectively.

Terminals 87 and 88 may be connected through capacitor systems to increase the stability of the system and reduce hunting if required.

To illustrate the effectiveness of the automatic control of the present invention when applied to primary ball mill operation, reference is had to the following example which shows the results of comparative tests on the primary ball mill of a gold ore milling plant in northern Ontario.

#### Example I

The primary ball mill on which this test was made was equipped with a 200 horsepower, 550 volt three-phase sixty cycle motor. Immediately prior to commencement of the test, the average capacity of the mill had been approximately 365 tons per day. In the first instance, the mill was operated on manual control in accordance with the established practice of the plant which manual control was carried out briefly according to the following procedure.

#### MANUAL CONTROL OF PRIMARY MILL

The amount of ore conveyed to the mill was adjusted by the operator by means of a variable resistor which was in series with a magnetic pulse type feeder. The water supply to the mill was adjusted by means of a valve at the ore chute leading to the mill, and also by

adding water to the classifier, which recirculated the larger ore particles in the mill product again through the primary mill.

These adjustments were made on the basis of sample weighings of the ore on the conveyor belt, and pulp density readings at the output end of the primary mill, together with pulp density readings taken at the input to the classifier, all of which occurred at 15 minute intervals. To a certain extent also adjustments were made to ore and/or water supply, when, in the judgment of the operator, the sound emanating from the mill departed from "normal."

While the mill was operated over a twelve-hour period, electric recording equipment was used to chart continuously the power drawn by the mill motor and the magnitude of the signal produced when the sound of the mill was converted into an electrical signal by means of a dynamic microphone placed centrally underneath the mill slightly towards the descending side thereof. The microphone system was provided with a high pass filter arrangement so that the signal produced was proportional only to sound having a frequency greater than 2,000 cycles per second.

The resulting graphs for the period of operation were studied and arbitrary values were selected for use as reference signals based upon the values of the recorded signals during the most favourable conditions of operation indicated by the graphs with a certain amount of interpolation.

During the whole period of manual operation, the rate of feed of ore to the mill was established by samplings taken at fifteen minute intervals from the feed conveyor belt while the "pulp density" was established by samplings taken at the output end of the mill at fifteen minute intervals. These readings were also recorded on a chart covering the whole period of operation, and from them the "pulp density" of the charge within the mill during the selected intervals of favourable operating conditions was interpolated to give an arbitrary value for the desired ratio of solids feed to liquid feed.

#### AUTOMATIC CONTROL OF PRIMARY MILL

Automatic control equipment was then installed in accordance with the block diagram illustrated in Figure 2. Sound was used for deriving the control signal and the ore reference signal was made equal to the arbitrary value which was selected as a result of the manual operation.

The liquids reference signal was set at an arbitrary value which was calculated to provide a "pulp density" within the mill of the same value as the "pulp density" which existed in manual operation during the selected intervals of most favourable operating conditions.

The mill was then run on automatic control for a fourteen hour period commencing at 7 p. m. and ending shortly after 9 a. m. the following morning. During this run, the recording equipment was used to chart continuously both the horse power drawn by the mill motor and the intensity of the sound emitted by the mill (which was recorded in the form of "inverse sound volts"). It might be mentioned here that the sound signal was inverted in view of the fact that the mill was equipped with a Syntron electromagnetic pulse type feeder which was controlled by a saturable core reactor and thyatron power control tube which provided an increase in feed for an increase in current. Since the current passed by the thyatron is proportional to the phase shift in the saturable core reactor (which is in turn proportional to the voltage of the control signal) a control signal was desired which increased in value to call for a higher rate of feed. It was thus necessary to invert the sound signal (which ordinarily becomes smaller for larger rates of feed) to provide a suitable control signal for the feeder arrangement used.

During the run, the samplings were taken from the feed belt and from the output side of the mill at fifteen min-

ute intervals to establish the feed rate and the "pulp density."

Since this test was to be used as a comparative test with the manually controlled operation, an identical operation period was used so that the operators would be the same and all extraneous variables would insofar as possible be the same. The ore used in both cases was the regular run-of-mill feed.

The graphs of horse power drawn by the mill motor and sound intensity as well as feed rate for each test run were plotted on the same time base and are shown in Figure 7. Curves A, C and E relate to the automatically controlled test run, and B, D and F relate to the manually controlled test run. It will be immediately apparent from reference to the chart that the automatic control was able to keep the sound intensity of the mill practically constant whereas under manual control the sound intensity varied considerably from its mean value. In addition, it will be observed that the same results appear from the graphs of the mill motor horse power and the general correspondence of peaks and valleys in curves B, D and F is quite remarkable. Finally, the increase in efficiency brought about by the automatic control is demonstrated conclusively by a comparison of curves E and F. For the test period, the average tons per hour was approximately twenty while operating on automatic control (curve E), whereas on manual control the average rate of feed was only fifteen tons per hour (curve F). Thus, an improvement in capacity of approximately 33% was brought about by the use of the automatic control.

One further feature was notable about the test run on automatic control and that was a noticeable reduction in the amount of slimes produced. This can be attributed to a reduction in the total amount of time in the test run during which the mill was operating at too high an ore-ball ratio. These periods correspond to the peaks on the sound intensity curve (the highest values of inverse sound volts corresponding to the periods of lowest sound emission by the mill).

Throughout the specification and claims, I refer to the datum or reference signal as being "similar" to the electrical signal which is produced and which is functional to or which varies with an operation condition within the mill. By "similar," I mean that the datum or reference signal and the electrical signal must be capable of being compared to produce a difference signal; that is to say, they must be generally the same type of signal, and their values must be expressed electrically in an analogous manner. For instance, in the description, it will be observed that the signals used are all D. C. pulses obtained by rectifying a 60 cycle A. C. voltage.

It will be observed also that I have spoken of "continuously" producing both the electrical signal and the "similar" datum signal, and "continuously" comparing the two to produce a difference signal. By "continuously," I mean that the whole operation of control is carried on over an extended period of time whether the frequency of pulses (where the signals used are a pulse type of signal) is long or short. Thus, if instead of having a pulse of voltage every  $\frac{1}{60}$  of a second as is the case where the signals are rectified 60 cycle D. C. voltages a pulse type signal were to be used which had a frequency measured in seconds, the control system described would obviously function satisfactorily. The word "continuously" is, therefore, to be understood as characterizing the production and utilization of the signals concerned whether these signals themselves be of intermittent nature or not.

What I claim as my invention is:

1. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing an electrical signal which varies with an operating con-

dition within the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to a desired state of said operating condition; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; and then varying in a continuous manner the rate of feed of at least one of said feed components to the mill in accordance with the sense and magnitude of the said difference signal thus produced.

2. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing an electrical signal which is proportional to vibration emitted by the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to desired operating conditions in said mill; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; and then varying in a continuous manner the rate of feed of at least one of said feed components to the mill in accordance with the sense and magnitude of the said difference signal thus produced.

3. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing an electrical signal which is proportional to sound emitted by the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to desired operating conditions in said mill; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; and then varying in a continuous manner the rate of feed of at least one of said feed components to the mill in accordance with the sense and magnitude of the said difference signal thus produced.

4. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing an electrical signal which is proportional to a selected portion of the sonic vibration emitted by the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to desired operating conditions in said mill; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; and then varying in a continuous manner the rate of feed of at least one of said feed components to the mill in accordance with the sense and magnitude of the said difference signal thus produced.

5. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing an electrical signal which is proportional to sound emitted by said mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to a desired viscosity of charge within said mill; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; and then varying in a continuous manner the rate of feed of said liquid feed component to the mill in accordance with the sense and magnitude of the said difference signal thus produced.

6. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed compo-

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nent which method comprises; feeding said mill with solids and liquid feed components; continuously producing an electrical signal which is proportional to sound emitted by said mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to a desired viscosity of charge within said mill; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; and then varying in a continuous manner the rate of feed of said solids feed component to the mill in accordance with the sense and magnitude of the said difference signal thus produced, while maintaining the rate of feed of said liquid feed component relatively constant.

7. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing an electrical signal which varies with an operating condition within the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to a desired state of said operating condition; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; and then varying in a continuous manner the rate of feed of said solids and liquid feed components to the mill in accordance with the sense and magnitude of the said difference signal thus produced.

8. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing an electrical signal which varies with an operating condition within the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to a desired state of said operating condition; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; then varying in a continuous manner the rate of feed of said solids feed component to the mill in accordance with the sense and magnitude of the said difference signal thus produced; and proportioning the feed of said liquid component to the mill in predetermined relationship to the amount of solids feed delivered to the mill.

9. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing an electrical signal which is proportional to sound emitted by the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to desired operating conditions in said mill; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; then varying in a continuous manner the rate of feed of said solids feed component to the mill in accordance with the sense and magnitude of the said difference signal thus produced; and proportioning the feed of said liquid component to the mill in predetermined relationship to the amount of solids feed delivered to the mill.

10. A method of comminuting material in a secondary wet grinding mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid-feed components; continuously producing an electrical signal which is proportional to sound emitted by the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and correspond-

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ing to a desired viscosity of charge within said mill; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; and then varying in a continuous manner the rate of feed of said liquid feed component to the mill in accordance with the sense and magnitude of the said difference signal thus produced.

11. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing an electrical signal which varies with an operating condition within the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to a desired state of said operating condition; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; applying a monitor signal to said difference signal to reduce the latter under certain predetermined conditions; and then varying in a continuous manner the rate of feed of said feed component to the mill in accordance with the sense and magnitude of the thus monitored difference signal.

12. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing an electrical signal which varies with an operating condition within the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to a desired state of said operating condition; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; applying a monitor signal to said difference signal to override and reduce the value of the latter whenever the power input to the motor driving said mill exceeds a predetermined value; and then varying in a continuous manner the rate of feed of said solids feed component to the mill in accordance with the sense and magnitude of the thus monitored difference signal.

13. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing a first electrical signal which varies with sound emitted by the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to desired operating conditions within the mill; continuously comparing said first electrical signal with said similar datum signal to produce a difference signal; continuously producing a similar second electrical signal proportional to the power input to the motor driving said mill; applying said second signal to monitor said difference signal whereby when said second signal exceeds a predetermined value, it overrides said difference signal to reduce the value of the latter; and then varying in a continuous manner the rate of feed of said solids feed component to the mill in accordance with the sense and magnitude of the thus monitored difference signal.

14. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing a first electrical signal which varies with power input to the motor driving the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to a desired power input corresponding to de-

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sired operating conditions; continuously comparing said first electrical signal with said similar datum signal to produce a difference signal; continuously producing a similar second electrical signal which varies with the ratio of the charge to the reduction medium in the mill; applying said second electrical signal to monitor said difference signal and override the latter to reduce the value of the same whenever said second signal reaches a value corresponding to a predetermined ratio of the charge to the reduction medium; and then varying in a continuous manner the rate of feed of said solids and liquid feed components to the mill in accordance with the sense and magnitude of the thus monitored difference signal.

15. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing a first electrical signal which varies with an operating condition within the mill; continuously producing a similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to a desired state of said operating condition; continuously comparing said electrical signal with said similar datum signal to produce a difference signal; varying in a continuous manner the rate of feed of said liquid feed component to the mill in accordance with the sense and magnitude of the said difference signal thus produced; applying a similar monitoring signal to said difference signal and varying in a continuous manner the rate of feed of said solids feed component in accordance with the sense and magnitude of the thus monitored difference signal whereby said monitor signal overrides said dif-

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ference signal to reduce the solids feed rate under given predetermined conditions.

16. A method of comminuting material in a material reduction mill of the rotating drum type adapted to receive a solids feed component and a liquid feed component which method comprises; feeding said mill with solids and liquid feed components; continuously producing an electrical signal which is proportional to sound emitted by the mill; continuously producing a first similar datum signal which is equal in value to a value of said electrical signal determined empirically and corresponding to a desired rate of solids feed to the mill; continuously comparing said electrical signal with said first similar datum signal to produce a first difference signal; varying in a continuous manner the rate of feed of said solids feed component to the mill in accordance with the sense and magnitude of the said first difference signal thus produced; continuously producing a second similar datum signal corresponding to a desired rate of liquid feed to the mill; continuously comparing said electrical signal with said second similar datum signal to produce a second difference signal; and varying in a continuous manner the rate of feed of said liquid feed component to the mill in accordance with the sense and magnitude of said second difference signal.

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