Aug. 21, 1962 V. W. MARCYES ETAL 3,050,264

SOUND ACTUATED CONTROL SYSTEM FOR BALL MILL AND THE LIKE

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2 Sheets-Sheet 1

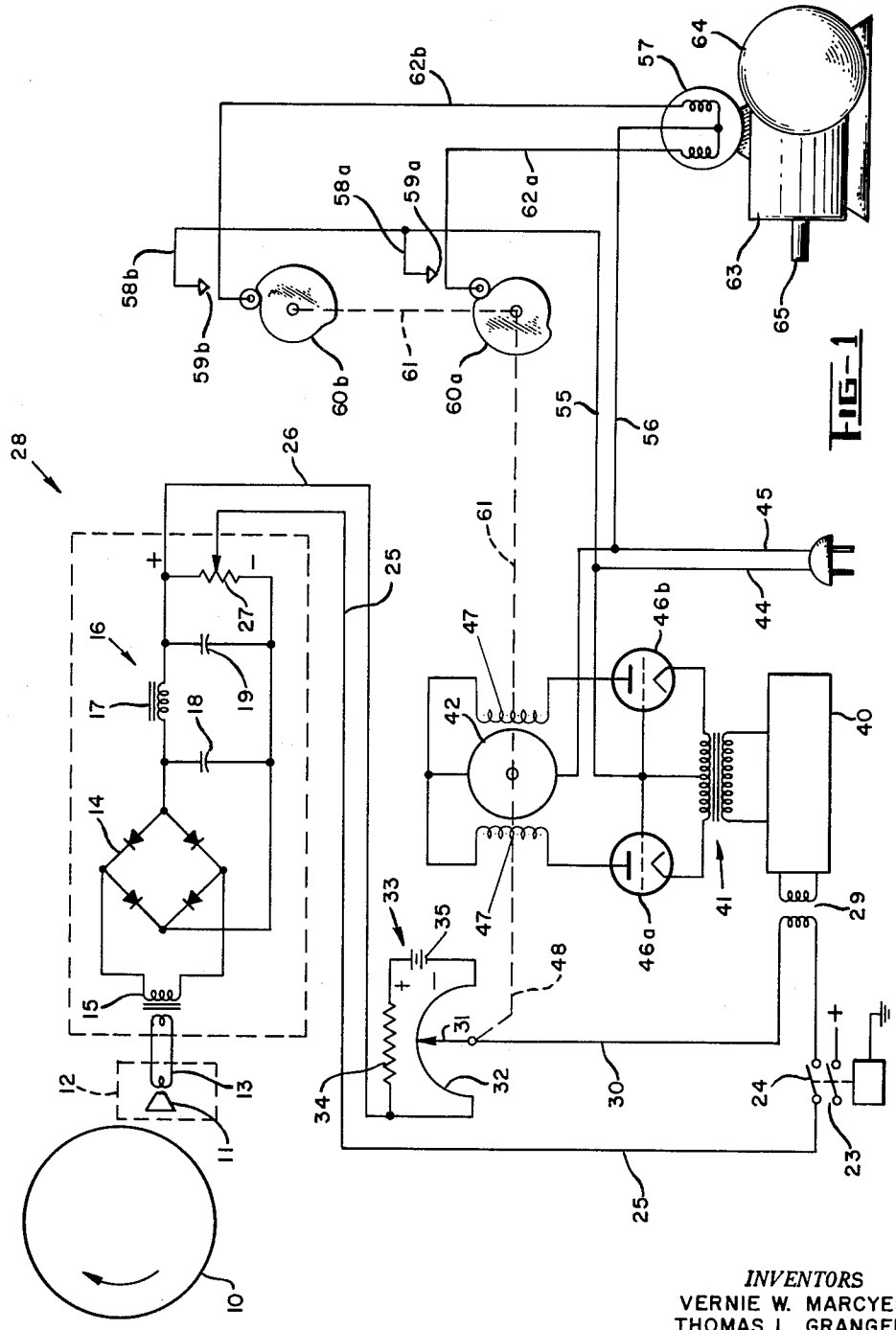

FIG-1

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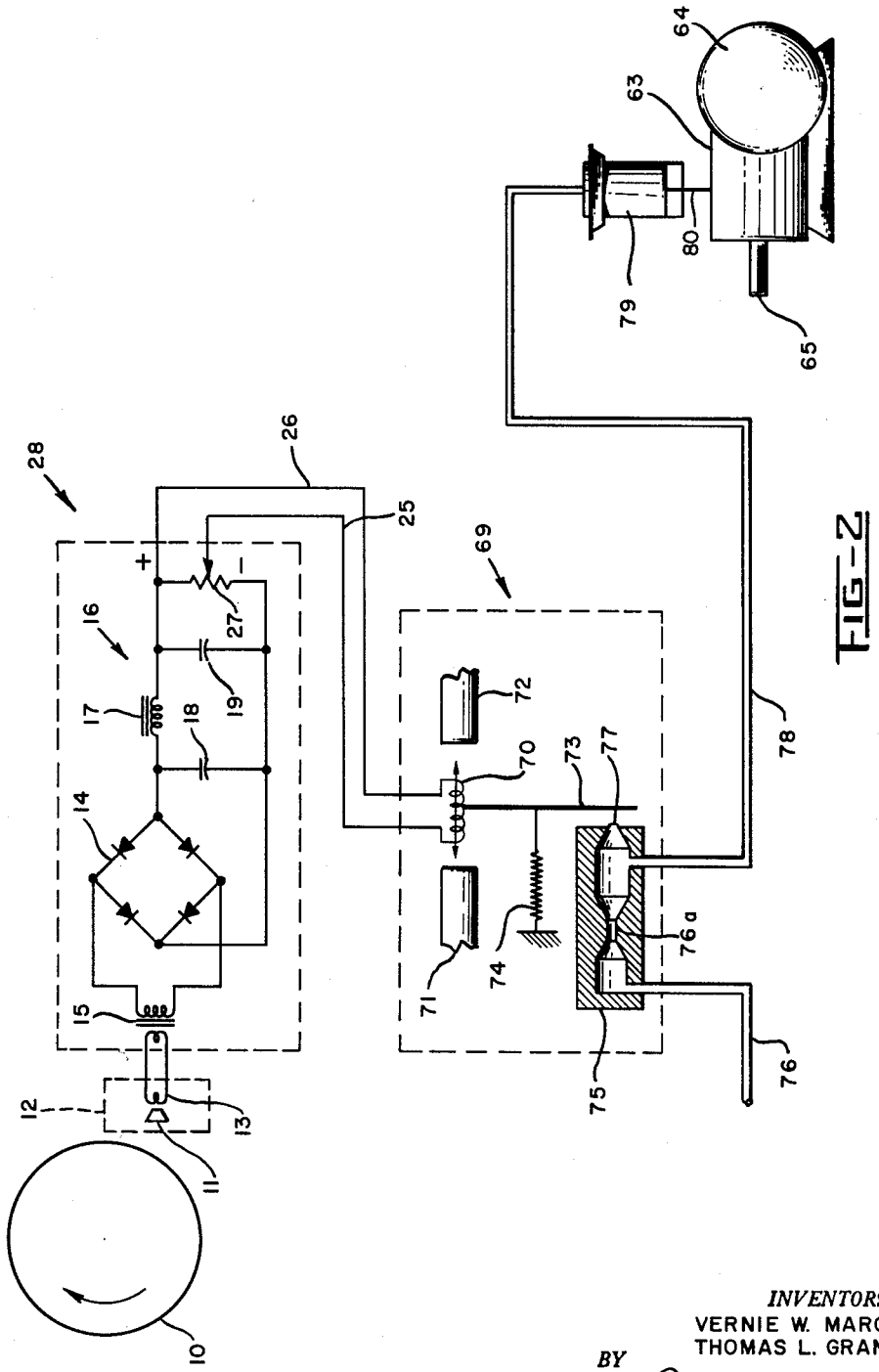

FIG-2

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SOUND ACTUATED CONTROL SYSTEM FOR BALL MILL AND THE LIKE

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5 Claims. (Cl. 241—34)

This invention relates to a sound actuated, automatic control for the feed to ball mills and the like.

Ball mills and other mills employed to grind rock and other solid materials are usually supplied with the raw material to be ground by means of an endless conveyor such as a motor driven conveyor belt. To operate a mill of this character most efficiently the feed should be varied so that, if the mill is overloaded, the supply of raw material will be diminished and, if the load in the mill is too small, the supply of material will be increased.

A mill of this character has an optimum operating condition. Thus, grinding in a ball mill is accomplished by tumbling of the solid material to be ground and by the impact and shearing force caused by the steel balls which are tumbled with the material which is being disintegrated. If an excessive amount of material is present, the steel balls, which are the chief grinding elements, are not efficient in their operation. If, on the other hand, too little material is present the balls cannot operate efficiently because they will tend to strike one another and the sides of the mill without accomplishing the intended disintegrating and grinding function. Not only will the balls be less effective as grinding instrumentalities but their impact against one another and against the sides of the mill will cause excessive wear.

It is known to provide a sound control for ball mills and the like, such being based upon the fact that a properly operating mill emits a characteristic sound whereas an overloaded mill operates more quietly and an underloaded mill operates more noisily. In one prior system of sound control a microphone is placed adjacent a mill to pick up sound from the mill and the A.C. electrical output of the microphone is rectified, but the fluctuating voltage so generated is used directly to operate a relay which opens and closes a circuit which, in turn, energizes the feed motor. The operation of this system is intermittent. This is to say, when a mill tends to become overloaded and, as a result, the sound level decreases the drive motor for the conveyor belt is stopped, then starts again when the load in the mill is corrected and the sound level returns to normal. Such a system must operate under a constant overload bias with means to keep the overload from exceeding a predetermined value, and the system is unable to modulate a mill supply continuously and to correct for both overload and underload.

Intermittent operation is undesirable because of the high starting torques imposed and the shock, vibration and abusive treatment of the equipment. Such abusive treatment is particularly damaging where long conveyor belts are loaded with large quantites of rock and must be stopped and started intermittently. It is also a disadvantage of prior systems that they cannot modulate for both overload and underload. Moreover, the prior systems employ dynamic elements such as relays which are subject to wear and which are likely to become clogged by dust.

It is an object of the present invention to provide an improved sound actuated control system for ball mills and the like.

It is a further object of the invention to provide a sound actuated control system of the character and for the purpose described which is continuous in its operation, and which acts to continuously modulate, i.e., to accelerate

and decelerate a drive motor for a conveyor belt or the like to keep a ball mill or the like adequately loaded at all times without the necessity of intermittent operation.

It is a particular object of this invention to provide a sound level control system for a ball mill wherein the measured output signal of the sensing unit, or "ear," has a potential and current output over its normal operating range that is similar to that of an iron/constantan thermocouple with a temperature range of 0° to 400° F., when used as a temperature measuring element for a pyrometer in an automatic temperature controller. Such a sound sensing signal output is desirable so that it can be substituted directly for such a temperature sensing means. With such a sound sensing element, a fully modulated control is available by use of conventional electrical, pneumatic and/or hydraulic controllers with their attendant automatic means for introducing rate and reset functions and transfer from manual to automatic control without upset of the feed control system.

Yet another object is to provide a control system of the character and for the purpose described which employs passive elements that are not likely to become inoperative in the presence of excessive vibrations, such as those encountered near a ball mill, or unreliable because of wear or fouling due to dust conditions frequently found around a ball mill.

The above and other objects of the invention will be apparent from the ensuing description and the appended claims.

Certain forms of the invention are illustrated by way of example in the accompanying drawings, in which:

FIGURE 1 is a generally diagrammatic view of one form of the invention in which the direct current output of the sound converter unit is employed in connection with a potentiometer and a voltage amplifier and a control motor for constantly modulating the speed reducer of the drive motor.

FIGURE 2 is a generally diagrammatic view of an alternative embodiment of the invention in which a pneumatic control is employed and is actuated and operated by the sound converter unit shown in FIGURE 1.

Referring now to the drawings and first to FIGURE 1, a ball mill is shown diagrammatically at **10** which rotates in the direction indicated by the arrow and therefore cascades the rock or other material which is being crushed and ground, together with the steel balls employed as the grinding elements, on the right-hand side of the mill as viewed in FIGURE 1 and therefore closely adjacent a microphone **11** which is enclosed in a box or housing **12**. Preferably the box or housing **12** has a sound insulating lining on its interior and an opening facing and adjacent the ball mill, so that background noises are more effectively screened out and the sound impulses imposed upon the microphone are substantially entirely those coming from the ball mill **10**. Various types of microphone may be used provided the microphone has physical characteristics which enable it to be used under conditions of rather severe vibration and high sound level. Preferably a permanent magnet-type microphone is employed. One such microphonic device useful for this purpose is a speaker manufactured by University Speaker Co., Model MM2L Imp.: 16 ohm, power: 25 watts. Preferably a microphone is used that has a resonant audio frequency of a few hundred cycles per second. As indicated this microphone is of the permanent magnet type so that an external power source for the coil is not required. However, suitable dynamic microphones can be substituted, if desired, provided the output is similar to that above-defined. The output of voice coil **13** of microphone **11** is impressed on a full-wave rectifier **14** through a suitable impedance matching transformer **15**. The output of the rectifier **15**, although it is a unidirectional current, is

nevertheless pulsating in character and for purposes of the present invention it is desirable that the pulsations be removed. To that end, a filter system **16** is provided comprising an inductance **17** and capacitors **18** and **19**.

The values of inductance **17** is about 13 henries at 65 milliamps, while condensers **18** and **19** are about 2000 mfds. each for the effective voltage range produced by microphone **11** and rectifier **14** of the present embodiment.

There results, therefore, as the output of the system as thus far described a steady, direct current voltage across resistor **27** that has a magnitude dependent upon the total signal generated by the sound of the mill. That is to say, the voltage between output wires or leads **25** and **26** is a steady, direct current voltage of predeterminable magnitude as long as the ball mill **10** is operating uniformly and generating the same sound output. Naturally, this direct current voltage fluctuates with the sound level from the ball mill **10** and advantage is taken of that fact for purposes of this invention. As illustrated, variable resistor **27** is employed for adjustment of the output signal as explained in detail hereinafter.

The transformer **15**, rectifier **14**, filter **16** and variable resistor **27** are boxed in as illustrated to indicate the fact that these elements may constitute, and preferably do constitute, a single integrated unit which is generally designated by the reference numeral **28** and which we call our "sound converter unit." As stated hereinabove each of the elements is passive in our sound converter unit so that it can be located directly adjacent to the ball mill under its control without requiring hermetic seals to prevent contamination by dust or elaborate damping means to suppress vibrations generated by grinding material in the ball mill. The remainder of the control system can thus be located at a more remote location so that vibration and dust are less prevalent.

The output wire or lead **25** is connected to the input coil, or primary, of a transformer **29** through contact **24** of vibrator **23**. Such primary coil is also connected by a wire **30** to a movable contact **31** which contacts a slide wire **32** of a potentiometer **33**, such potentiometer also having a fixed resistance **34** in parallel to the slide wire **32** and having a source of power indicated as a battery **35**.

The purpose of vibrator **23**, of course, is to convert any unbalanced potential between slide wire **32** and that appearing on lines **25** and **26** to a pulsing direct current having an amplitude corresponding to the magnitude of such unbalance and a phase corresponding to the sense or direction of the imbalance. Thus, an A.C. input is supplied to amplifier **40** that represents the direction and amount of corrective action required to maintain the sound output at a desired level.

To this end, the output, or secondary winding, of the transformer **29** is connected to the voltage amplifier **40** whose amplified output is impressed upon the primary winding of a transformer **41**.

The control loop comprising slide wire **32**, vibrator **23** and transformer **29** may, of course, include rate and reset circuit components, where desired, to offset the normal droop in the proportional mode of control described hereinbefore. Circuits can also be used that assist in transfer from manual to automatic control in this same loop. These circuits, of course, are well known but require individual engineering design unless the voltage input is within the range of D.C. current specified above. With such D.C. output of the sound converter as we use, commercially available controllers can be used without modification.

A control motor **42** is provided of reversible type which is powered by a 115 volt, 60 cycle, A.C. source through wires **44** and **45**, the wire **44** being connected to the center tap of the secondary winding of the transformer **41** and also to the grid of thyratron tubes **46***a* and **46***b*. The power lead **45** is connected to one terminal of the reversible control motor **42**. As illustrated the secondary winding of the transformer **41** is connected to the cathodes of the thyratron tubes **46***a* and **46***b* and the plates of these thyratron tubes are connected through field windings **47** to the other terminal of the reversible control motor **42**. It will be apparent that, depending upon the electrical balance, if current is passed to the motor **42** through the left-hand thyratron **46***a* the motor **42** will rotate in one direction and if it is passed to the motor through the other thyratron **46***b* it will rotate in the opposite direction. As illustrated, the motor **42** has a mechanical connection diagrammatically shown at **48** to the movable contact member **31** whereby the motor **42** is enabled to move the said movable contact member in a direction to null the output voltage impressed on leads **25** and **26** by resistor **27** in the sound converter unit.

A pair of branch power leads **55** and **56** are shown which connect to the main power leads **44** and **45**, respectively. The branch lead **55** connects through wires **58***a* and **58***b* to a first set of contacts **59***a* and a second set of contacts **59***b*, respectively. The contacts **59***a* are controlled by a cam **60***a* and the contacts **59***b* are controlled by a cam **60***b*. As will be seen, a mechanical connection **61** is provided between the control motor **42** and the cams **60***a* and **60***b* so that it is the motor **42** which operates the cams **60***a* and **60***b* as well as the movable contact member **31** of potentiometer **33**.

The power lead **56** connects to one of the terminals of a reversible motor **57**. The other two terminals of the motor **57** are connected to leads **62***a* and **62***b* which in turn are connected to the contacts **59***a* and **59***b*, respectively. It will be apparent that, depending upon the position of the cams **60***a* and **60***b*, if one set of contacts **59***a* or **59***b* is closed then the other set of contacts must be open. (In normal operation both sets of contacts are open.) Correspondingly the motor **57** will be rotated in one direction or the other to modulate the rate at which material is continuously supplied to mill **10**.

The motor **57** operates and controls a speed reducer **63** which is operatively connected to a drive motor **64**, such motor being the primary source of power for operating a conveyor belt (not shown) which supplies rock or other material to be crushed to the ball mill **10**. The output shaft **65** of the motor speed reducer unit is the element which transmits power from the motor to the conveyor belt and, inasmuch as the motor **64** is a constant speed motor, it is the setting of the speed reducer **63** which in turn is determined by the motor **57** which controls the speed of the shaft **65** and therefore the rate of feed of rock or other material to the mill **10**. Thus, mill **10** is continuously supplied with material by the conveyor belt driven by rotation of shaft **65**, but the rate of supply is varied by the setting of speed reducer **63**. In this way, the input of material is continuously modulated to achieve a preselected value, i.e., by the sound or noise level in mill **10**.

At the commencement of operation, by a procedure of trial and error, the variable resistance **27** will be adjusted suitably for a sound output of the mill **10** which corresponds to optimum operation; that is to say, the sound output resulting from operation of the ball mill **10** when it is neither overloaded or underloaded. As long as this condition continues, i.e., as long as the mill **10** operates at optimum loading and its sound output is uniform, the voltage between the wires **25** and **26** and hence the A.C. applied by vibrator **23** across the primary winding of the transformer **29** will remain uniform and nulled by the D.C. potential of opposite and equal amplitude supplied by the output of slide wire **32**. Thus no voltage will be induced in the secondary winding of the transformer **29**, hence the voltage amplifier **40** will have no output and no change in the system will take place.

Assume now, however, that the mill **10** becomes overloaded. In that case its sound output will diminish and the voltage across the primary winding of the transformer **29** will diminish. The change in voltage will induce a

corresponding voltage of proper phase and amplitude in the secondary winding of the transformer **29** which will result in an output from the voltage amplifier **40**, such output being in a direction or of a sign to cause current to pass through one of the thyratron tubes (say, for example, the thyratron tube **46***a*). This will cause the motor **42** to rotate in a direction to close one of the pairs of contacts **59***a* and **59***b* (say, for example, the pair **59***a*) to initiate operation of the motor **57** in a direction to adjust the speed reducer **63** so as to slow down the shaft **65** and thereby diminish the rate of feed of rock to the mill.

Inasmuch as the feed to the mill is diminished the supply of rock in the mill will also diminish and the sound level will increase which will result, through the electrical system described, in an increase of the voltage across the primary winding of the transformer **29** and this in turn will cause the control motor **42** to operate in the opposite direction thereby restoring the system to its normal state of balance.

It will be apparent that if the load in the mill **10** diminishes below the desired optimum level, the sound level will increase and that such deficiency will be corrected by the system described, the end result of which is to operate the motor **57** in a direction to speed up the output shaft **65** thereby increasing the rate of delivery of rock to the mill.

It will, therefore, be apparent that, a system has been provided which constantly adjusts or modulates the speed or rate of feed of rock or other solid material to a ball mill or the like and which obviates the necessity of intermittent on and off operation with its consequent disadvantages.

Referring now to FIGURE 2, another embodiment of the invention is there shown in which the prescribed range of D.C. potential provides the input to a "pyrometer" or pneumatic control unit **69** which is operated by the same sound converter unit as illustrated in FIGURE 1. In its elementary form, as shown, the output wires **25** and **26** of the sound converter unit **28** are connected to opposite ends of a winding or movable coil **70** which is located between opposite poles of two magnets **71** and **72**, or alternatively between the poles of a single horse shoe magnet. A flapper member **73** is provided which is suspended from the movable coil **70** and which is normally held in a predetermined position by a spring **74**. An orifice block **75** is provided which is supplied with compressed air, for example, at 15 lbs. per square inch gauge through an air duct **76** which communicates with a passageway **76***a* within the block **75** and which terminates and communicates with the atmosphere at **77**. The orifice **77** is closely adjacent the flapper **73** so that the latter offers a resistance to escape of air therefrom, in effect functioning as a valve. An air duct **78** branches from the passageway **76** and connects to a diaphragm operated member **79** having a mechanical connection **80** with the speed reducer **63** of the drive motor **64**, thereby governing the speed of the output shaft **65**.

The operation of the system of FIGURE 2 will be evident from an inspection thereof and from the above description of FIGURE 1. Thus if the current passing through the movable coil **70** diminishes owing to a diminished sound level from the ball mill **10** and a consequent reduced voltage between the wires **25** and **26**, the coil **70** will be caused to move in one direction, thereby altering the throttling of air escaping from the orifice **77** and correspondingly altering the air pressure which bypasses the orifice **77** and passes through the conduit **78** to the diaphragm operated control member **79**. When the current flowing through the coil **70** increases because of the fact that the noise level in the ball mill **10** increases, thereby increasing the voltage difference between the wires **25** and **26**, the opposite effect will be produced. It will be apparent therefore that a continuous modulation of the feed will be effected by the pneumatic means of FIGURE 2 as in the case of the electrical means in FIGURE 1.

It will, therefore, be apparent that apparatus has been provided for continuously and very effectively modulating the feed of rock or other material to a ball mill or the like so as to maintain the load of rock in the mill at the optimum value at all times, such being accomplished without the necessity of intermittent start and stop operation.

We claim:

1. Apparatus for continuously modulating the input to a ball mill or the like to maintain the loading of said ball mill at a preselected value which comprises microphone means for detecting the audio output from said mill and for converting said output to an A.C. signal, rectifier means inductively connected to said microphone means for rectifying said A.C. signal, filter means connected to said rectifier means and an adjustable resistor connected across said filter means to provide a D.C. potential proportional in amplitude to the audio ouput of said ball mill and means responsive to said D.C. potential for continuously controlling the input of material to said mill to maintain said D.C. potential at a preselected value.

2. Apparatus for continuously modulating the feed of material to a ball mill wherein the feed system for said mill comprises, a material conveyor, drive means for said conveyor, and variable speed means for connecting said drive means to said conveyor, said apparatus comprising sound detecting means responsive to the noise generated by grinding of said material in said ball mill, means for generating a direct current proportional in magnitude to the level of noise measured by said detecting means, a balanceable control network connected across said direct current means, amplifier means for detecting the direction and magnitude of any departure of said direct current from a preselected control point due to a change in load in said ball mill, and means controlled by said amplifier means for actuating said variable speed means in a direction and to an extent to reduce the unbalanced voltage in said control network to zero and simultaneously correct the rate of drive of said conveyor.

3. Apparatus for generating a direct current electrical signal proportional in amplitude and sense to the grinding rate in a ball mill which comprises a microphone for detecting the sound level in said mill and for generating an alternating current proportional to said level, a full wave rectifier inductively connected to the output of said microphone to convert said alternating current to a pulsating unidirectional signal proportional in magnitude to said level, a filter circuit connected to said rectifier to generate a relatively smooth direct current signal and an output resistor connected in parallel with said filter to permit a portion of the current flowing therethrough to be used as a control signal proportional in magnitude to sound level of said mill so that a fully modulated control of the feed means for said mill may be continuously supplied with a signal proportional in magnitude and sense to a departure of the grinding rate from said preselected value.

4. Apparatus for continuously supplying material to a ball mill to maintain grinding therein at maximum efficiency which comprises microphone means for detecting the sound level in said ball mill, means for converting the output of said microphone to a D.C. signal including rectifier means, filter means and a load resistor, said signal being proportional in magnitude to the sound level detected by said microphone, means connecting the output of said load resistor in a balanceable control circuit including a slide wire potentiometer, amplifier means connected to the output of said balanceable control circuit for detecting the direction and magnitude of any unbalanced signal in said circuit due to a change in the sound level of said mill, means operable under the control of said amplifier means to vary the supply of material to said mill in manner to return said grinding toward its maximum efficiency and said amplifier operable means

being adapted to adjust the output of said slide wire potentiometer to yield a signal opposite in sense and equal in magnitude to said D.C. signal from said load resistor.

5. Apparatus for continuously supplying material to a ball mill to maintain grinding therein at maximum efficiency which comprises microphone means for detecting the sound level in said ball mill, means for converting the output of said microphone to a D.C. signal including rectifier means, filter means and a load resistor, said signal being proportional in magnitude to the sound level detected by said microphone, motive means for continuously supplying material to said mill, and a pneumatic control system for controlling said motive means to modulate the rate of supply of material to said mill, said pneumatic control system including a control valve connected to a source of compressed air and to said motive means to effect control of the latter in response to the air pressure delivered by the valve, said pneumatic control system including also a valve control element and electromagnetic means operated in response to the D.C. signal on said load resistor and serving to operate the valve control element.

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