⑲ Europäisches Patentamt
European Patent Office
Office européen des brevets

⑪ Publication number: **0 109 157**
A2

⑫
EUROPEAN PATENT APPLICATION

㉑ Application number: **83305786.2**

㉒ Date of filing: **27.09.83**

(51) Int. Cl.³: **B 02 C 17/16**, B 02 C 25/00

㉚ Priority: **15.10.82 US 434589**

㊸ Date of publication of application: **23.05.84**
Bulletin 84/21

(84) Designated Contracting States: **BE DE FR GB**

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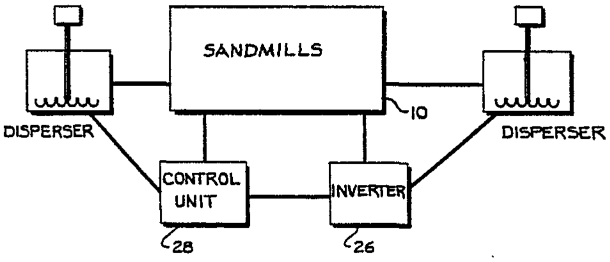
(54) **Automated sandmill control system.**

(57) The operating parameters of one or more variable speed sandmills (10) and related apparatus are automatically and continuously monitored and controlled by controllers (26) programmed by a master control unit (28).



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AUTOMATED SAND MILL CONTROL SYSTEM

Background of the Invention

This invention relates to the processing or grinding of solids within liquids, and more particularly to that process commonly referred to as sand milling. The invention also relates, to a lesser extent, to related processes wherein solids are reduced in particle size or more uniformly dispersed within liquids.

Sand milling refers to that process wherein a liquid having solid particles therein is pumped through a vessel containing a grinding media, which is agitated by a series of rotor disks as the product passes through the vessel. When this process was first developed, sand was used as the grinding media, which gave the process its name. However, instead of sand, manufactured small diameter spheres made of various materials such as steel, glass, or ceramic is typically used now.

The process has been used for a wide variety of materials such as paint and related products, dyes, foodstuffs, magnetic coatings and other such materials. In addition, more recently, the process has been used for combining coal with oil or water in providing fuels. In these operations, the size of the solid particles entering the sand mill can vary significantly from relatively large chunks to rather small particles. During the milling process, these solids can be greatly reduced in size to the desired level, down to and including micron or sub-micron size. With mixtures or slurries having relatively large particle sizes, it is common to first pass the product through a high speed dispersing operation wherein the particles are fairly uniformly dispersed within the liquid and decreased in particle size, usually to some minor extent and deaglomerated. As can be appreciated, the physical characteristics of the product introduced to the sand mill vary tremendously, with variables including in addition to the particle size, the uniformity of particle sizes, the qualities of the particles that determine their resistance to being broken into smaller particles, the density, and the liquid viscosity. Further, these characteristics vary significantly within a particular type of product. For example, there are hundreds of paint pigments, and many different types and categories of coal and oil. Then of course there are the additional variables introduced by the temperature both of the incoming product and throughout the processing operation.

While this multitude of variables has been recognized in a general and somewhat vague sense, they have been to a large extent ignored. For example, although variable speed rotors for sand mills are known, the mechanisms used have been slow responding mechanical arrangements limited to adjustments within certain ranges. More importantly, the bulk of the apparatus being utilized has a fixed speed for the rotor, which is determined by the characteristics of the electric motor commonly employed to drive the rotor, rather than by the characteristics of the product. Since sand mills are made with rotors of different diameters, this of course means that the rotor tip speed varies considerably between sizes, and yet this is an important consideration in determining the effectiveness of the grinding operation. Fixed speed rotors also introduce start-up problems because of the significant loads usually involved.

With a fixed speed rotor, the most common method for varying the quality of the product output has been to control the length of time that the product is subjected to processing, this in turn is basically a function of the rate at which the product is pumped through the vessel, although in more recent years the product might be run through the same vessel more than once or run through a series of vessels. Typically, this variable is determined through trial and error, such as by taking a sample of the product output and having it analyzed to determine particle size and distribution. If the desired product is not being obtained, adjustments are usually made in the length of time of processing the product. Such analyzing would of course primarily only apply with respect to the given sample taken, and variations of the product being introduced in variations and characteristics because of temperature, etc. were basically being ignored.

In short, sand milling has been to a large extent a trial and error process involving many compromises. As more and more uses are recognized for the sand milling process, there is a greater need for increased sophistication in control, predictability, and repeatability of the sand milling process. Such controls not only provide an improvement in the quality and consistency of the end product but also greatly increase the versatility and usefulness of such apparatus.

Summary of the Invention

In accordance with this invention, there is provided a sand milling system in which a multitude of variables of a sand milling operation are sensed and fed to a microprocessor-based control unit, which, in turn, is connected to cause the control of various paramaters of the operation by other controllers. For example there is provided an electric speed controller which controls the speed of the rotor within the sand mill. The control unit likewise controls the flow rate of the product through the sand mill. If the product is to pass through one or more sand mills the control unit controls the flow to provide the desired particle size and distribution.

The temperatures and pressures of the product are also sensed and fed to the control unit which displays this data and programs other independent controllers to make any necessary adjustments to control the operation of the sand mill to obtain the desired result.

The various control parameters are preferably displayed on an operator's console at the control unit having the desired dials, gauges, digital readouts or cathode ray tube displays. Thus the operator can remotely make the necessary adjustments of the parameters to obtain the desired output product based upon tests of the output product quality. Once this output has been obtained, the control unit continues to monitor and adjust the process to continue to provide this desired output product automatically. A record is maintained of all of the products processed by the apparatus, together with the processing variables used to manufacture a product having those characteristics. Thus, if a particular product is to be processed in the future, such as certain paint base and pigment, the proper processing parameters may be simply recalled from the control unit memory or storage medium and used to control that particular operation. Of course, human readable record can be obtained of all aspects of the processing information.

This procedure can be followed for a multitude of products which are processed by sandmills. As another example, in the manufacture of magnetic tape, magnetic particles within a coating are applied to the tape. In processing the coating, a sandmill is employed wherein the particles are ground to an extremely small and uniform size to obtain proper performance from the tape. Once a proper processing procedure is established, the procedure may be stored such that the record for that operation may be quickly placed into use.

For a more diverse operation, large particles of coal may be ground in oil or water wherein not only particular sizes are desired, to produce a desirable combustible product and to help maintain the particles in suspension within the liquid during long storage periods. The control unit can again provide the necessary control once the desired parameters have been established.

In short, the system of the invention greatly modifies and improves present methods of dispersing and milling solids within liquids to provide precise specific controls over operations that have heretofore been incompletely controlled, or controlled through inconsistent trial and error methods. Thus, higher reliability and ease of repeatability of results is achieved through more complete sensing and control of process parameters by use of real time automated process control techniques.

Description of Drawings

Figure 1 is a schematic perspective view of the components of the invention.

Figure 2 is a side elevational, partially cut-away, sectionalized view of a milling machine of the system of Figure 1.

Figure 3 is a schematic flow chart of the system of Figure 1.

Figure 4 is a display from the control unit of the system of Figure 1 schematically illustrating the controls on the first milling machine.

Figure 5 is another display schematically illustrating the operation of the fourth milling machine of the system.

Figure 6 schematically illustrates the use of dispersers located at the front and at the end of the system illustrated in Figure 1.

Figure 7 is a schematic diagram of the hardware-software control and sensing apparatus for the seal oil pump.

Figure 8 is a schematic diagram of the hardware-software control and sensing apparatus for the slurry and binder pumps.

Figure 9 is a schematic diagram which is typical of the hardware-software control and sensing apparatus for each of the sand mills.

Figures 10-13 are a simplified diagram of the basic algorithm of the control unit 28.

Detailed Description of a Preferred Embodiment

Referring to Figures 1 and 3, there is schematically illustrated milling apparatus 10 consisting of series of four milling machines, M1, M2, M3, and M4, mounted on a single frame. Each of the milling machines includes a vessel 16 having liquid inlet and outlet connections for pumping, by pump 18, a slurry through the vessels. In addition, referring to Figure 3, each of the machines includes a rotor 20 driven by an electric motor 22, and each of the vessels is partially filled with a grinding media 24. The media is preferably a small diameter steel shot, although a variety of grinding media may employed. During the process, the slurry of solid particles within liquid is pumped upwardly through the vessel while the media is being agitated by the rotor driven by the motor. This operation finely grinds and disperses the solid particles in the liquid.

The motors employed are variable speed electric motors, and, referring back to Figure 1, the motors are electrically connected to an inverter 26 or other electrical controller means for varying the speed of the electric motors. The inverter 26 is controlled by a master control unit 28 which receives manual input instructions, monitors parameters of the milling process, provides displays of the desired parameters, as well as the sensed parameters and provides output instructions to the inverter 26 and other parameter controllers. The control unit 28, in addition to including several microprocessor-based hardware modules and some standard software modules, includes a manually operable keyboard 30 for inputting instructions to the control unit, a cathode ray tube display screen 32 and a panel 34 of analog and digital readouts and guages. Permanent copy of any of the displays or readouts may be obtained by way of the printer 36 associated with the control unit 28.

Various programmable control units 28 are available. One such unit is manufactured by the Industrial Instrumentation Division of Robert Shaw Controls Company of Anaheim, California for controlling the instrumentation of various industrial processes and is designated the DCS-1000/1500". Robert Shaw Controls Company has developed a general purpose program for process control purposes, identified by that company as the Digital Supervisory Module DSM-1000. The Digital Supervisory Module contains 4 standard "virtual control modules". Suitable instructions or configurations are then provided to configure the standard modules to the particular process described herein.

Referring again to Figure 2, each sandmill is designed to have the slurry under pressure within the vessel during operation. To prevent product from escaping the vessel at the locations where the rotor drive shaft leaves the vessel, a suitable schematically illustrated seal 38 is provided. The pressure within the vessel is exposed to one side of the seal 38. Higher pressure of a lubricant coolant is applied on the other side of the seal sufficient to prevent leakage past the seal out of the vessel.

To keep the vessel 16 from becoming too hot during the milling operation, which generates considerable heat, a cooling jacket 42 surrounds the vessel and a suitable coolant, usually water, is pumped therethrough.

Referring now to the schematic diagram of Figure 3, the liquid flow system is illustrated in simplified form. The pump 18 is shown receiving the slurry in a line 44 from a liquid input supply 46 and a solid particle input supply 48. The slurry fed to the pump 18 is pumped through a conduit 50 to the inlet at the lower end of the vessel 16 for the milling machine M1. As may be seen, the four milling machines are arranged with their vessels 16 serially connected. That is, the output from the vessel of mill M1 is ducted by conduit 51 to the lower end of the vessel for the mill M2; the outlet at the upper end of the mill 2 is ducted by conduit 52 to the lower end of vessel in mill M2. Similarly output from the vessel of mill M3 is connected to the inlet at the lower end of vessel for mill M4.

The slurry being processed through the milling machines may consist of a large variety of different materials, as mentioned above. In many of these processes, the only product input is directly into the first milling machine. In some situations however it is desireable to introduce additional constituents of the product at a point downstream from the first milling machine. In the system illustrated in Figure 3, an additional liquid is introduced from two supply tanks 54 and 56 to a conduit 58 leading to a pump 60, which in turn has its output line 62 joining the slurry line 53 to be fed into the lower end of the fourth milling machine M4. This additional constituent is dispersed within the fourth milling machine and the resulting product flows out the upper end of the vessel in milling machine M4 through the conduit 64.

The system shown in Figure 3 was designed for the production of coating for use in connection with the manufacturer of magnetic tape. In this arrangement, magnetic particles in a suitable solvent are provided through the slurry input tank 36 and combined with a suitable liquid carrier from the tank 48. The magnetic particle are finely milled as the slurry is pumped through the milling machines. The liquid from the pump 60 is a suitable binder material.

As indicated above, the sand mill vessels are operated with the slurry under pressure and with lubricant pressurizing the vessel seals. This is illustrated in Figure 3 wherein lubricant from a supply 66 is pumped by pump 68 through lines 70 to the seals in the vessels.

As further mentioned above each mill is provided with a cooling jacket 42 through which is circulated a suitable coolant such as water. For this purpose, there is schematically illustrated a coolant conduit 72 leading to each of the jackets 42. While all of the details of the cooling water system are not shown, it should be understood that the coolant may flow one time through the system or coolant may be suitably cooled through a heat exchanger and re-circulated through the jacket 42. A control valve 74 is positioned in each of the branch lines leading to the respective cooling jackets so that individualized control of the coolant flow is provided for each of the vessels.

The electric motors 22 are for convenience shown located below the mill vessels in Fig. 3, although the motors are actually located above the vessels. As mentioned above, each of the electric motors for driving the rotors is of the variable speed type and is electrically connected to the speed control 26 and the control unit 28. Each motor has a speed sensor S1-S4 which senses the speed of the motor and transmits the information to independent speed controllers within the control unit 28. Each electric motor has an overload sensing device 21 which monitors the current flowing in the motor and which trips if the current becomes too high. Such device for Mill M1 is shown inFigure 3 for convenience but are actually located in the speed control 26 or elsewhere as desired. Each overload device can be read by the control unit 28 to determine if the overload device is in a tripped state indicating an overload has occurred. The actual electrical connections for this purpose are only schematically illustrated in Figure 3 by the lines leading from the speed control 26 and the control unit 28 to the milling apparatus 10 and between the units 26 and 28. The product input pumps 18 and 60 also include suitable variable speed electric motors which are connected to the control unit 28 and the speed control 26. The oil seal pump 68 may also be connected to the speed control however that pump does not have to be variable speed. Similarly, the cooling water pump (not shown) could also be connected to the speed control, although it is not necessary that the motor for that pump be of the variable speed type, since coolant flow control is obtained by the valves 74. A variety of suitable inverters are available. One type that is acceptable is that manufactured by Reliance Electric of Cleveland, Ohio.

To obtain the desired control of the various operating parameters of the system it is necessary such parameters be sensed by suitable transducers and that signals from such instruments be transmitted to the master control unit 28. For this there is provided a suitable flow meter F1 positioned in the output line 50 of the slurry pump 18. A flowmeter F2 is also positioned in the flowline 62 of the binder pump 60, and a similar flowmeter F3 is positioned in the product line 64 leading from the milling machine M4. It is also desirable to measure the flow of cooling water, which is accomplished by a suitable flowmeter F4 positioned in the cooling water input line 72.

As mentioned above, the speed of the motors for mills M1, M2, M3, and M4 be sensed and monitored by sensors schematically illustrated as S1, S2, S3 and S4 adjacent the motors 22. Various transducers may be utilized for this purpose, one satisfactory approach being a magnetic pick-up device mounted on the motor output shaft which senses the revolutions of the motor. However, since mill rotors 20 are manufactured in various diameters, the more meaningful value in terms of effectiveness in agitation of the grinding media within the vessels is the linear rim speed of the rotor. Accordingly, the diameter of the rotor is utilized to convert revolutions per minute into rim speed in feet per second in the individual controller in the control unit 28.

Another variable to be sensed is the liquid pressure at various points in the system. For this purpose, there is provided a suitable sensor P1 in the slurry input line 50 leading to the first mill M1. Similar sensors P2, P3, and P4 are positioned in the slurry input lines leading to mills M2, M3 and M4 respectively. Pressure sensor P11 is positioned in the lubricant line 70 leading to the seals for the mills. Also, pressure sensor P12 is located in the binder flow line 62 leading to milling machine M4.

To monitor the temperature of the slurry within the sand mill vessels, there are provided suitable temperature sensors T1, T2, T3 and T4 respectively appropriately located on the sand mills.

The information from the various sensors is fed to the control unit 28 through suitable electrical connections (not shown).

Operation

During start-up of the system it is necessary that certain steps be followed in a pre-determined sequence, and the control unit is programmed to cause the mill to follow this specified sequence. Since it is critical that the slurry not escape from the seals of the mill vessels, and the vessels are to be operated under pressure, the first step in the sequence is to energize the lubricant pump 68. Energizing the pump 68 causes an indicator light to be energized on the gage panel 34 as well as a light on the pump 68 itself shown on the display screen 32, if that particular display has been called for by the operator. This is the logical display for initiating operation. Shortly after energizing the pump 68, a pressure sensed by the sensor P11 should rise and an indication of this transmitted to the control unit 28 indicating that the next step may be initiated. This pressure may be visually observed by the operator on the gage panel 34.

With the seal lubricant pressure at a safe minimum level, the slurry pump 18 is energized to commence pumping slurry to the first milling machine M1. When the slurry pressure in the line 50, as sensed by the sensor P1, reaches a pre-determined level, the electric motor 42 for mill M1 is energized. Because the start-up load on the motor 22 and the rotor 20 as well as the shafts connecting them, is substantial due to the heavy grinding media plus whatever residual slurry may be in the vessel 16, the motor 22 is actually placed in operation by a jogging sequence wherein power is supplied and interrupted repeatedly so as to jog the motor into movement before continuous power is supplied. This approach reduces the liklihood of mechanical breakdown and lengthens the overall life of the apparatus.

This sequence is than repeated for the remainder of the sand mills in series. That is, when the pressure, as sensed by sensor P2, rises to a certain level, the motor for mill M2 is jogged into operation, followed by similar actions for mills M3 and M4. In addition, when the pressure in the line 53 to the mill M4 reaches a certain level as sensed by sensor P4, the binder pump 60 is energized to commence pumping binder material into mill M4.

As the system continues to operate, the temperatures within the vessels in each of the mills increases due to the heat of the milling operation. The temperature is continually monitored and controlled by sensors T1, T2, T3 and T4. The set points for this control are established by the control unit 28. If the temperature is outside of a pre-determined range, coolant flow is initiated and the appropriate valve 74 is automatically opened or closed as the case may be by a suitable signal from the control unit 28. Thus, the coolant flow may be initiated anywhere within the start-up sequence or where desired.

When the system is to be shut down, an appropriate sequence is also automatically followed as controlled by the control unit 28 after receiving a suitable signal from the operator. The product slurry pump 18 and the binder pump 60 are de-energized to stop product flow through the mills and the electrical motors for the mills are then de-energized. The lubricant oil pump 68 is the last component to be de-energized, except that the cooling water through the mill jackets will continue to flow if there should be any temperature buildup in any of the vessels.

Returning now to the operational phase, a major advantage of the system is the complete and continuous automatic control of the operation under the supervision of the control unit 28. This results in more cost effective operation since a single operator could run several machines making different products without constant attendance at any of them and with little time needed to establish the parameters if that particular product had been manufactured in the process before and the value of the parameters stored. If it is determined that the final product flowing from the mill M4 does not have the solid particles reduced to a desired level, the operator can make the desired adjustment, such as increasing the rim speed of the mill rotors. Or, the flow through the system can be reduced by adjusting the output of the slurry pump 18, and by appropriately adjusting the output of the binder 60. The desired ratio of the output of the two pumps may, of course, be initially established so that the proper adjustment of the two is simultaneously made. The actual values of the various parameters being sensed can be displayed directly on the diagram illustrated in Figure 3 adjacent the various sensors. Figure 3 is essentially a replica of one of the displays, with the exception that the values being sensed at a given time are not shown in Figure 3.

Another useful display summarizes the various parameters being sensed by category of parameter. That is the flow rates F1, F2, F3 and F4 are grouped and the pressures P1, P2, P3, P4, P11 and P12 are grouped, as are the temperatures T1, T2, T3 and T4. The actual values of these parameters as sensed during the operation are also continuously and instantaneously available. Thus, for example, if the pressure within the mills as a group is desired to be readily observed and compared, this display is very convenient for this purpose.

If, on the other hand, it is desired to observe only the parameters being sensed for the various milling machines for easy comparison, a separate display is provided. The motor speed, the product pressure and the coolant water temperature for each mill are conveniently displayed by mill. In addition, on that display, the fluid flow rates through the system are also summarized. The actual values sensed during operation of a system are continuously indicated on this display for purposes of quickly checking them.

Another useful display is to isolate a particular sand mill, visually showing the various inputs and outputs to the sand mill, together with the actual values of the parameters being sensed. For example, there is shown in Figure 4 a display of mill M1. In addition to showing the slurry input and output pressures as well as the seal oil pressure, the actual rotor rim speed is shown at a given instant together with the desired rim speed which has been set for that mill. The square in the center of the motor is a light which indicates whether the motor is energized. The bottom figure in the box indicating motor speed is a percentage of the actual speed in relation to the maximum speed attainable. This is valuable information in that it tells the operator what capacity that mill has for increasing speed to increase the particle size reduction obtained by that mill.

Similarly, the temperature of the cooling water is displayed in that manner. That is, the actual temperature sensed is shown, together with the set temperature and a percentage of capacity of the coolant flow is indicated by an arrow pointing to the flow valve 70. This information is, of course, related to the rotor speed information. For example, if the operator would like to increase the motor speed and the motor actually has additional capacity for this, he would expect that the temperature within that mill would rise, thus requiring a greater flow of coolant through the cooling jacket. If, however, the capacity of coolant flow is already approaching 100%, the operator may decide that increasing the rotor speed is not appropriate, or he may realize that there is some malfunction in the cooling system.

Another temperature control that may also be displayed is the trend or rate of change of temperature. If the temperature is increasing at a certain rate, it is known that it will be difficult to prevent exceeding a specified limit. Thus, the control unit will call for more coolant if the specified rate is exceeded, or the system may provide some other action if it is known that the coolant will not be able to handle the heat buildup.

The coolant control feature is particularly important because of a wide variety of materials that may be processed by the milling machines. Some materials can tolerate only relatively low temperatures, and yet other materials can be milled better at considerably higher temperatures.

Figure 5 shows a similar display for mill M4 showing the input from the binder supply as well as the other parameters shown for mill M1 in Figure 4.

Another significant advantage of this system is that once a successful operation for a particular product is obtained, the actual settings for the various parameters for that particular product can be stored in the memory or in the permanent storage medium of the system that is readily accessible by the control unit 28 so that the information can be recalled as desired for future use for processing the same product at a later time. This information may also be obtained from the printer, indicating not only the settings for the various parameters but also the actual product being prepared at what time, for what customer, together with whatever additional information is desired and fed into the control unit 28. Likewise, any of the various displays referred to above may be obtained in printed form for whatever use is desired. The system also has the great advantage of remote controlled operation wherein the control unit 28 need not necessarily be positioned near the sand mills, but instead be at very remote locations. Similarly, recorded control information may be sent to another location for use on a different processing unit.

The accuracy and repeatability of the system is particularly important in processing products having precise parameters. For example, with prior art methods of processing magnetic particle coating for magnetic tape, only about 70% of the coated tape has been acceptable for high performance applications. Increasing this percentage is of great value because of the cost of the poor quality tape. Also, flaws in the tape can produce failure of expensive apparatus used with or controlled by the tape.

Recorded information of the operational history of a milling machine is also valuable data from the standpoint of maintenance and design of such equipment.

Some additional information that is conveniently obtained from the system and that in the past has been largely ignored or has either been not obtainable or obtainable, only with considerable calculation and effort. One example of this is the electrical power consumption of the system. This information may be obtained on a motor-by-motor basis or on a combined system basis. Such information is useful in cost control and pricing and is also of value in analyzing the efficiency or practicality of a given operation. For example, as was mentioned above, the milling system may be utilized in producing fuel composed of coal and oil. It is useful to know the power consumption of production so that it may be compared to the electrical power that can be produced from the fuel which is being processed.

Another related cost and supply problem is that of the cooling water. A complete record of such is available to permit someone to analyze the data to determine cost of the product as well as when to consider alternate cooling systems with recirculated coolants.

Alternate Systems

From the foregoing, it may be appreciated that the controls of the above system may be modified to fit other similar systems. For example, the system discussed above adds a binder material into the fourth milling machine. Many operations require only the initial slurry be processed through the various mills. Also, the system may be utilized for controlling the operation of any number of mills, varying from one to the desired number. In other operations, it is desireable to add additional process equipment or other related apparatus. For example, in Figure 6 there is schematically illustrated the use of a high-speed disperser blending solid particles into a liquid carrier to form the slurry to be directed to the series of sand mills. If solid particles such as pieces of coal are to be milled in combination with water or oil, it may be desireable to initially reduce the size of the pieces somewhat and to disperse the pieces within the liquid by processing the materials through the disperser. Similarly, on occasion, it may be desireable to mix the output from different sets of sand mills, blending the outputs in a final dispersing operation. The monitoring and controlling of such dispersing operations may, of course, be integrated into the electrical speed control and the computerized master control unit.

Likewise, other operations of an overall process such as further handling of the ingoing or outgoing product may be incorporated into an integrated system completely controlled by the control unit 28.

Referring to Figure 7 for further explanation of the system detail, there is shown a schematic diagram of the hardware-software control and sensing apparatus for the seal oil pump 68 in Figure 3. The seal oil pump 68 is controlled by a hardware switch logic module 67 which, in the preferred embodiment is a DFM-1500-A3 manufactured by the Robert Shaw Controls Company of Anaheim, California. All model numbers mentioned hereinafter are Robert Shaw Controls Company model numbers. The hardware logic module 67 interfaces with a software interlock module 69 which is one of the four standard Virtual Control Modules within the Digital Supervisory Module DSM-1000 software sold by the Robert Shaw Controls Company as part of the control unit 28 model DSC-1000/1500.

The standard Robert Shaw software and hardware modules which will be discussed with reference to Figures 7, 8 and 9 have been configured or "softwired" together to implement an algorithm specifically adapted to run the sand mill of this invention. That algorithm is specified in Table I herein and will be discussed in connection with Figures 11-14. Table I gives the Boolean expression implemented by each of the interlock and control software loops in the Boolean Logic Module of the standard Digital Supervisory Software residing in the control unit 28. There are three other standard Virtual Control Software Modules in the control unit 28. They are a computational module, a ramp generator module and a high/low signal selector module, which is not used in this application. The computational module performs arithmetic operations and the ramp generator module is used to gradually increase and decrease motor speeds for various motors in the system after the starting and ending RPM and the elapsed time for the ramp is specified.

The software interlock module 69 implements the Boolean expression in Table I on the I116 row. The variable A and B in the expression refer to the logical results of two other loops C120 and I122. These other loops themselves implement the Boolean expressions listed for them on the corresponding rows of Table I. The variables in the expressions for the loops C120 and I122 are themselves other loops or are pressure, temperature or other transducers or various overload or switch devices. When all the variables are combined, the result of each loop is a logic 1 or logic 0 which may or may not become a variable in another expression.

After the I116 logical expression is evaluated, the result as a logic 1 or 0 is coupled to the hardware switch module 67 which either applies or disconnects power to the seal oil pump motor 68.

The output seal oil pressure on the line 70 is sensed by a pressure indicator hardware module P13 which, in the preferred embodiment, is a model AFM-1500-A3. The control unit 28 can read the seal oil pressure on the line 70 through the pressure indicating module P13.

Referring to Figure 8, there is shown a schematic diagram of the hardware-software control and sensing apparatus for the slurry and binder pumps 18 and 60 in Figure 3. The power to the slurry pump 18 is controlled by a model DFM-1500-A3 hardware switch module 19 and the software interlock module 21. The software interlock module 21 implements the Boolean expression for the I117 row in Table I. The pressure output of slurry pump 18 in the conduit 50 is monitored by the pressure indicating module P1 which is a model AFM-1500-A3. The amount of slurry in the line 50 in terms of volume of flow is indicated by the flow indicating controller module F1 which, in the preferred embodiment, is a DCM-1500-A2-A2.

The flow indicating controller F1 also controls the speed of the slurry pump motor 18 and has its own microprocessor. The F1 module is programmed initially with a set point from the supervisory microprocessor in the control unit 28. After the set point is supplied, F1 independently controls the speed of the slurry pump motor through signals to the inverter 26 to maintain the desired flow rate without further interaction by the control unit 28 supervisory microprocessor. The supervisory microprocessor will hereinafter be referred to as the control unit or controller, although the control unit also contains numerous other microprocessors in the individual hardware control modules for the motors and valves in the system.

As in Figure 8, the control unit 28 can read the model AFM-1500-A3 pressure indicating device P1 to determine the pressure in the line 50, and can read the flow indicating controller F1 to determine the volume of flow in the line 50. Further, the controller unit 28 can control the speed of the slurry pump 18 by changing the set point of F1.

The control circuitry for the binder pump 60 is coupled to the output line 50 of the slurry pump 18 by a model DCM-150-D2-A4 flow ratio controller F2. The flow ratio controller F2 is programmed with a set point by the controller 28 to control the speed of the binder pump 60 so as to control the amount of flow in the output line 62 from the binder pump 60 in accordance with the amount of flow sensed by the flow ratio controller F2 in the output line 50 of the slurry pump 18. That is, the flow ratio controller F2 controls the speed of the binder pump 60, thereby controlling its output volume to be a specific percentage of the flow in the output line 50 from the slurry pump 18. This flow controller F2 can be addressed by the control unit 28 and can store data from the control unit 28 which establishes the percentage mixture of binder to slurry.

The output pressure in the line 62 from the binder pump can be sensed by a model AFM-1500-A3 pressure indicating hardware module P12. This pressure indicating module P12 can be read by the control unit 28 to determine the output pressure in the line 62. Two interlock software modules 63 and 65 which implement the Boolean expressions for loops I121 and I122 in Table I use the P12 pressure as a variable. The software logic module 63 is an interlock that controls the emergency stop function which will be described in connection with a discussion of Figure 14. The software interlock 63 implements a Boolean equation of seven terms, five of which are pressures, one of which is the overload sensor 21 which, in reality, are a single overload sensor, and the last of which is a manual emergency stop button located on the operator's console of the control unit 28. The five pressures sensed are from the pressure indicating modules P1 through P4 and P12 in Figure 3. The interlock module 63 will shut down the machine if any one of these terms indicates a fault condition.

The interlock software module 65 checks the pressures from the sensors P1 through P4 and P12, which are its logic terms A through E, and implements the Boolean expression /A + /B + /C + /D + /E. The purpose of the interlock module 65 is to ensure that proper pressures exist in the binder and slurry system. The software module 65 is used by the control unit 28 in determining whether the proper slurry and binder pressures exist. Power to the binder pump 60 is controlled by the hardware module 67 and the software interlock module 69. The hardware switch module 67 is a model DFM-1500-A3. The software interlock module 69 implements the expression for I118 in Table I.

Referring to Figure 9, there is shown a symbolic diagram which is typical for the hardware-software control and sensing apparatus for each of the sand mills. Figure 10 is the control for mill M4 and differs from the control and sensing apparatus of the sand mills M1 - M3 in that M4 has two additional sensing units on its output line 64 which are not found on the output lines of sand mills M1, M2 or M3. These additional sensing units are pressure indicating unit hardware module P11 and flow indicating hardware module F3. Both P11 and F3 are of the AFM-1500-A3 model type. Both P11 and F3 serve as logic terms for the software interlock modules 123 and 117. The Boolean expressions for these software interlock modules 123 and 117 are given in Table I below for the I123 and I117 loops.

The rotor speed in the sand mill M4 is controlled by the speed of the motor 29 in Figure 3 which is controlled by the speed control hardware module 31 and the software modules 218 and 219. The speed indicator software module 220 represents the computation module within the digital supervisory module DSM-1000. It has a digital input on the line 395 from the speed indicating control hardware module S4 which is mechanically coupled to the shaft of the motor 29 to sense its speed and electrically coupled by the line 392 to control the motor speed. The hardware module 31 is a DCM-1500-A2-A2.

The speed indicating control module 31 controls the speed of the motor 29 in conjunction with the ramp generator software module 218, which is part of the digital supervisory module DSM-1000. The purpose of the software module 218 is to enable the control unit 28 in Figure 3 to cause the speed of the motor 29 to be increased or decreased gradually by changing the set point of the speed indicating controller 31 under certain conditions, which are controlled by the software interlock module 219. The software interlock module 219 implements the Boolean expression in Table I and controls when the ramp generator 218 is controlling the set point of the speed indicating controller S4. The interlock software I219 causes the ramp generator 218 to come into effect during the mill startup and shutdown sequences. The motor

29 is interlocked with other parameters in the system through a model DFM-1500-A3 hardware switch module 108 and the software interlock module 216. The software module 216 implements the Boolean expression given in Table I below and controls power to the motor 29 through the hardware interface module 108. The binder material comes into the input conduit 62 through the binder conduit 71, while the seal oil enters the seal through the conduit 70. Pressure indicating unit P4 is an AFM-1500-A3 model and senses the input pressure in the line 62.

The flow of the cooling water through the pipe 72 and the cooling jacket surrounding the sand mill M4 is controlled by the electrically operated valve 79. The valve 79 is controlled by a temperature indicating control unit 81 which is a model DCM-1500-A2-A2. This unit can be programmed with a set point by the control unit 28 and thereafter independently controls the temperature by controlling the amount of cooling water flowing through the valve 79. The temperature indicating and control unit 81 also has alarm limits which set flags indicating whether the temperature is outside the acceptable range. The temperature control hardware module 81 communicates with the software interlock module 119 which implements a Boolean logic expression given in Table I below for I119. The temperature indicating control hardware module 81 can be read by the control unit 28 to determine the temperature of the slurry in the sand mill. The software interlock module 119 communicates with the temperature indicating unit 81 as part of the sand mill temperature check routine which is continuously executed during operation of the sand mill, as will be described with reference to Figure 12.

Referring to Figures 10-13, there is shown a simplified flow diagram for the algorithm of the control unit 28 in Figure 3. The normal start routine starts on Figure 10 at point A. The digital supervisory module performs a normal start routine which commences with the three decision blocks 300, 302 and 304. The decision block 300 determines whether the emergency stop button on the operator's console has been pushed. If it has, the software loops back to point A by the path 306. If it has not, program execution proceeds to decision block 302 via the path 308. In the decision block 302, the control unit determines if the temperature in any of the sand mills exceeds the upper temperature limit by reading the temperature indicating controllers such as 81 in Figure 10. The interlock module 119 in Figure 9 is represented by the decision block 302 in Figure 10 and will cause processing control to proceed along a path 310 if the temperature in any of the sand mills is too high.

If the temperatures in the sand mills are within acceptable limits, the digital supervisory module procedes along the path 312 to determine whether the start button has been pushed as represented by the decision block 304. If the start button has not been pushed, program control transfers back to the point A on the path 314.

If the start button has been pushed, program control is transferred to the block 316 to establish the system parameters. The system parameters are the set points and alarm limits for the various controllers in the system. For example, there will be a set point for the speed indicating controller 31 and the temperature indicating controller 81 in Figure 9 and for the flow indicating controllers F1 and F2 in Figure 8. Each sand mill has a set point for the corresponding speed and temperature controllers associated with it.

Each of the controllers in the system has its own microprocessor which uses the set point as the target for controlling the speed of the motor associated with the controller. The controllers operate independently of the digital supervisory module in the control unit after the control unit 28 has established the set point for each controller. After these set points are established, the control unit 28 need only monitor the system parameters and display them. Each of the controllers and other indicating device systems generate analog signals which can be read by the control unit 28 and converted to digital data for purposes of display to the operator of the various pressures, temperatures and flow rates in the system. The various controllers and other indicating hardware modules in the system previously discussed in connection with Figures 7, 8 and 9, also have alarm limits to establish acceptable ranges for flow, pressure and temperature. Each alarm limit has a flag associated with it which can be read by the control unit 28 to determine whether the particular parameter in question is outside acceptable limits. These limits can be established by the control unit 28.

Referring again to Figure 10, the system parameters can be established in the block 316 in either of two ways. The system set points and alarm limits can be established manually by the operator from the console on the control unit 28. Alternatively, the system parameters and alarm limits can be brought in from bulk storage, such as a disk, used for keeping archival records for previous runs which have proved satisfactory for the production of certain products. These archival records may be stored by the operator after he has experimented with the system parameters by a trial and error method of examining the output product versus the desired end product and adjusting the parameters accordingly to alter the output product. Once the operator is satisfied with the system parameters and alarm limits, he can store the parameters on the archival disk or tape which is symbolically illustrated by the block 318 on Figure 11.

After the system parameters are established, the control unit 28 is ready to begin the start-up sequence which begins with the block 320 in Figure 10. The start-up sequence requires that seal oil pressure be established on the outside seal to balance the pressure on the other side of the seal within the sand mill vessel. The first step in the start-up sequence is to start the seal oil pump which is represented by the block 320. Referring to Figure 7, the seal oil pump 68 is started when the Boolean conditions implemented by the interlock module 69 are satisfied. The Boolean conditions are specified in Table I below. When all the conditions are satisfied, the hardware module 67 applies power to the seal oil pump 68 and seal oil pressure on the line 70 begins to rise.

After the seal oil pump is started, the seal oil pressure in the line 70 is sensed to determine whether the seal oil pressure is within the established limit. This action is represented by the block 322 in Figure 10, and physically involves a reading operation by the control unit 28 to determine the condition of the lower limit flag at the pressure indicator P13 in Figure 7, to determine if the seal oil pressure is above the established lower limit. The pressure indicating unit P13 is continuously read until the pressure has reached the acceptable level, as represented by the processing path 324. Once the seal oil pressure has risen to an acceptable level, the control unit starts the slurry supply pump 18 in Figure 8, represented by the block 326. With reference to Figure 8 and Table I, slurry pump 18 is started when the Boolean equation for the software interlock module 21, i.e. I117, evaluates to a logic 1. The logic 1 causes the hardware switch module 19 to apply power to the slurry pump motor 18. After the power is applied to the slurry pump 18, the flow indicating controller F1 will automatically regulate the speed of the slurry pump 18 in accordance with the set point established by the operator or brought in from the archival store.

After the slurry pump is started, the pressure in the outlet line 50 is checked by the control unit by reading the pressure indicating hardware module P1 in Figure 8. This step is represented symbolically in Figure 10 by the decision block 328. The control unit 28 will wait until the slurry input pressure to the sand mill M1 on the line 50 has reached an acceptable level, as represented by the processing control path 330.

When the pressure has risen to an acceptable level, processing transfers to the decision block 334 on the path 332. Block 334 is the first step in the portion of the start-up sequence having to do with establishing the rotor tip speeds for the four sand mills. Because the sand mills sometimes become difficult to start after a long period of being shut down, a motor jogging sequence is used if the amount of time that a particular mill has been shut down exceeds a predetermined amount of time. The purpose of the block 334 in Figure 10 is to determine whether the shutdown time has been exceeded. If not, the processing transfers to a block 336 via a path 338 to initiate the speed control for the motor 22 driving sand mill M1 in Figure 3. Block 336 represents the operations of establishing the set point in the speed indicating controller 31 in Figure 9.

If the shutdown time has expired, then the mill M1 drive motor must be jogged three times to break it loose. This is represented by the block 340 in Figure 10. After the motor has been jogged three times, processing proceeds to the previously-described block 336.

After mill M1 is started, the output pressure from the mill on the line 51 is checked by reading the pressure indicating device P2 in Figure 3. This step is symbolized by the block 342 and Figure 10. If the slurry output pressure indicated by P2 is not within the acceptable range, the control unit 28 will delay starting mill M2 until the pressure is within the acceptable limit. This is symbolized by the path 344 in Figure 10.

Once the output pressure from mill M1 has reached an acceptable level, processing proceeds to the decision block 346 to determine whether the shutdown time for mill M2 has exceeded the maximum permissible time. Processing then continues in a similar fashion as for mill M1 to start the motor 25 for mill M2. This processing is symbolized by the blocks 346, 348, 350 and the path 352.

After the motor 25 for mill M2 has been started and the speed control associated with it is programmed with the set point, the output pressure for mill M2 is checked by reading the pressure indicating device P3 in Figure 3. This step is symbolized by the block 354 on Figure 11. Once the output pressure from mill M2 has risen to an acceptable level, the control unit 28 begins the process of starting the motor for mill M3. The processing steps are the same as for mills M1 and M2 and are represented by the blocks 356, 358, 360 and the path 362 in Figure 11.

After the motor 27 driving mill M3 is started and the speed controller associated with it is programmed with the set point for the speed for mill M3, the speed controller for the motor automatically controls the speed of the mill M3 at its set point through the speed transmitter S3 and the inverter 26 until the set point is changed. Before the motor 29 driving mill M4 can be started, the input slurry pressure on the line 71 must be checked by reading the pressure from pressure indicating hardware module P4 in Figure 3. This step is symbolized by the decision block 364 in Figure 12.

After the input pressure to mill M4 has reached a sufficient level, processing proceeds to the block 366 where the controller unit 28 starts the binder supply pump 60 in Figure 3. Referring to Figure 9, the binder supply pump 60 is started when the Boolean expression implemented by the interlock software module 69 is satisfied. Referring to the I116 in Table 1, the Boolean expression for the software module 69 is given. When the conditions implemented by the software module 69 are satisfied, the hardware switching module 67 will apply power to the binder pump 60 and binder material will be pumped into the input line for mill M4 in the line 62. The speed of the binder pump 60 will be controlled by the flow ratio indicating controller F2 in Figure 9 which has been programmed by the control unit 28 with its set point to determine the desired percentage mix of binder to slurry.

After the binder supply pump has been started, the shutdown time for mill M4 is compared to the time limit as represented in the block 368. Processing then continues to start the mill M4 motor in a similar fashion as was done for mills M1 through M3. These steps are represented by the blocks 368, 370, 372, and the path 374 in Figure 11.

After the operator is satisfied that the output product is as desired, he has the option of storing the system parameters in a bulk storage media for future reference. These system parameters include the motor speed set points for the mills M1 through M4, the ramp profiles for starting and stopping the motors in terms of the RPM of the starting and ending points and the time interval during which the transition is made, the temperature set points and the pressure alarm limits for the slurry, binder and seal oil as well as all other variables in the system involved in the Boolean expressions typified in Table I. This optional storing operation is represented by the block 376 in Figure 11.

During the operation of the mills, the maximum temperature alarm limits of the slurry in the various mills is monitored by the control unit 28 to determine if any of the sand mills is overheating. This scanning process is symbolized by the block 378 in Figure 11. If any of the mills is overheating, an emergency stop routine is entered as symbolized by the path 379. The control unit 28 can also read the temperature indicating controllers T1-T4 to determine the percentage of total coolant capacity flow rate which remains to be used.

During the operation of the sand mill, all the system parameters are monitored and displayed by the control unit 28. This operation is symbolized by the block 380 in Figure 11. The control unit can also display the rotor speed in relation to the maximum rotor speed available from the system. The accumulated system parameter data can be displayed in one of several optional formats.

The sand mills continue to operate until the operator orders a manual stop symbolized by the block 382 or until an emergency stop condition has occurred in the system which is symbolized by the block 384. If the operator has pushed the manual stop button, processing control transfers to a normal stop routine depicted on Figure 12 starting at E and symbolized by the path 386 in Figure 11. If an emergency stop condition has occurred, processing control transfers to an emergency stop routine starting at F on Figure 13 as symbolized by the path 387 in Figure 11. If neither an emergency stop nor a manually-ordered stop has occurred, processing control returns to the point I in Figure 11.

Referring to Figure 12, the normal stop routine implements a shut-down sequence to stop the motors in the system in the proper order. The first step is to stop the binder supply pump 60 in Figure 3. This step is symbolized by the block 388 in Figure 12.

After the binder supply pump is stopped, the slurry supply pump is stopped as symbolized by the block 390. Thereafter, the motors for mills M1 through M4 are ramped down to zero RPM by the ramp generator software modules and interlock software such as 218 and 219 in Figure 9. The ramp generator 218 controls the set point of the speed indicating controller hardware module 31. The speed control module 31 then controls the armature current for the motor 29 via the line 392 which symbolizes the control of the motor current through the inverter 26 in Figure 3.

The speed indicating controller 31 also sends a digital signal representing the rim speed to the speed indicating computational software module 220 which is a computational Virtual Control Module forming part of the Digital Supervisory Module DSM-1000. The software module 220 computes the motor shaft speed from the rim speed signal on the line 395 and makes this computational result available for display by the control unit 28.

The ramp-down sequence starts with the motor for mill M4 and proceeds backward to mill M1 as indicated by the blocks 394, 396, 398 and 400 in Figure 12. The control unit 28 then reads the speed indicating software module 220 in Figure 9 to determine whether mill M4 has stopped as represented by the block 402 in Figure 12. If it has not stopped, the control unit waits for it to stop as represented by the processing control line 404. After it has stopped, the control unit 28 turns off the mill M4 drive control hardware module 108 in Figure 9 through the interlock software module 216 as represented by the block 406 in Figure 12.

The control unit then tests the speed indicating unit for mill M3 to determine whether the mill M3 motor has stopped. This is represented by the block 408 in Figure 12. When it is satisfied that the mill M3 motor has stopped, the control unit turns off the mill M3 drive control, thereby removing the power from the motor 27 in Figure 3. This is represented by the block 410 in Figure 12. This process is repeated until all motors have their power cut off.

The normal stop routine continues on Figure 13 at H. After the control unit 28 is satisfied that mill M1 has stopped and has shut off the power to mill M1's motor, the control unit reads all the pressure indicating hardware modules in the system except for the seal oil pressure indicating module P13, to determine whether all pressures are below the low alarm limits. If they are not, the control unit waits until all pressure indicating units indicate pressures below their lower alarm limits as symbolized by the block 420 in Figure 13 and the control path 422. After all pressure levels are below the low alarm limits, control is transferred to a block 424 wherein the control unit stops the seal oil pump 68 in Figure 3. Thereafter, the shutdown timer is started as symbolized by the block 426 in Figure 13.

Referring to the emergency stop routine starts at F on Figure 13. The first steps are to determine the cause of the emergency stop, and the control unit 28 looks in three places to determine the cause. The first cause could be that the supply pressures are low. Accordingly, the control unit 28 reads various supply pressures in the system and compares them in accordance with the Boolean expression implemented by the interlock module I123 in Table 1 as depicted on Figures 8 and 9 as software interlock modules 63, 123 and 121.

The next possible cause is an overload in the mill drive motors 22, 25, 27 and 29. Accordingly, the control unit 28 reads the overload circuit 21 associated with the motors which is shown typically only for the motor for mill M1.

The third possible cause would be that the manually-operated emergency stop button has been pushed. The scanning sequence embodied in the emergency stop routine is symbolized by the blocks 428, 430 and 432 in Figure 13 and is expressed in Boolean form in the logic expressions associated with software interlock modules I121, I123 and I122 in Table 1. If none of the three causes show up, the scan is continued until one of the causes does show up as symbolized by the path 434. Once the cause is determined, a message regarding the cause is printed on the printer 36 in Figure 1 and processing control transfers to the block 436 in Figure 13 which symbolizes the operation of stopping all pumps and mill drives except the seal oil pump. Processing control then transfers to the block 438 which symbolizes the steps taken by the control unit 28 to determine whether all supply pressures have dropped below the lower alarm limits. The control unit 28 waits until all supply pressures drop below the lower alarm limits as symbolized by the path 440. Once this low pressure condition is satisfied, processing control transfers to the block 442 which symbolizes the operation of stopping the seal oil pump. Thereafter, the control unit returns to the point A on Figure 10 and waits for a normal start sequence to begin.

Figures 10 through 13, taken together with the Boolean expressions of Table 1, together describe the custom portion of the algorithm used in the system described in Figure 1. All other hardware and software in the control unit 28 is available commercially from the Robert Shaw Controls Company in the model designations given herein. A listing of the object code of the custom portion of the software for the control unit 28 is attached hereto as Appendix A.

Although the invention has been described in terms of the preferred embodiment disclosed herein, all other embodiments accomplishing the same function in substantially the same way using substantially the same means are intended to be included within the scope of the claims appended hereto.

TABLE I

Physical Connotation	Software Control On Interlock Module	Boolean Expression	Variables Defined
Seal Oil Pump Co.	I116	$A + B$	A = C120 loop
Auto Start/ Stop	C120	$\bar{A} \cdot B \cdot C$	A = I123 B = I119
Binder/Slurry Pressure Check	I122	$\bar{A} + \bar{B} + \bar{C} + \bar{D} + \bar{E}$	A = P1 pressure B = P2 pressure C = P3 pressure D = P4 pressure E = p12 pressure
Emergency	I123	$A + (B \cdot C) + D$	A = I121 loop B = I122 loop C = P11 pressure D = I123
Mill Temp. Check	I119	$\bar{A} \cdot \bar{B} \cdot \bar{C} \cdot \bar{D}$	A = T1 temperature B = T2 temperature C = T3 temperature D = T4 temperature

Emergency Stop Pressure Check	I121	$A+B+C+D+E+F+G$	A = P1 pressure B = P2 pressure C = P3 pressure D = P4 pressure E = P12 pressure F = C8 drive overload; 21, Fig. 3 G = C16 emergency stop button
Slurry Pump Control	I117	$\bar{A} \cdot B \cdot \bar{C}$	A = I123 B = C120 C = P11 pressure
Binder Pump Control	I118	$A \cdot B \cdot C$	A = I123 B = C120 C = P4 pressure
Mill #4 Drive Control #1	I216	$\bar{A} \cdot B \cdot \bar{C}$	A = I123 B = P4 pressure C = C217

Mill #4 Drive Control #2	C217	$\overline{A} \cdot B \cdot C \cdot D \cdot E$	A = C100 shutdown timer B = C218-06 Mill #4 speed ramp C = C218-08 Mill #4 speed ramp D = C218-10 Mill #4 speed ramp E = C218-12 Mill #4 speed ramp
Ramp Hold Mill #4	I219	$A \cdot B$	A = C120 B = C218-12 Mill #4 speed ramp

Boolean expressions for Mills #1-3 are similar to those of Mill #4.

WHAT IS CLAIMED IS:

1. A system for milling and dispersing solid particles within liquids comprising:

one or more milling machines including a vessel with a grinding media therein, a rotor within the vessel for agitating the media, and a motor for rotating the rotor;

a pump for pumping a liquid/solid slurry through the vessel while the media is being agitated by the rotor to thereby perform the milling and dispersing operation;

an electric speed control for controlling the speed of the motor;

means for sensing various parameters of the milling and dispersing operation including motor speed; and

control means for receiving and processing input instructions from said sensing means and for providing output signals to said speed control to control the speed of said motor to obtain desired characteristics of the output product as it leaves the milling machines.

2. The system of Claim 1 including means for manually inputting control instructions to the control means to modify said output signals.

3. The system of Claim 2 including display means linked to said control means for indicating various parameters of the milling and disbursing operation.

4. The system of Claim 3 wherein said display means receives information from said control means to indicate the linear rim speed of said rotor.

5. The system of Claim 3 wherein said sensing means includes means for sensing the flow of slurry into said vessel and said control means continuously monitors the slurry flow and provides an indication of such flow on said display means.

6. The system of Claim 5 wherein said sensing means includes means for sensing the output flow of said product output and the control means continuously monitors the product output flow and said display means indicates the output product flow.

7. The system of Claim 1 including means for circulating coolant in heat-transfer relation with said vessel.

8. The system of Claim 7 including means for controlling the quantity of coolant passing in heat-transfer relationship with each vessel, and wherein said sensing means includes means for sensing the temperature of the slurry within said vessel and said control means provides an output signal to said coolant flow control means to increase or decrease the coolant flow and maintain the slurry temperature within said vessel at a desired level.

9. The system of Claim 8 wherein said display means includes means for indicating the temperature of the slurry in said vessel, means for indicating the coolant flow, and means for indicating the coolant flow in relation to the capacity of coolant flow that is available.

10. The system of Claim 8 wherein said coolant flow control includes valve means monitored and programmed by said microprocessor means for controlling the flow coolant circulated adjacent said vessel.

11. The system of Claim 1 including means for indicating the rotor speed in relation to the maximum rotor speed attainable from the system.

12. The system of Claim 1 wherein said milling machine includes:

a rotor shaft extending out of said vessel;

rotor seal means for preventing slurry from escaping from said vessel along the rotor shaft;

means for maintaining a lubricant under pressure on one side of said seal means to balance the slurry pressure on the other side of the seal; and

wherein said sensing means includes means for sensing said lubricant pressure with such pressure signals being fed to said control means to monitor said lubricant pressure to insure that adequate lubricant pressure is obtained during operation of said system.

13. The system of Claim 1 including two or more milling machines with said slurry being pumped through the vessels of said machines; and including means for pumping a supplementary liquid into a vessel downstream from the first vessel to be dispersed with said slurry to form a constituent of the product at the output of said system.

14. The system of Claim 13 wherein said sensing means includes means for sensing the pressure and the flow of said supplementary liquid to enable the control means to monitor such parameters and enable said display means to indicate such parameters.

15. The system of Claim 13 wherein said slurry includes magnetic particles in the liquid carrier for such particles to make a coating utilized in the fabrication of magnetic tape, and said supplimentary liquid is a binder necessary for such coating.

16. A system for milling and dispersing solid particles in liquids comprising:

a series of milling machines, each including a vessel with a grinding media therein, a rotor within the vessel for agitating the media, the rotor including a shaft extending out one end of the vessel with a seal surrounding the shaft to prevent product leakage out of the vessel, a motor for driving the rotor through said shaft, and a cooling jacket adjacent the vessel for controlling the temperature within the vessel;

a pump for pumping a slurry through the vessel while the media is being agitated by the rotor to thereby perform the milling and dispensing operation;

means for applying fluid pressure to said seal to balance the pressure applied to the seal from the interior of the vessel;

means for circulating coolant through said jacket to control the temperature within said vessel;

means for sensing various parameters of the milling and dispersing operation, including means for sensing motor speed, means for sensing the output of the slurry pump, means for sensing the fluid pressure applied to said seal, means for sensing the temperature of the slurry within the vessel, means for sensing the pressure of the slurry applied to the vessel, and means for sensing the flow of coolant through said jacket; and

a master control unit for receiving and processing input instructions from said sensing means and for continuously and automatically monitoring and controlling the various parameters to obtain the desired characteristics of the output product as it leaves the milling machines.

17. The system of Claim 16 including means for storing the information for controlling a particular operation so that it may be readily recalled and used at a later time.

18. The system of Claim 16 wherein said master control unit also controls the start-up and shut down of the system in predetermined sequences.

19. A method of milling and dispersing solid particles within liquids comprising:

pumping a liquid/solid slurry through one or more milling machines including a vessel having a grinding media therein and a rotor therein for agitating the media;

rotating the rotor within said vessal to agitate the media while the slurry is being pumped through the vessel;

sensing various parameters of the operation including the speed of the rotor;

continuously and automatically controlling the speed of the rotor to obtain the desired characteristics of the output product including the receiving a signal of said sensed parameter by a control unit and the transmitting of control signals from the control unit to an electrical variable speed control for controlling the speed of the motor driving the rotor.

20. The method of Claim 19 wherein said sensing step includes the step of sensing the flow of the slurry to the milling machines, feeding the sensed flow signal to said control unit, transmitting signals from the control unit to the variable speed control for controlling the pumping flow.

21. The method of Claim 19 including the step of circulating coolant in heat exchange relation with the vessel to control the temperature of the slurry within the vessel; and wherein said sensing step includes the sensing of temperature of the slurry in said vessel; and controlling the flow of coolant by said control unit in response to the sensed temperature to maintain the desired temperature for the slurry.

22. The method of Claim 19 wherein said slurry is pumped through at least two vessels of said milling machines; including the step of pumping an additional liquid forming a constituent of the output product into a vessel downstream of the first vessel to mix such additional liquid with said slurry, sensing the flow of said additional liquid and continuously and automatically controlling the the pumping of the additional liquid to maintain the desired flow in relation to the flow of said slurry.

23. The method of Claim 22 wherein said slurry includes magnetic particles dispersed within a suitable carrier needed for the preparation for a coating of magnetic tape and said additional liquid is a binder likewise needed as a component of coating for making magnetic tape.

24. The method of Claim 22 wherein said sensing step includes the sensing of the pressure of the slurry being fed to the first of said vessels, sensing the pressure of the slurry output from the first of said vessel, sensing the pressure of the additional liquid being pumped, sensing the pressure of the product at the outlet of the last milling machine, and continuously monitoring such pressures by said sensors and said control unit and maintaining the pressures within a desired range.

25. A method of dispersing and milling a slurry of solid particles within liquid by pumping the slurry through one or more vessels in one or more milling machines, with each of the vessels containing a grinding media and a driven rotor for agitating the media as the slurry is pumped through the vessels, comprising:

Controlling the output of said pumping and controlling the speed of said rotors by way of electrical speed control means;

sensing the output of said pumping and the speed of said rotors;

employing a control unit to continuously and automatically monitor the sensed parameters and provide output signals to said electrical speed control means to obtain the desired output and utilizing said control unit to initiate operation of the system in the following sequence, start the slurry pump, automatically sense the pressure within the first milling machine and start the motor for the first milling machine when the pressure therein reaches a predetermined minimum, sense the pressure in the second milling machine and start rotating the rotor in the second milling machine when the pressure therein reaches a predetermined minimum level, and continue the sequence for any succeeding milling machines.

26. The method of Claim 25 wherein said milling machines include seal means for preventing the slurry from escaping the vessels adjacent the rotor, and means for maintaining pressurized fluid on one side of said seal greater than the pressure on the other side of the seal within the vessel, said system further including a pump for maintaining said fluid pressure, and wherein said start-up sequence includes first starting the pump for establishing the fluid pressure and secondly sensing the fluid pressure and initiating the operation of the slurry pump after the fluid pressure has obtained a predetermined minimum.

27. The method of Claim 26 including reversing the sequence of said steps to shut down said system.

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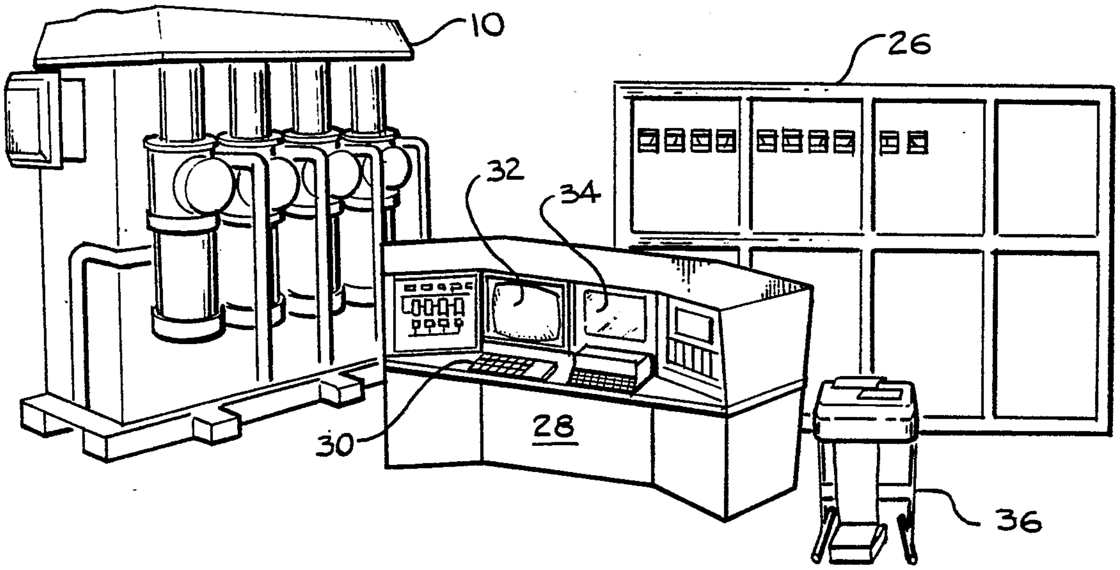
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26
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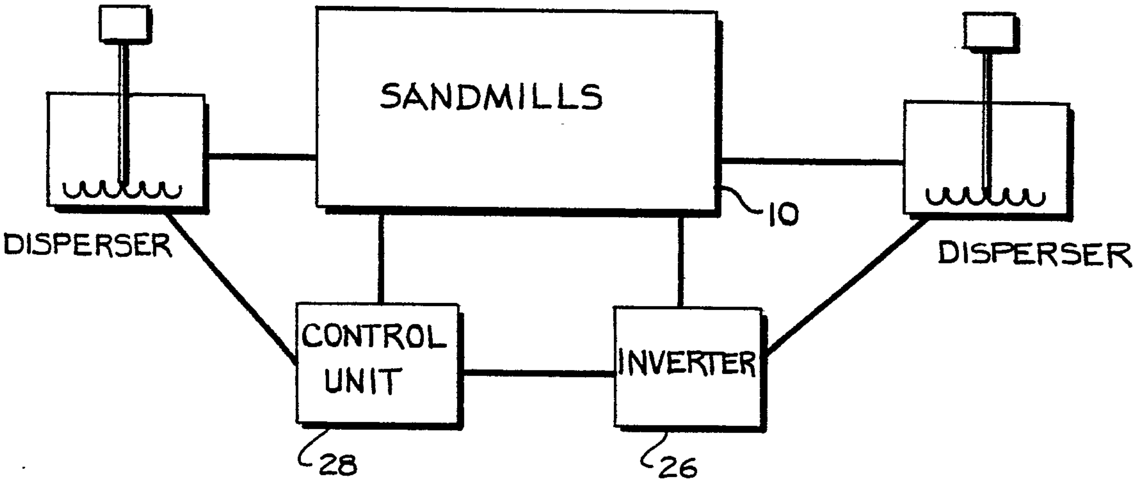
34
28
30
36

Fig. 1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DISPERSER
DISPERSER
CONTROL UNIT
INVERTER
28
26

Fig. 6

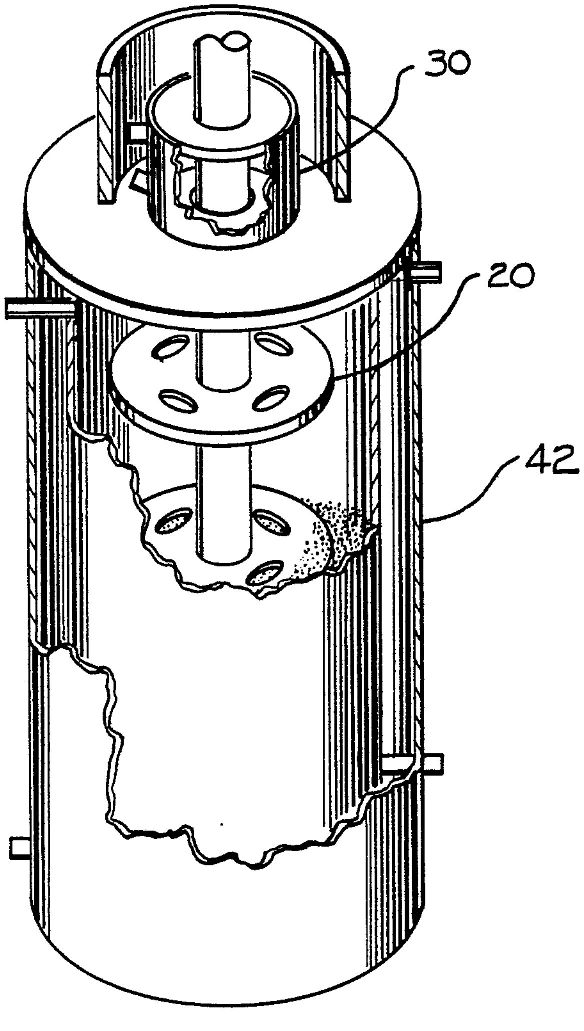

Fig. 2

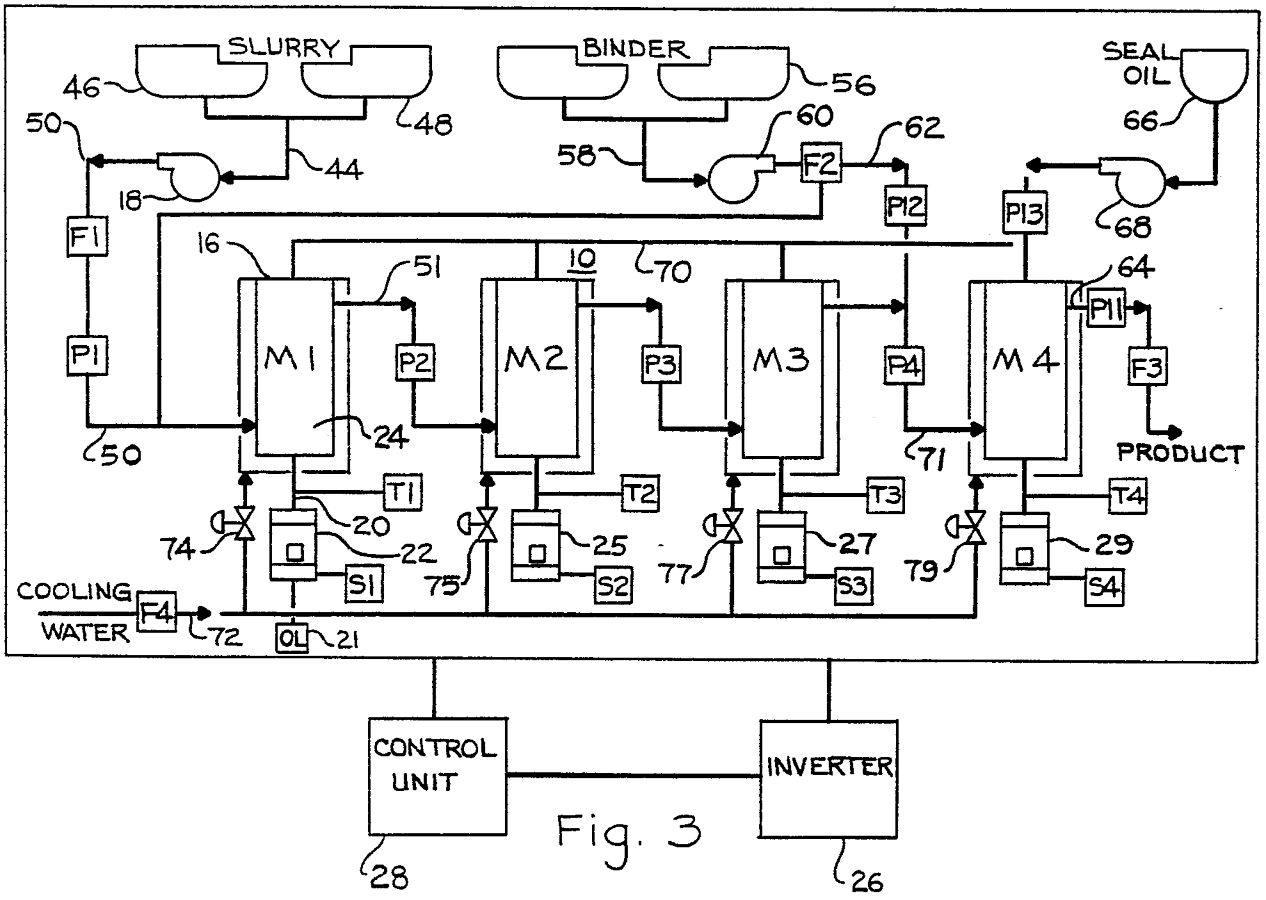
SLURRY
BINDER
SEAL OIL
46
48
44
50
18
F1
P1
50
16
M1
24
51
P2
10
70
M2
P3
M3
P4
71
M4
64
P11
F3
PRODUCT
56
58
60
F2
62
P12
P13
66
68
T1
T2
T3
T4
20
22
25
27
29
S1
S2
S3
S4
74
75
77
79
COOLING WATER
F4
72
OL
21
CONTROL UNIT
INVERTER
28
26

Fig. 3

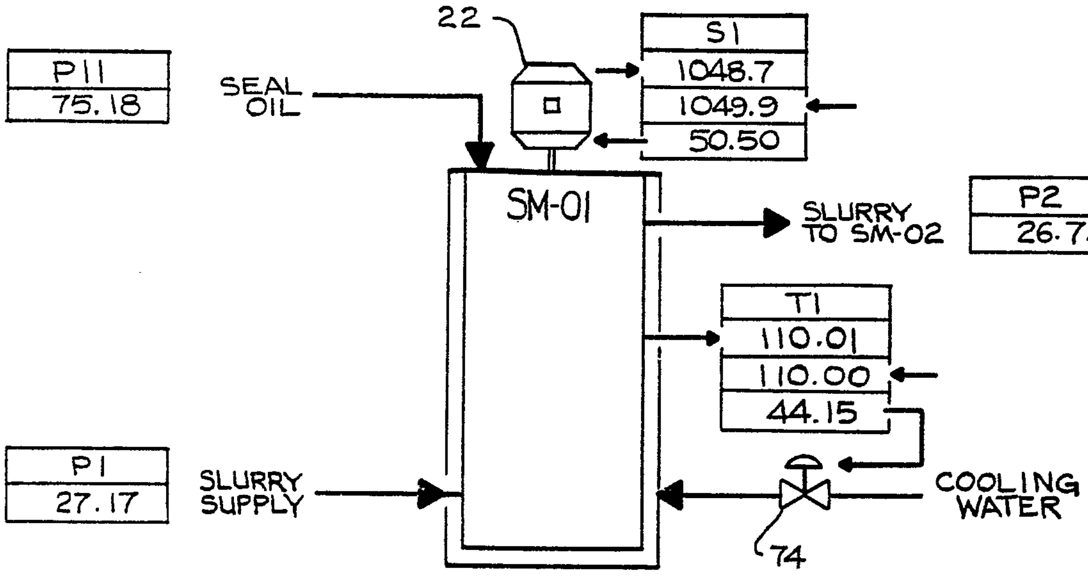
22
P11
75.18
SEAL OIL
S1
1048.7
1049.9
50.50
SM-01
SLURRY TO SM-02
P2
26.73
T1
110.01
110.00
44.15
P1
27.17
SLURRY SUPPLY
COOLING WATER
74

Fig: 4

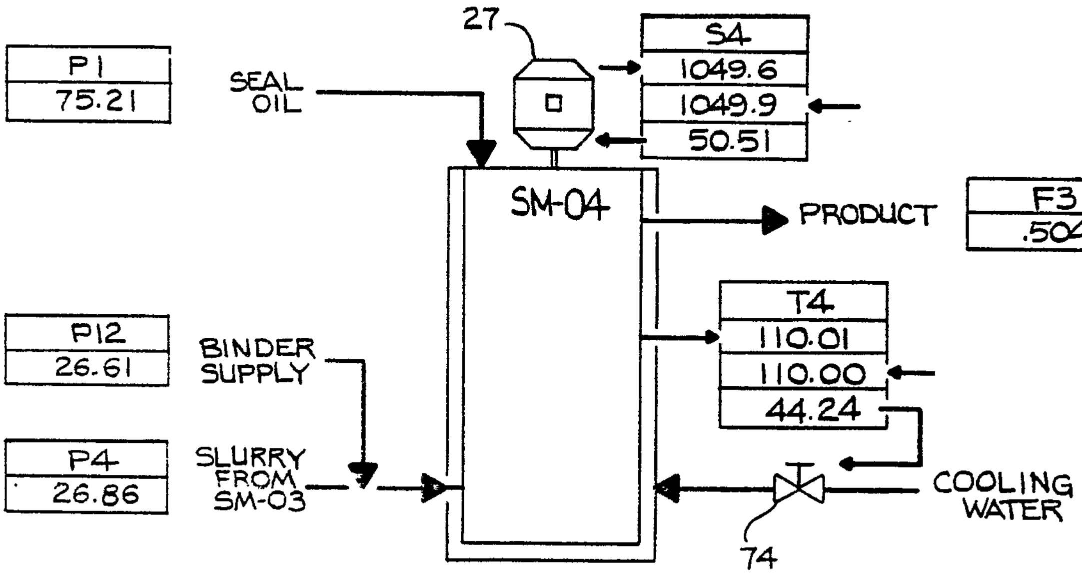
27
P1
75.21
SEAL OIL
S4
1049.6
1049.9
50.51
SM-04
PRODUCT
F3
.5047
T4
110.01
110.00
44.24
P12
26.61
BINDER SUPPLY
P4
26.86
SLURRY FROM SM-03
COOLING WATER
74

Fig. 5

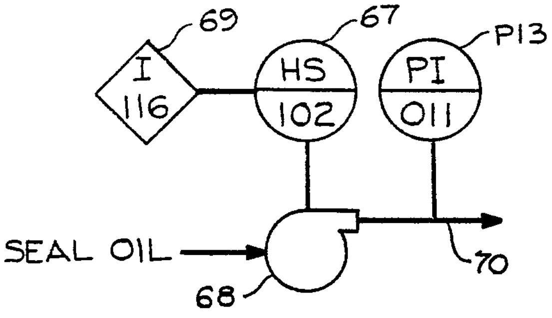

Fig. 7

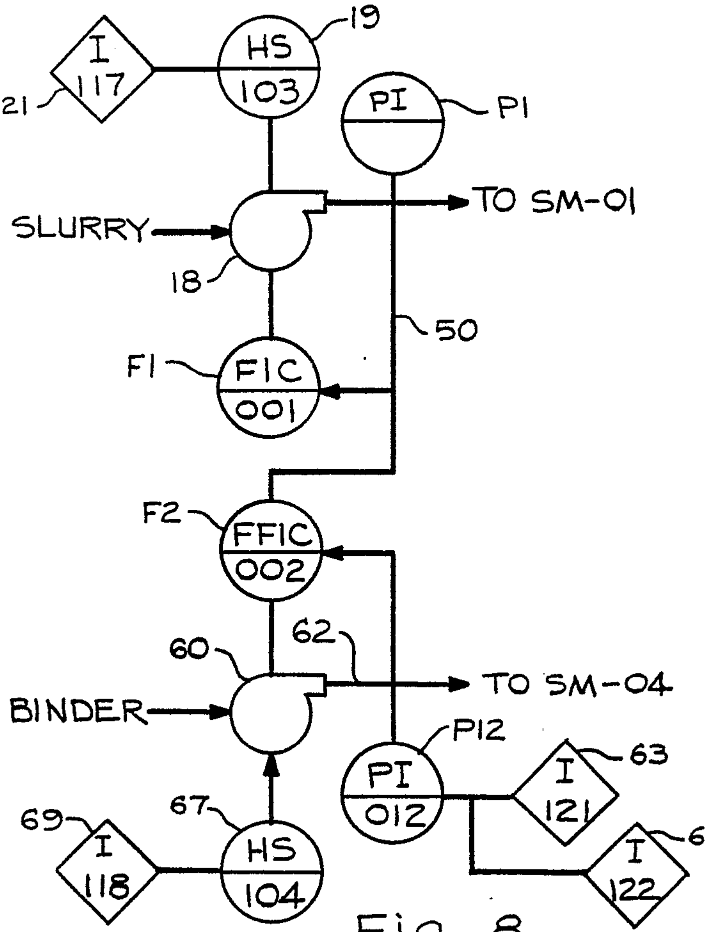

Fig. 8

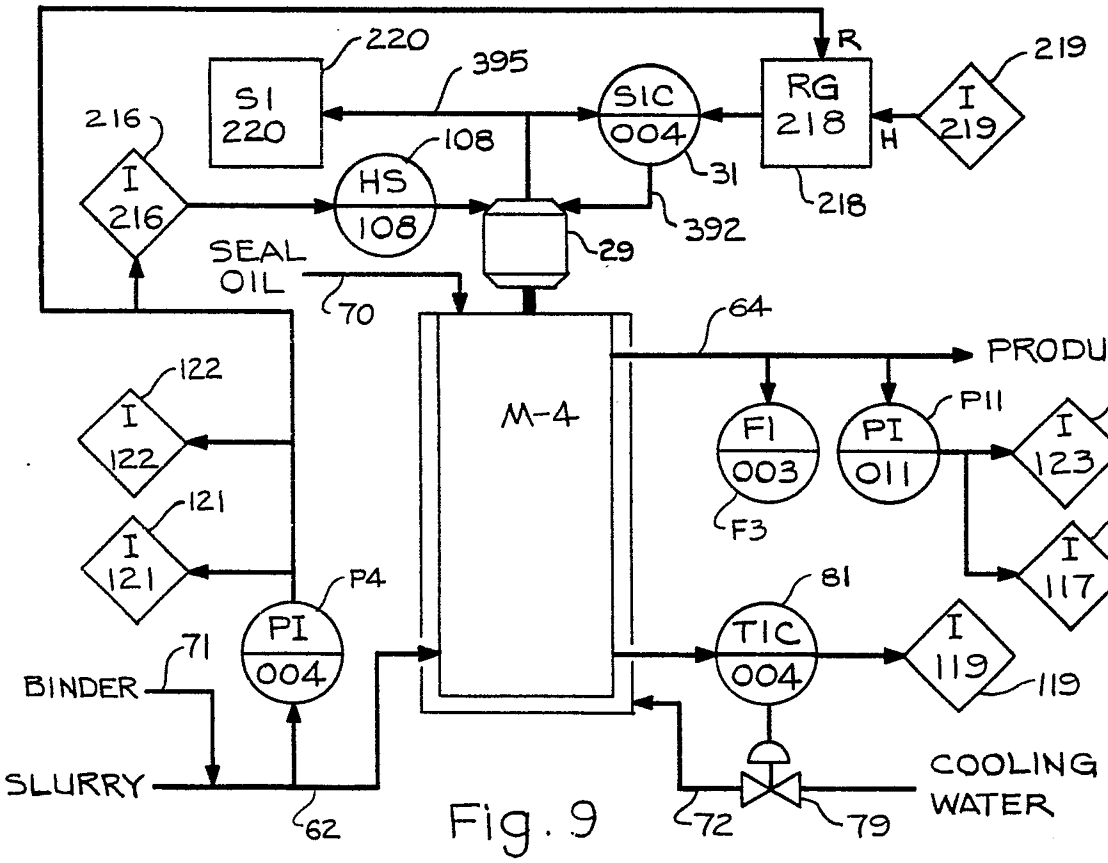

Fig. 9

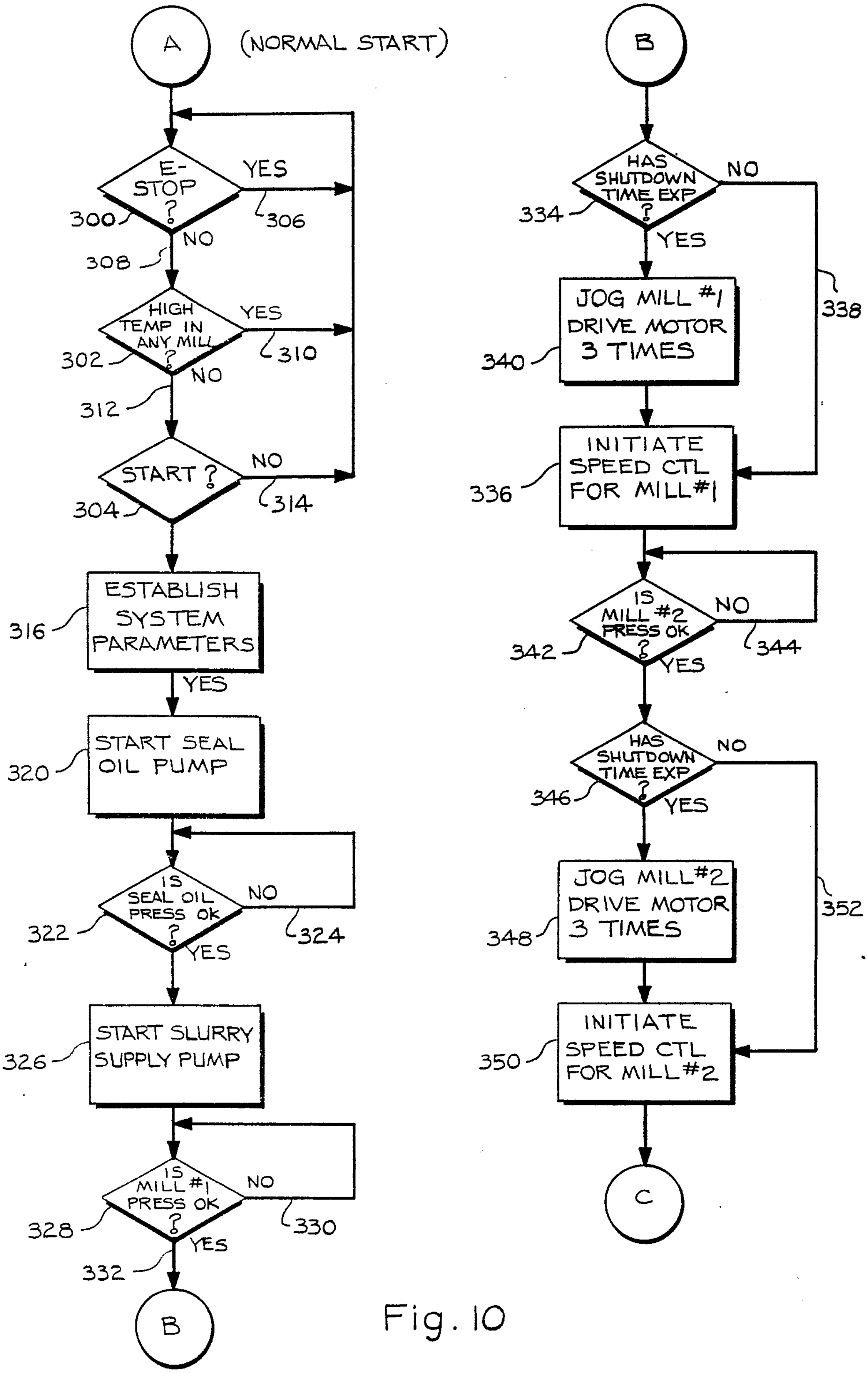
A
(NORMAL START)
E-STOP ?
YES
NO
300
306
308
HIGH TEMP IN ANY MILL ?
YES
NO
302
310
312
START ?
NO
304
314
ESTABLISH SYSTEM PARAMETERS
316
YES
START SEAL OIL PUMP
320
IS SEAL OIL PRESS OK ?
NO
YES
322
324
START SLURRY SUPPLY PUMP
326
IS MILL #1 PRESS OK ?
NO
YES
328
330
332
B
B
HAS SHUTDOWN TIME EXP ?
NO
YES
334
338
JOG MILL #1 DRIVE MOTOR 3 TIMES
340
INITIATE SPEED CTL FOR MILL #1
336
IS MILL #2 PRESS OK ?
NO
YES
342
344
HAS SHUTDOWN TIME EXP ?
NO
YES
346
352
JOG MILL #2 DRIVE MOTOR 3 TIMES
348
INITIATE SPEED CTL FOR MILL #2
350
C

Fig. 10

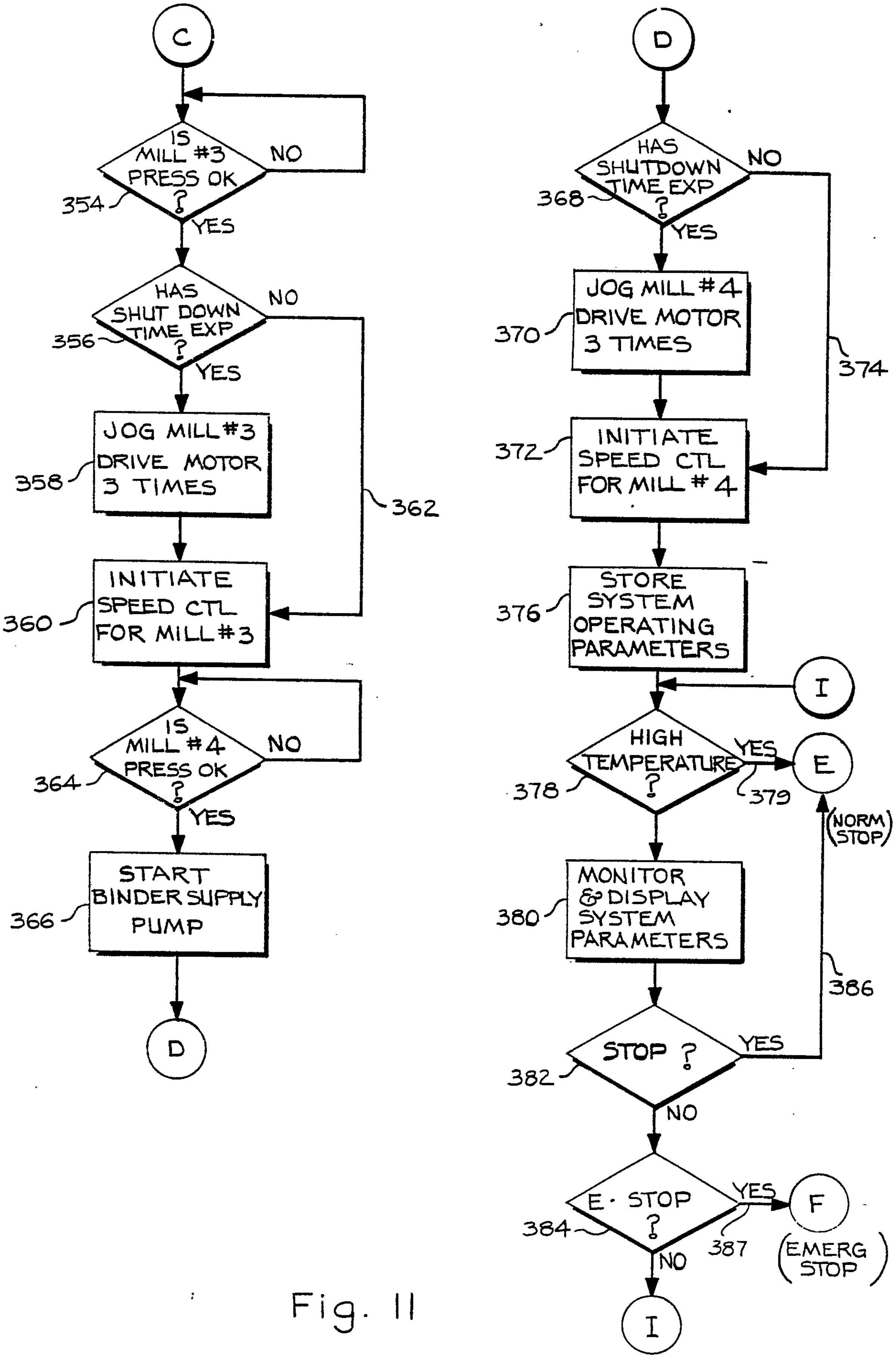
C
IS MILL #3 PRESS OK ?
NO
354
YES
HAS SHUT DOWN TIME EXP ?
NO
356
YES
JOG MILL #3 DRIVE MOTOR 3 TIMES
358
362
INITIATE SPEED CTL FOR MILL #3
360
IS MILL #4 PRESS OK ?
NO
364
YES
START BINDER SUPPLY PUMP
366
D
D
HAS SHUTDOWN TIME EXP ?
NO
368
YES
JOG MILL #4 DRIVE MOTOR 3 TIMES
370
374
INITIATE SPEED CTL FOR MILL # 4
372
STORE SYSTEM OPERATING PARAMETERS
376
I
HIGH TEMPERATURE ?
YES
E
378
379
(NORM STOP)
MONITOR & DISPLAY SYSTEM PARAMETERS
380
386
STOP ?
YES
382
NO
E · STOP ?
YES
F
384
387
(EMERG STOP)
NO
I

Fig. 11

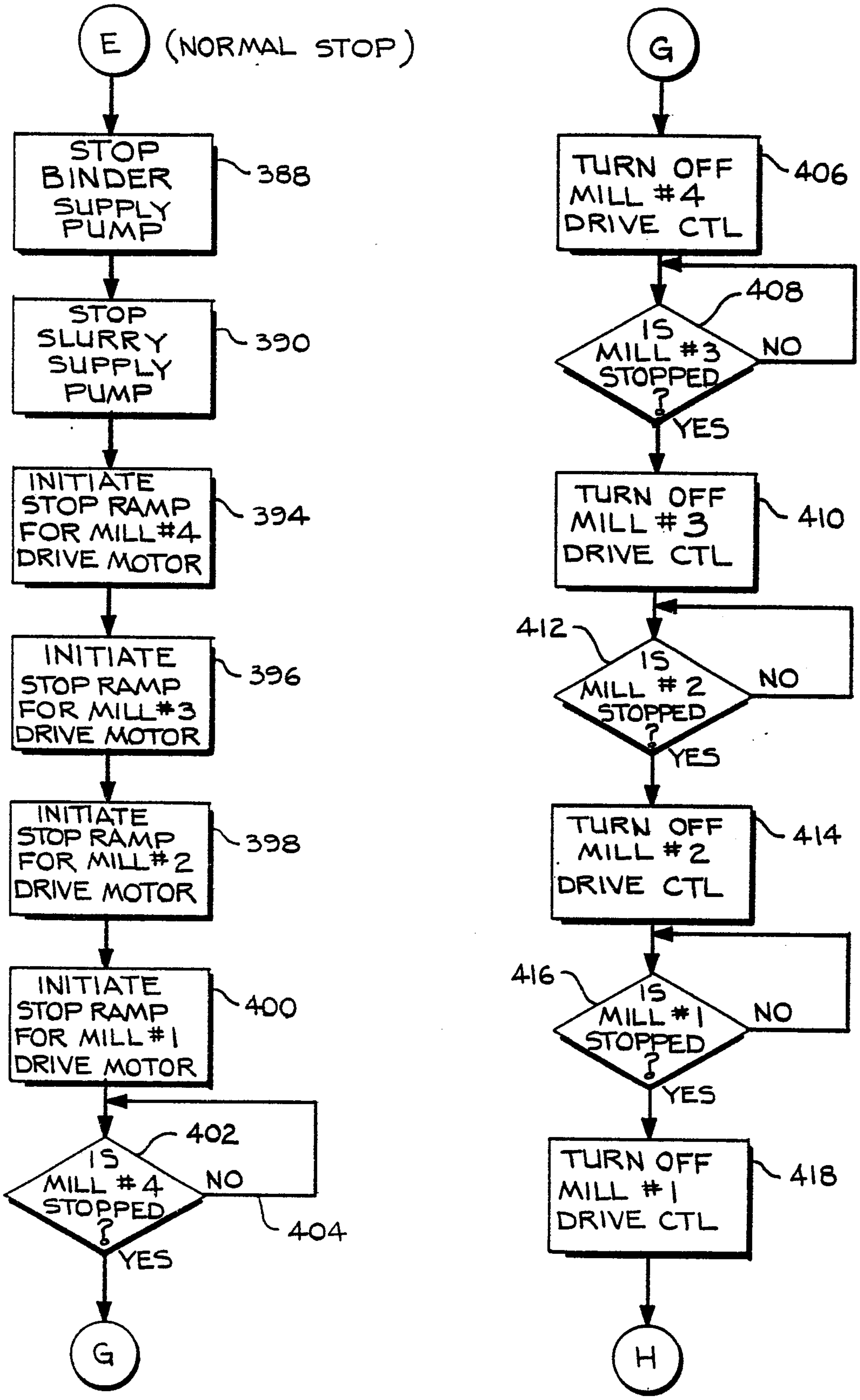
E
(NORMAL STOP)
STOP BINDER SUPPLY PUMP
388
STOP SLURRY SUPPLY PUMP
390
INITIATE STOP RAMP FOR MILL #4 DRIVE MOTOR
394
INITIATE STOP RAMP FOR MILL #3 DRIVE MOTOR
396
INITIATE STOP RAMP FOR MILL #2 DRIVE MOTOR
398
INITIATE STOP RAMP FOR MILL #1 DRIVE MOTOR
400
IS MILL #4 STOPPED ?
402
NO
404
YES
G
G
TURN OFF MILL #4 DRIVE CTL
406
IS MILL #3 STOPPED ?
408
NO
YES
TURN OFF MILL #3 DRIVE CTL
410
412
IS MILL #2 STOPPED ?
NO
YES
TURN OFF MILL #2 DRIVE CTL
414
416
IS MILL #1 STOPPED ?
NO
YES
TURN OFF MILL #1 DRIVE CTL
418
H

Fig. 12

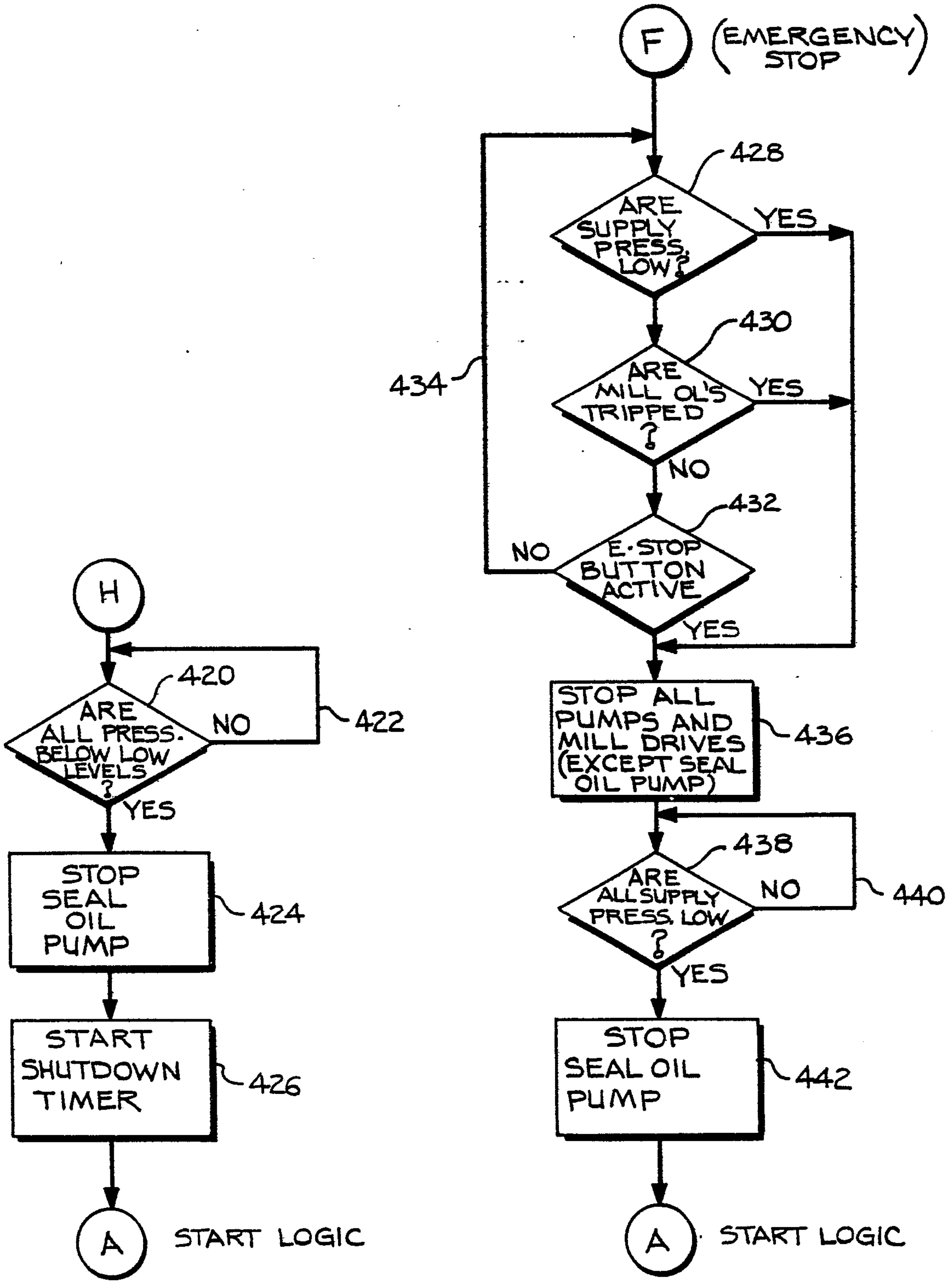
H
ARE ALL PRESS. BELOW LOW LEVELS ?
420
NO
422
YES
STOP SEAL OIL PUMP
424
START SHUTDOWN TIMER
426
A
START LOGIC
F
(EMERGENCY STOP)
428
ARE SUPPLY PRESS. LOW?
YES
430
ARE MILL OL'S TRIPPED ?
YES
NO
434
432
NO
E-STOP BUTTON ACTIVE
YES
STOP ALL PUMPS AND MILL DRIVES (EXCEPT SEAL OIL PUMP)
436
438
ARE ALL SUPPLY PRESS. LOW ?
NO
440
YES
STOP SEAL OIL PUMP
442
A
START LOGIC

Fig. 13