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Bay

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[54] METHOD AND APPARATUS FOR CEMENT KILN CONTROL

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[51] Int. Cl. F27b 7/00
[58] Field of Search 432/17, 19, 24, 36, 432/51

[56] References Cited

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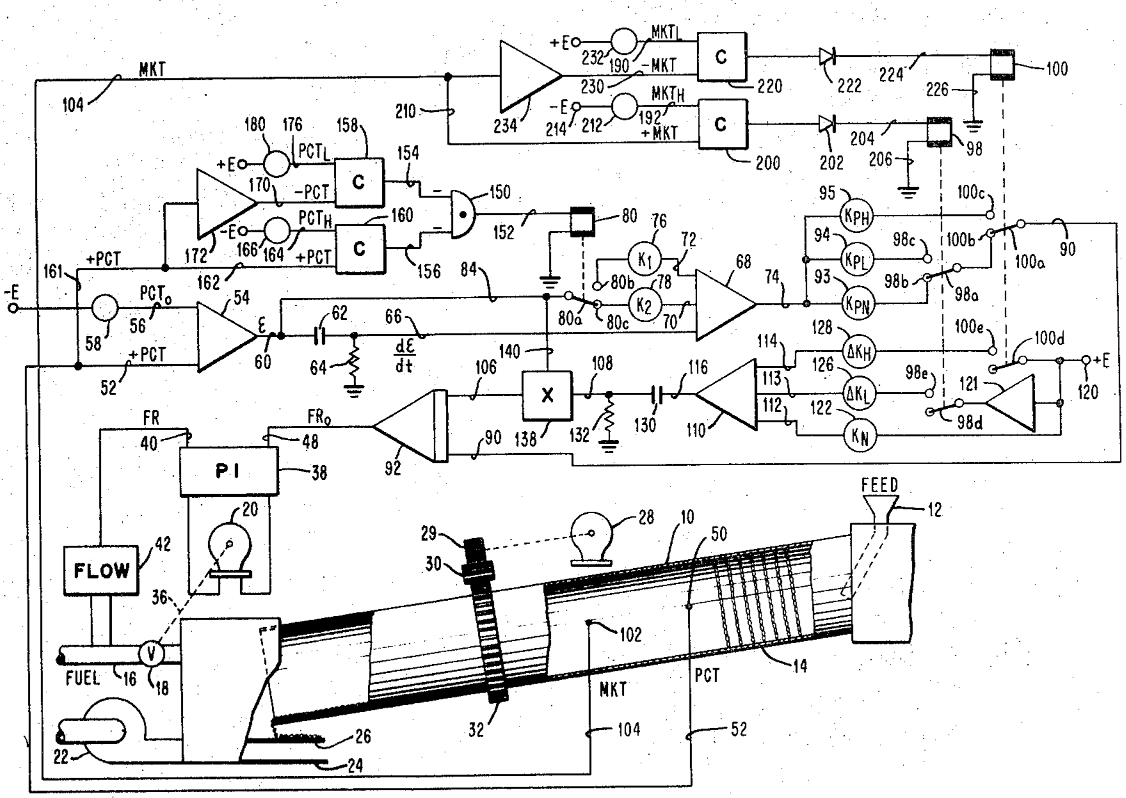
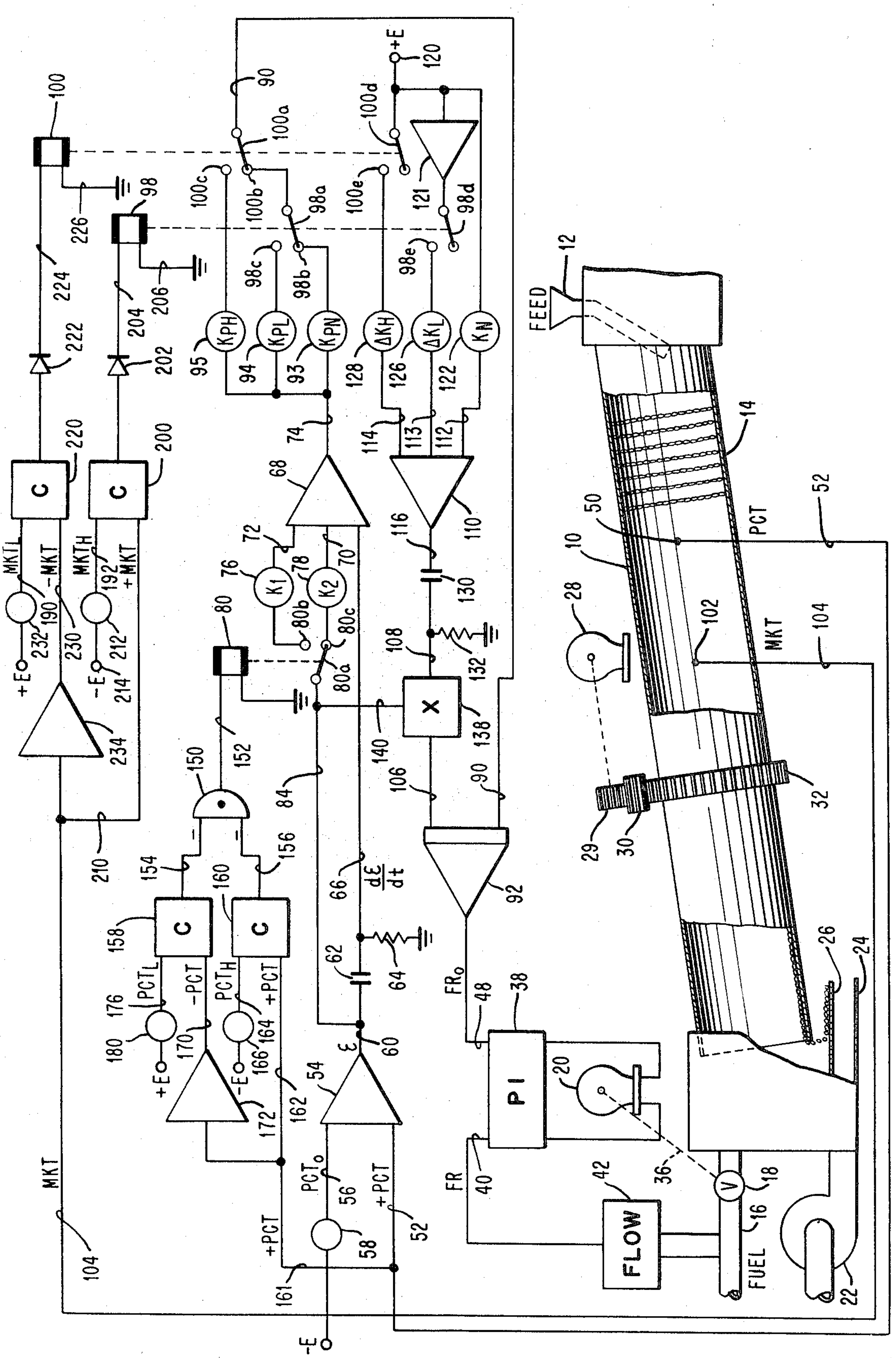
Attorney—William G. Miller, Jr. et al.

[57] ABSTRACT

A control system for controlling the firing rate in a rotary cement kiln so as to maintain the temperature just ahead of the chain section at a predetermined set point. The control system includes both proportional and integral control and is adaptive in that the reset rate of the controller is increased when the temperature deviation exceeds a predetermined amount. In addition the overall gain of the control system is modified so that the gain is changed to a lower value when a temperature measurement in the mid-kiln region exceeds a certain high value with the gain being changed to a higher value when that mid-kiln temperature is below a predetermined minimum value. Means are provided to compensate for the discontinuity in the proportional control action when the mid-kiln temperature causes a change in the controller gain.

8 Claims, 1 Drawing Figure




FEED
FUEL
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PI
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-PCT
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-E

METHOD AND APPARATUS FOR CEMENT KILN CONTROL

BACKGROUND OF THE INVENTION

This invention relates to the production of cement in rotary kilns and is particularly directed to an improved method and apparatus for controlling the temperature of the material being processed in a kiln so as to provide more stable kiln operation as well as a more uniform product.

The typical rotary cement kiln is a large steel cylinder which may, at the extreme, be on the order of 25 feet in diameter and over 700 feet long. These cylinders are lined with refractory brick and are inclined in a slight angle and rotated at speeds on the order of 20 to 120 revolutions per hour. The raw material for producing the cement includes finely ground limestone, clay or shale intermixed in the proportions desired. This mixture may be in the form of a dry pulverized mixture or in the form of a finely ground slurry. The raw material is fed into the upper or cold end of the rotary cement kiln.

As the kiln is rotated the raw materials move slowly down the kiln at a rate of speed which is a function of the kiln rotational speed. As the raw materials move down the kiln they pass through successive zones known as the chain zone, the preheating zone, the calcining zone, the clinkering or burning zone and the cooling zone. When the kiln is used for the wet process, that is, when the feed is in the form of a wet slurry, the moisture in the slurry is evaporated in the chain zone which may extend for 25 percent of the kiln length. In the chain zone, chains are suspended from the kiln to contact the slurry and to serve as a heat exchange medium between gases and slurry to drive off moisture.

As the raw materials move down the kiln they are heated by a stream of hot gases produced from a burner located at the material discharge end of the kiln. Those gases and any insufflated dust, which would be introduced at the material discharge end of the kiln, flow counter to the movement of the material in the kiln as a result of the negative pressure created at the feed end of the kiln by an induced draft fan. The heat from the combustion gases as well as the heated dust which may be insufflated causes the raw material to undergo successive changes due to the steady increase in the temperature of the material as it progresses toward the discharge end of the kiln.

The temperature of the dried raw material increases until the calcining temperature is reached. The calcining zone occupies the major portion of the kiln length. The temperature of the material changes little in that zone since the calcining reaction is endothermic and requires the absorption of the heat from the hot gases. When calcination is complete the temperature of the solid material begins to increase rapidly to a point where the exothermic clinkering reactions are initiated. The material leaves the clinkering zone at a high temperature and is thereafter cooled in the kiln and cooler.

It is well known that the degree of completion of the chemical reaction in the clinkering zone depends upon the feed composition, the temperature, and the period of time the material spends in that zone. The kiln must be controlled in such a manner as to produce a clinker product of uniform quality. It is, therefore, desirable that the temperature gradient along the kiln length be maintained and that any upset in that gradient should be quickly corrected.

In the past, the variation of the fuel feed has served only to control the temperature in the burning zone, or clinkering zone, as it is sometimes called. In some control arrangements such as that described in U.S. Pat. No. 3,566,091, which issued to me and my co-worker Charles W. Ross on Feb. 23, 1971, manipulation of the kiln speed is used as an alternate to manipulation of the fuel feed rate to control the burning zone temperature. Such a system may be extended where dust is being insufflated so that the burning zone temperature may be subject to control by modifying the insufflation of dust as a first preference and by then modifying the fuel feed rate as a second preference with control of the kiln speed as a last resort, as the range of control may require.

Applicant has found that in long kilns supplied with wet slurry it is important to maintain control of the material leaving the drying or chain zone. This will minimize the disturbances propagating down the kiln due to inconsistent drying of material in the drying zone. It has been found that the temperature just ahead of the chain section (downstream as the material flows from the chain section) can be utilized as a variable which can be controlled by adjusting the firing rate when the firing rate is not being used to control the temperature in the burning zone. When firing rate is so used, proper adaptation of the control system provides improved temperature gradients along the kiln and more constant burning zone temperatures can be maintained. It is, therefore, an object of this invention to provide an improved apparatus and method for controlling a rotary cement kiln.

It is another object of this invention to provide an improved apparatus and method for controlling the temperature in the drying zone in a rotary cement kiln.

SUMMARY OF THE INVENTION

In carrying out the improved method of control of a rotary cement kiln there is provided a method of control which includes the following steps and means for carrying out those steps. The steps include measuring the temperature in the prechain area of the kiln and controlling the firing rate of the kiln so as to tend to maintain the prechain temperature at a predetermined set point.

BRIEF DESCRIPTION OF THE DRAWING

The drawing is a circuit diagram in block form showing an embodiment of the invention in analog form.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the FIGURE there is shown a rotary cement kiln **10** including a means **12** for introducing the raw material feed to the upper end of the kiln. This raw material feed may be in the form of a finely ground slurry which will be dried in the chain section **14** of the kiln as the material progresses toward the discharge end. The kiln **10** is shown as having a source of heat at the material discharge end by way of the introduction through the pipe **16** of fuel which is burned in the kiln, with the rate of flow of fuel and hence the firing rate in the kiln being adjustable by varying the position of the valve **18** as by motor **20**. There is also shown in the FIGURE a fan **22** which serves in conjunction with the cooler **24** to cool the clinker which is discharged from the lower end of the kiln onto cooling grate **26**.

The kiln **10** is rotated by means of motor **28** through gearing including the gears **29** and **30** which engage the ring gear **32** around the periphery of the cylindrical kiln.

The firing rate in the kiln is controlled, as mentioned, by means of positioning motor **20** which positions valve **18** so that the position of shaft of motor **20** which couples by way of mechanical coupling **36** to the valve **18** is adjusted by the controller **38**. The controller **38** is shown as providing both proportional and integral action which may be referred to respectively as proportional and reset action. The controller **38** operates to modify the flow of fuel in line **16** until the firing rate as represented by the signal on line **40**, which is derived from the flow measuring device **42** connected to measure the flow of fuel through line **16**, corresponds to the firing rate set point represented by the signal on line **48**.

While control systems utilized in the past have determined the firing rate FR_0 from measurements such as measurements of the burning zone temperature as explained in U.S. Pat. No. 3,566,091 it has been found advantageous in very long kilns which utilize a wet slurry feed to base the control of firing rate whenever possible on the temperature measured in the area just ahead or downstream of the chain section **14** which temperature measurement will be referred to as the prechain temperature. That temperature measurement may be made, for example, by a thermocouple **50** which is subjected to the temperature of the surroundings including the raw material in the area of the kiln just before the hot gases reach the chain area **14**.

The prechain temperature measured by the thermocouple **50** is then represented by a signal on line **52** which is identified as +PCT and which provides ont input to amplifier **54**. The other input to amplifier **54** is a signal on line **56** identified as PCT_o which represents the prechain temperature set point and which is produced from a potential source −E by the adjustment of potentiometer **58**.

The amplifier **54** operates to compare the signal on line **52** with the signal on line **56** so as to develop on its output line **60** a signal repersenting the control error ϵ.

The error signal on line **60** is differentiated by the series connected capacitor **62** and the shunting resistor **64** which is connected from line **66** to ground, line **66** being an input line to the operational amplifier **68**. The input to amplifier **68** from line **66** which represents $d\epsilon/dt$ establishes a signal which represents the proportional control action for the control system operable to control the firing rate set point FR_0.

The integral or reset response for the control controlling FR_0 is established by selectively providing another input by way of lines **70** or **72** to amplifier **68** so that amplifier **68** serves to sum signals representing the proportional and reset control actions so that a signal is provided on its output line **74** indicative of that sum.

The reset control action is selectively established with either one of two pre-established reset rates as determined by the constants K_1 and K_2 which respectively represent the settings of potentiometers **76** and **78** in input lines **72** and **70** of amplifier **68**. The relay **80** is energized during that period when the prechain temperature is between its low and high limits, PCT_L and PCT_H, respectively. With the relay operator **80** energized, the relay contact **80a** will be positioned in contact with the fixed contact **80b** so that the line **84** connects from the output of amplifier **54** through the potentiometer **76** to the input line **72** of amplifier **68**. Thus, with the prechain temperature in its normal range of values, the reset rate is established by the constant K_1. When the prechain temperature exceeds the high and low limits, it is desirable to increase the reset rate so as to more quickly establish by stronger control action the desired prechain temperature PCT_o. That increased reset rate is effected when the relay **80** is de-energized so that the contact **80*a*** is in contact with the fixed contact **80*c***, thus connecting the line **84** through the potentiometer **78** and input line **70** to amplifier **68**. The potentiometer **78**, having a setting representing constant K_2, operates to establish the reset rate represented by K_2.

The signal on line **74** which represents the sum of the proportional and reset control actions is then supplied as an input on line **90** to integrator **92** by way of one of the potentiometers **93–95** as selected by the movable contacts actuated by the relay operators **98** and **100** which serve to determine which of the potentiometers **93–95** is in the connection between line **74** and line **90**.

If, for example, the relay contact **98*a*** is in contact with its fixed contact **98*b*** and if at the same time the relay contact **100*a*** is in contact with its fixed contact **100*b***, then the potentiometer **93**, which is adjusted to represent a constant K_{PN}, forms the connection between line **74** and line **90** and is effective to establish the overall gain of the control system for determining the firing rate set point FR_0. The constant K_{PN} represents the normal gain for the control system and is intended to be that gain which is effective whenever the temperature measured in the mid-kiln region such as in the preheating zone, by thermocouple **102**, establishes a signal on line **104** representing the mid-kiln temperature MKT which is between a predetermined low and high limit which can be respectively identified as MKT_L and MKT_H.

When the relay operator **98** is energized so that the relay contact **98*a*** is operated to contact its fixed contact **98*c*** then the overall gain of the control is established by potentiometer **94** at a value represented by K_{PL}. On the other hand, whenever the relay operator **100** is energized the movable contact **100*a*** is made to contact the fixed contact **100*c*** and the potentiometer **95** is effective to establish the overall gain of the control system at a value represented by the setting of the potentiometer K_{PH}.

The use of the relay operators **98** and **100** and the associated relay contacts to modify the overall gain of the control system is a useful adaptation of the control in response to changes in the mid-kiln temperature for it has been found desirable to increase the controller gain whenever the mid-kiln temperature is below the predetermined low limit MKT_L and conversely, to decrease the controller gain whenever the mid-kiln temperature exceeds the high limit MKT_H. This type of modification of the overall gain of the control system has been found to be useful since excessively low mid-kiln temperatures indicate an above average absorption of heat in the mid-kiln region and consequently, indicate that a greater change in the firing rate is required for each degree of deviation of the prechain temperature from its set point as compared with what would be required if the mid-kiln temperature were in its normal range of values. Similarly, when the mid-kiln temperature exceeds a value indicating that the mid-kiln temperature is excessive, there then becomes a need to reduce the response of the firing rate of the control system to deviations in the prechain temperature, and that is accomplished by decreasing the overall gain of the control system.

The signal on line 90 which represents the sum of the signals representing the proportional and reset control actions is effectively integrated by the integrator 92 to produce a signal representing the firing rate set point FR_0.

Because of the form in which the control system is shown in the diagram, it is necessary to introduce into the integrator 92 by way of the input line 106 a signal for correcting for the discontinuous change in the proportional response of the controller in producing the output FR_0 which results from the switching effected by relay operators 98 and 100, which by modifying the gain of the controller in discontinuous fashion serve to modify the proportional action of the controller in a like fashion and cause a resultant loss in proportional information, sometimes referred to as proportional windup. Thus, the signal introduced on line 106 is intended to compensate for the discontinuity in the signal resulting from the switching, resulting from relay operators 98 and 100.

In order to introduce on line 106 the compensating signal, it is necessary to establish on line 108 a signal representing the change in the controller gain constant with time. Thus, amplifier 110 is effective to sum the inputs on lines 112–114 so as to produce on the output line 116 of amplifier 110 a signal representing either K_{PN}, K_{PL} or K_{PH} depending upon the state of energization of relay operators 98 and 100.

If both relay operators are de-energized as shown in the FIGURE, then a potential +E, introduced at terminal 120 provides by the setting of potentiometer 122, a signal representative of K_N to amplifier 110. That input to amplifier 110 will effectively produce on output line 116 a signal representing the constant K_{PN}.

When relay operator 98 is energized the movable contact 98*d* is operated to be in contact with its fixed contact 98*e* so as to connect the potential +E to line 113 by way of the sign inverting amplifier 121 and potentiometer 126. Potentiometer 126 is adjusted to have a setting representing a constant ΔK_L which represents the difference between K_{PN} and K_{PL} so that as amplifier 110 sums the values K_N and ΔK_L there is produced on line 116 a signal representing K_{PL}.

When relay operator 100 is energized the movable contact 100*d* is actuated to contact the fixed contact 100*e* so as to connect the potential source +E through potentiometer 128 which is set to represent a constant ΔK_H so as to provide a signal to amplifier 110 by way of line 114 which will produce on output line 116 a signal representing K_{PH} since K_N plus ΔK_H equals K_{PH}.

The signal produced on line 116 is then differentiated by means of the series connected capacitor 130 and the shunt resistor 132 connected between line 108 and ground so that there is produced on line 108 a signal representing the derivative of the controller gain constant with respect to time. The signal on line 108 is then provided as the input to multiplier 138, the other input being supplied from line 140, which is representative of the error ϵ. Thus, the signal produced on the output line of multiplier 138, namely, line 106, represents the error ϵ times the derivative of the controller gain with respect to time and that signal serves to compensate for the proportional windup resulting from the change in the controller gain effected by relay operators 98 and 100.

The energization of the relay operator 80 to change the reset rate of the controller, as previously mentioned, is effected whenever the AND gate 150 produces a positive signal on line 152. That energization of relay operator 80 will occur whenever there is simultaneously presented on the input lines 154 and 156 of the AND gate 150, signals of negative potential from the respective comparators 158 and 160. The comparator 160 will produce a negative signal on its output line whenever the prechain temperature represented by the signal on line 162, +PCT, has a value which is less than the value of the signal on line 164 representing the high limit of the prechain temperature PCT_H as established by the setting of the potentiometer 166 in combination with the potential source −E. Whenever the signal on line 162 exceeds in value the signal on line 164, as when the prechain temperature exceeds the high limit, MKT_H, the signal on line 156 is positive in value and the relay operator 80 would be de-energized.

The comparator 158 operates to compare the prechain temperature with its low limit PCT_L. The prechain temperature appears as a negative potential, −PCT, on line 170 which is an output of the sign changing amplifier 172 whose input from line 161 is derived from line 52 which is in turn connected to the thermocouple 50 which measures the prechain temperature. Thus, the comparator 158 compares the −PCT with the lower limit PCT_L as established on the comparator input line 176, and whenever the signal on line 170 has a value which exceeds that on line 176, indicating that the prechain temperature is above the low limit, there is a negative signal on line 154 and the relay operator 80 can be energized if simultaneously there is a negative signal on line 156. The signal PCT_L on line 176 is obtained by way of the potentiometer 180 which connects a potential +E to line 176. Thus, it will be evident that the logic established by the elements 160–180 as shown in the FIGURE are effective to maintain the relay 80 energized whenever the prechain temperature is between the low and high limits predetermined for that temperature, and is effective to cause the relay operator 80 to be de-energized whenever the prechain temperature is below the low limit or above the high limit.

The energization of the relay operators 98 and 100 is accomplished in accordance with the relationship of the magnitude of the signal on line 104, namely, the mid-kiln temperature MKT with respect to the signal established on lines 190 and 192 representing respectively the low and high limit values MKT_L and MKT_H. Thus, relay 98 is energized whenever the output of the comparator 200 is positive so as to produce through diode 202 a signal causing a current flow in line 204 to the relay operator 98 which has its other connection by way of line 206 connected to ground. A positive output from the comparator 200 is effected whenever the signal +MKT on line 210 exceeds in value the signal on line 192, thus indicating that the mid-kiln temperature exceeds the high limit previously established by the adjustment of the potentiometer 212 which serves to establish the signal on line 192 when taken in combination with the potential source −E connected to terminal 214.

Similarly, the comparator **220** is effective to energize the relay operator **100** whenever the output is positive so that there is current flow through the diode **222** and line **224** to one connection for relay operator **100.** The other connection to the relay operator **100** by way of line **226** which is connected to ground. The output of comparator **220** will be positive whenever the signal on line **190,** namely, MKT_L, exceeds in value the signal on line **230,** −MKT, indicating that the mid-kiln temperature is below the low limit MKT_L. The signal on line **190** is obtained by means of potentiometer **232** which connects the potential source +E to line **190,** and the signal on line **230** is obtained from line **104** by way of the sign changing amplifier **234.**

Thus, it will be evident that the logic established by the elements **190–234** as shown in the FIGURE are effective to cause an energization of relay operator **98** when the mid-kiln temperature exceeds a predetermined high limit. Similarly, relay operator **100** is energized when the mid-kiln temperature is below a predetermied low limit.

Those skilled in the art will understand that a change in the gain of the proportional control action of the controller in response to the MKT exceeding its limits is an alternate approach to that shown in the FIGURE where the overall controller gain is changed. Both approaches change the effective proportional gain, that is the relationship of the proportional action taken by the controller in response to a particular deviation of the controlled variable from its set point.

While the control system illustrated in the FIGURE is shown in an analog form, it will be evident to those skilled in the art that the control of the prechain temperature in a rotary cement kiln can be carried out by utilizing the same method as set forth above through the programming of a general purpose digital computer to provide the firing rate set point FR_0.

What is claimed is:

1. A control system for controlling the temperature of the material being processed in a rotary cement kiln comprising:

means for measuring the temperature in the prechain area of the kiln, and

means for controlling the firing rate of the kiln to tend to maintain said prechain temperature at a predetermined set point.

2. A control system as set forth in claim **1** in which the controlling means includes:

means for providing proportional control action, and

means for providing reset control action.

3. A control system as set forth in claim **2** in which the reset rate of the controlling means is increased when the prechain temperature deviates from its set point by more than a predetermined amount.

4. A control system as set forth in claim **2** which includes:

means for measuring a temperature representing the temperature of the material being processed as it passes through the mid-kiln region, and

means operable to change the effective proportional gain of the controlling means to a lower value when the mid-kiln temperature exceeds a certain high value and to change said gain to a higher value when said mid-kiln temperature is below a predetermined minimum value with the effective proportional gain being at a predetermined normal value when said mid-kiln temperature is between said low and high values.

5. A method for automatically controlling the temperature of the material being processed in a rotary cement kiln comprising:

automatically measuring the temperature in the prechain area of the kiln, and

automatically controlling the firing rate of the kiln to tend to maintain said prechain temperature at a predetermined set point.

6. A method set forth in claim **5** in which the automatic control includes proportional control action and reset control action.

7. A method as set forth in claim **6** in which the reset rate of the reset control action is increased when the prechain temperature deviates from its set point by more than a predetermined amount.

8. A method as set forth in claim **6** which includes the steps of:

automatically measuring a temperature representing the temperature of the material being processed as it passes through the mid-kiln region, and

automatically changing the effective proportional gain of the controlling means to a lower value when the mid-kiln temperature exceeds a certain high value and changing said gain to a higher value when said mid-kiln temperature is below a predetermined minimum value with the effective proportional gain being maintained at a predetermined normal value when said mid-kiln temperature is between said low and high values.

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