United States Patent

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[73] Assignee General Electric Corporation

[54] **METHOD AND APPARATUS FOR ROTARY KILN CONTROL**
10 Claims, 5 Drawing Figs.

[52] U.S. Cl. 263/32 R
[51] Int. Cl. F27b 7/20
[50] Field of Search 263/32 R

[56] **References Cited**
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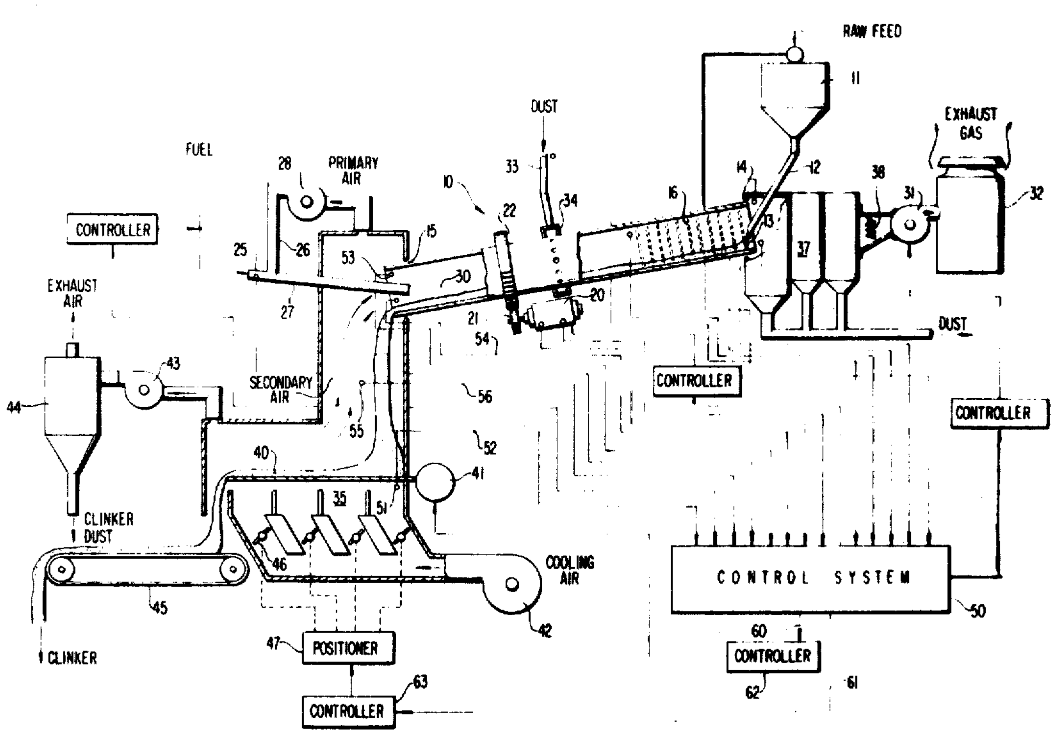
ABSTRACT: A rotary kiln control system and method for stabilizing kiln temperature. Measurements of kiln temperature and the air pressure under the cooler grate determine cooler grate speed to vary material depth on the grate to maintain the kiln-lining temperature constant. In addition, the temperature of cooling air from the material is measured and the flow of cooling air through the material is regulated in response to this measurement.



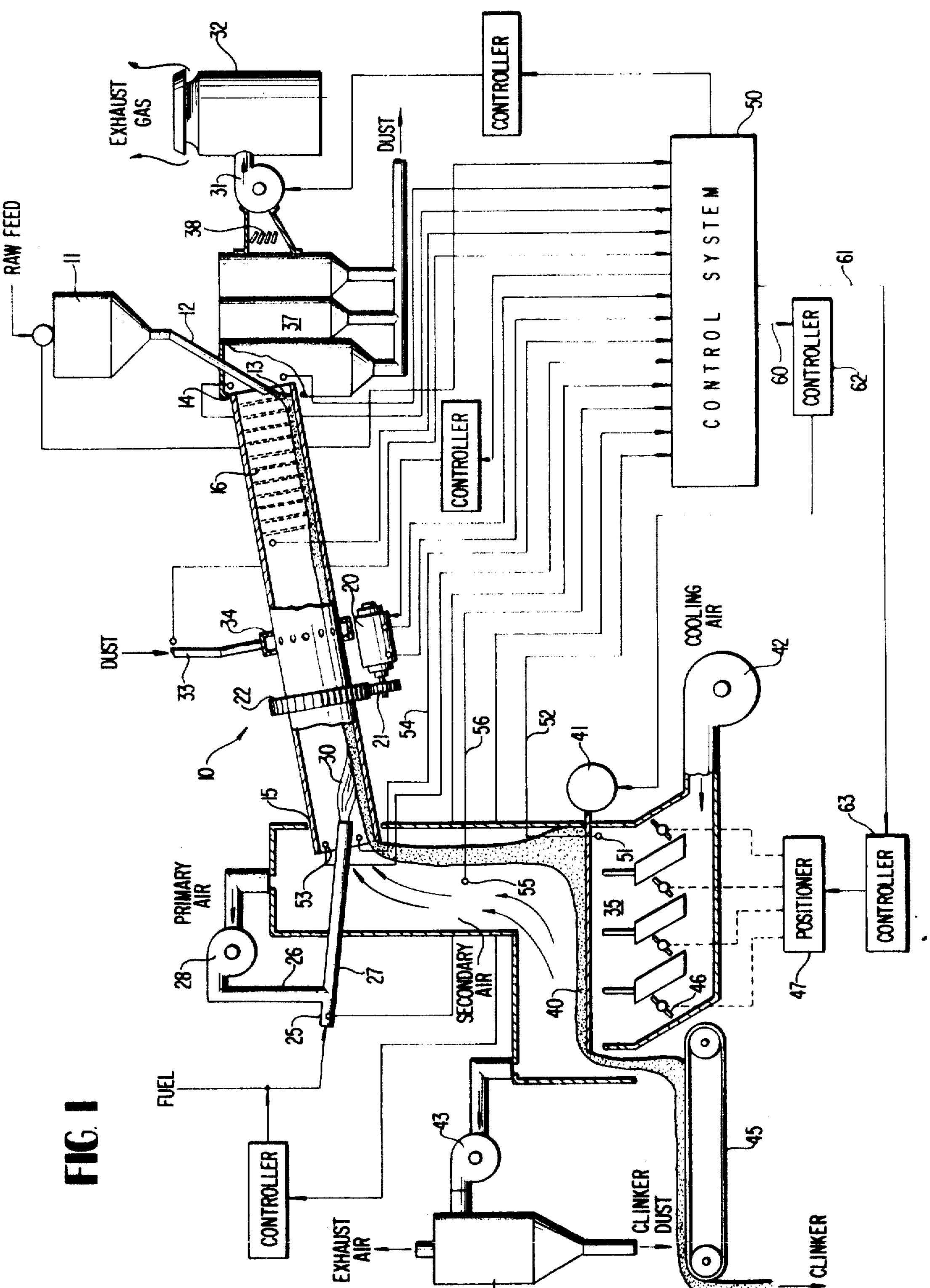


FIG 1

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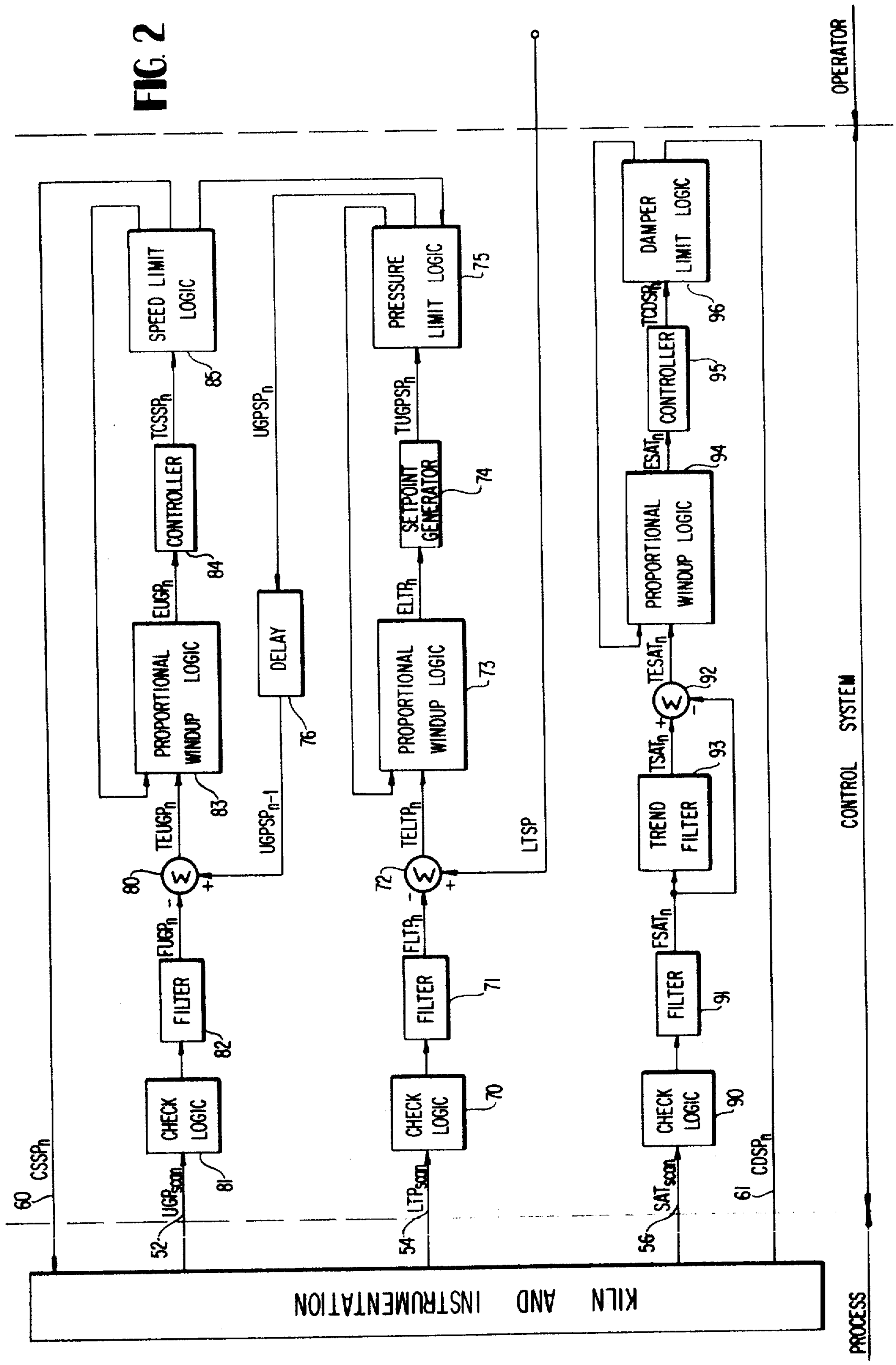
FIG. 2


OPERATOR
CONTROL SYSTEM
PROCESS
KILN AND INSTRUMENTATION
SPEED LIMIT LOGIC
CONTROLLER
PROPORTIONAL WINDUP LOGIC
FILTER
CHECK LOGIC
DELAY
PRESSURE LIMIT LOGIC
SETPOINT GENERATOR
DAMPER LIMIT LOGIC
TREND FILTER
CSSPn
UGRscan
FUGRn
TEUGRn
EUGRn
TCSSPn
UGPSPn
UGPSPn-1
LTPscan
FLTRn
TELTRn
ELTRn
TUGPSPn
LTSP
SATscan
FSATn
TSATn
TESATn
ESATn
TCDSPn
CDSPn
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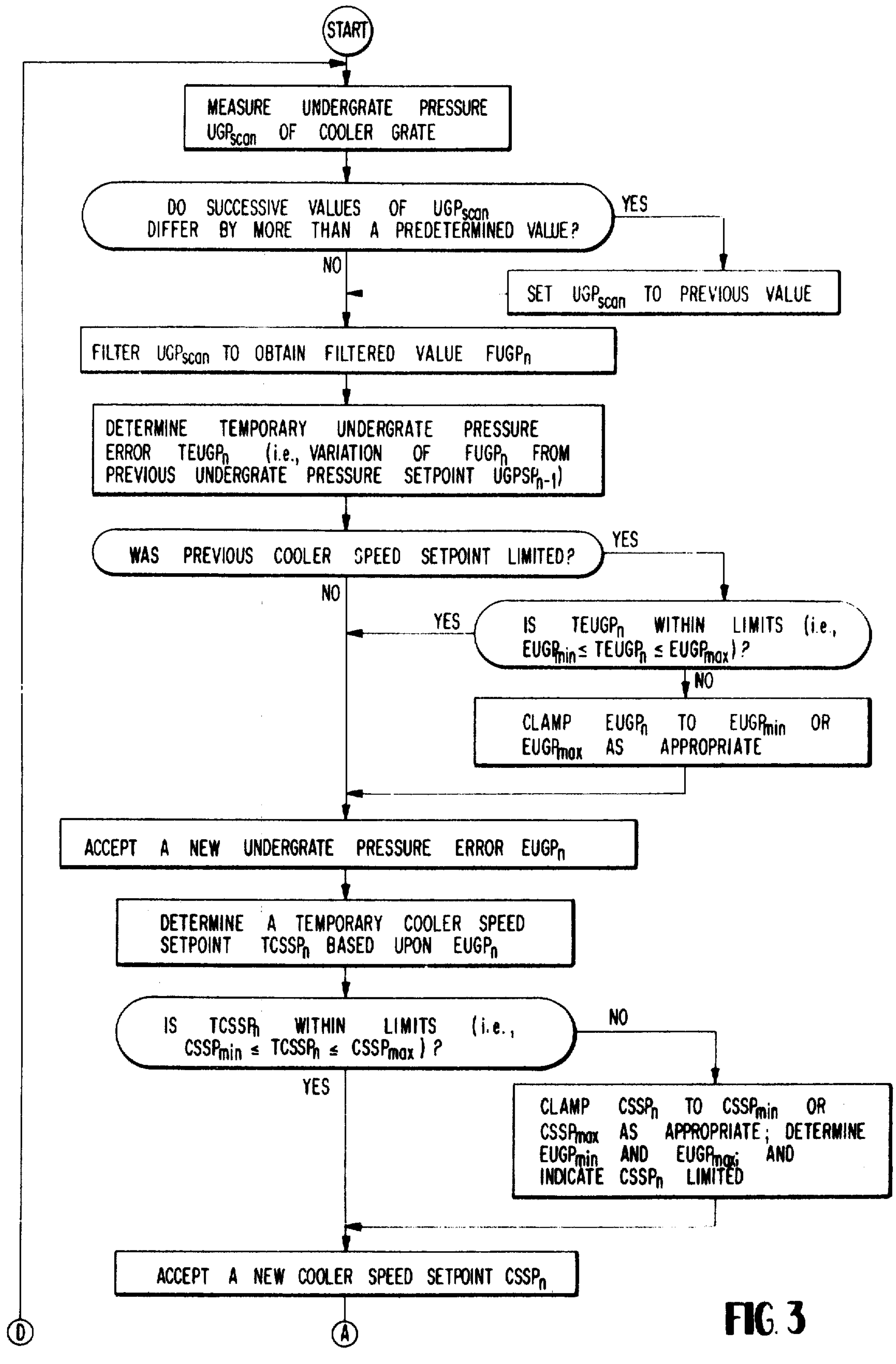
START
MEASURE UNDERGRATE PRESSURE UGP$_{scan}$ OF COOLER GRATE
DO SUCCESSIVE VALUES OF UGP$_{scan}$ DIFFER BY MORE THAN A PREDETERMINED VALUE?
YES
NO
SET UGP$_{scan}$ TO PREVIOUS VALUE
FILTER UGP$_{scan}$ TO OBTAIN FILTERED VALUE FUGP$_n$
DETERMINE TEMPORARY UNDERGRATE PRESSURE ERROR TEUGP$_n$ (i.e., VARIATION OF FUGP$_n$ FROM PREVIOUS UNDERGRATE PRESSURE SETPOINT UGPSP$_{n-1}$)
WAS PREVIOUS COOLER SPEED SETPOINT LIMITED?
YES
NO
IS TEUGP$_n$ WITHIN LIMITS (i.e., EUGP$_{min}$ ≤ TEUGP$_n$ ≤ EUGP$_{max}$)?
YES
NO
CLAMP EUGP$_n$ TO EUGP$_{min}$ OR EUGP$_{max}$ AS APPROPRIATE
ACCEPT A NEW UNDERGRATE PRESSURE ERROR EUGP$_n$
DETERMINE A TEMPORARY COOLER SPEED SETPOINT TCSSP$_n$ BASED UPON EUGP$_n$
IS TCSSP$_n$ WITHIN LIMITS (i.e., CSSP$_{min}$ ≤ TCSSP$_n$ ≤ CSSP$_{max}$)?
NO
YES
CLAMP CSSP$_n$ TO CSSP$_{min}$ OR CSSP$_{max}$ AS APPROPRIATE; DETERMINE EUGP$_{min}$ AND EUGP$_{max}$; AND INDICATE CSSP$_n$ LIMITED
ACCEPT A NEW COOLER SPEED SETPOINT CSSP$_n$
D
A

FIG. 3

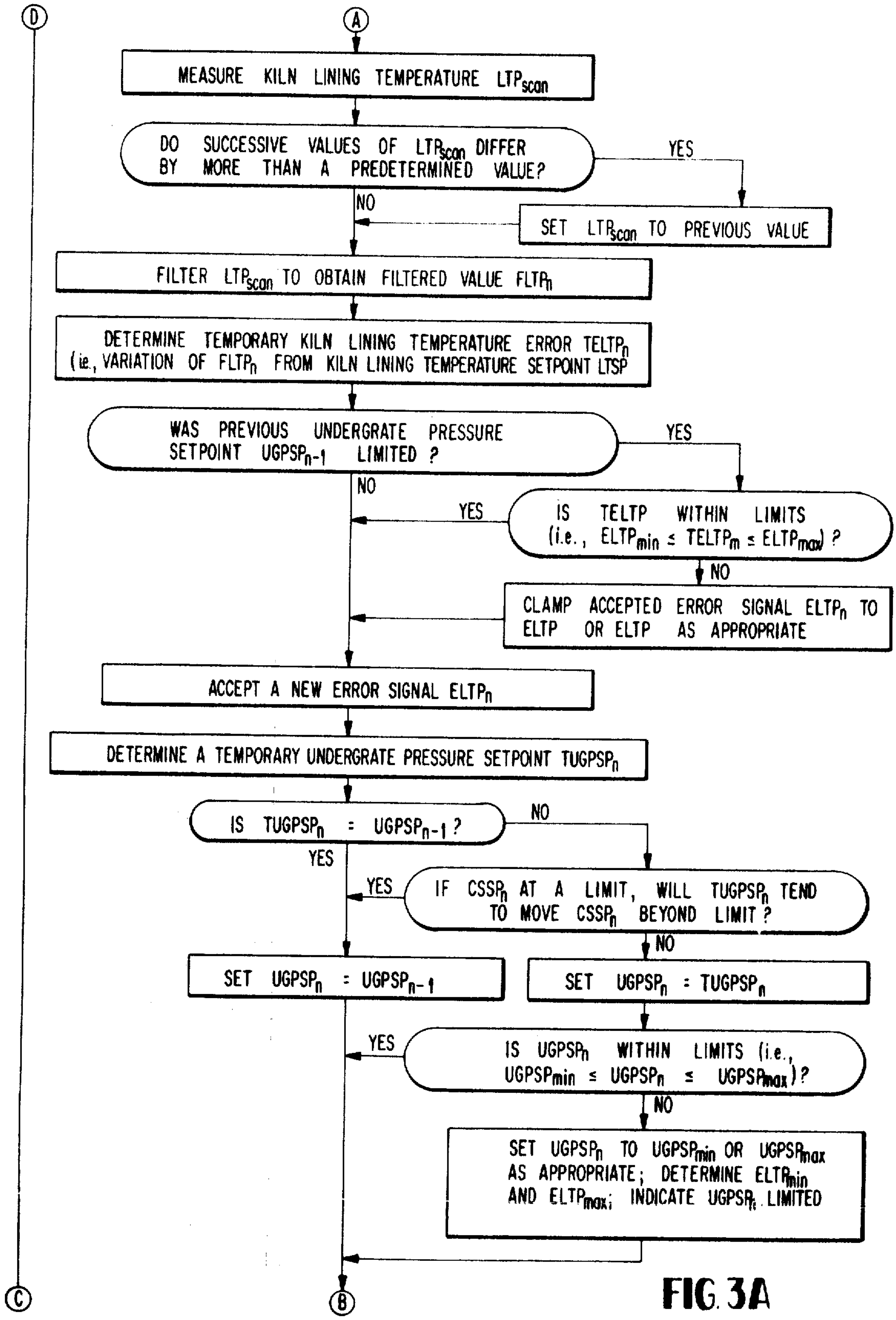
D
A
MEASURE KILN LINING TEMPERATURE LTP$_{scan}$
DO SUCCESSIVE VALUES OF LTP$_{scan}$ DIFFER BY MORE THAN A PREDETERMINED VALUE?
YES
NO
SET LTP$_{scan}$ TO PREVIOUS VALUE
FILTER LTP$_{scan}$ TO OBTAIN FILTERED VALUE FLTP$_n$
DETERMINE TEMPORARY KILN LINING TEMPERATURE ERROR TELTP$_n$ (ie., VARIATION OF FLTP$_n$ FROM KILN LINING TEMPERATURE SETPOINT LTSP
WAS PREVIOUS UNDERGRATE PRESSURE SETPOINT UGPSP$_{n-1}$ LIMITED ?
YES
NO
YES
IS TELTP WITHIN LIMITS (i.e., ELTP$_{min}$ ≤ TELTP$_m$ ≤ ELTP$_{max}$) ?
NO
CLAMP ACCEPTED ERROR SIGNAL ELTP$_n$ TO ELTP OR ELTP AS APPROPRIATE
ACCEPT A NEW ERROR SIGNAL ELTP$_n$
DETERMINE A TEMPORARY UNDERGRATE PRESSURE SETPOINT TUGPSP$_n$
IS TUGPSP$_n$ = UGPSP$_{n-1}$?
NO
YES
YES
IF CSSP$_n$ AT A LIMIT, WILL TUGPSP$_n$ TEND TO MOVE CSSP$_n$ BEYOND LIMIT ?
NO
SET UGPSP$_n$ = UGPSP$_{n-1}$
SET UGPSP$_n$ = TUGPSP$_n$
YES
IS UGPSP$_n$ WITHIN LIMITS (i.e., UGPSP$_{min}$ ≤ UGPSP$_n$ ≤ UGPSP$_{max}$)?
NO
SET UGPSP$_n$ TO UGPSP$_{min}$ OR UGPSP$_{max}$ AS APPROPRIATE; DETERMINE ELTP$_{min}$ AND ELTP$_{max}$; INDICATE UGPSP$_n$ LIMITED
C
B

FIG. 3A

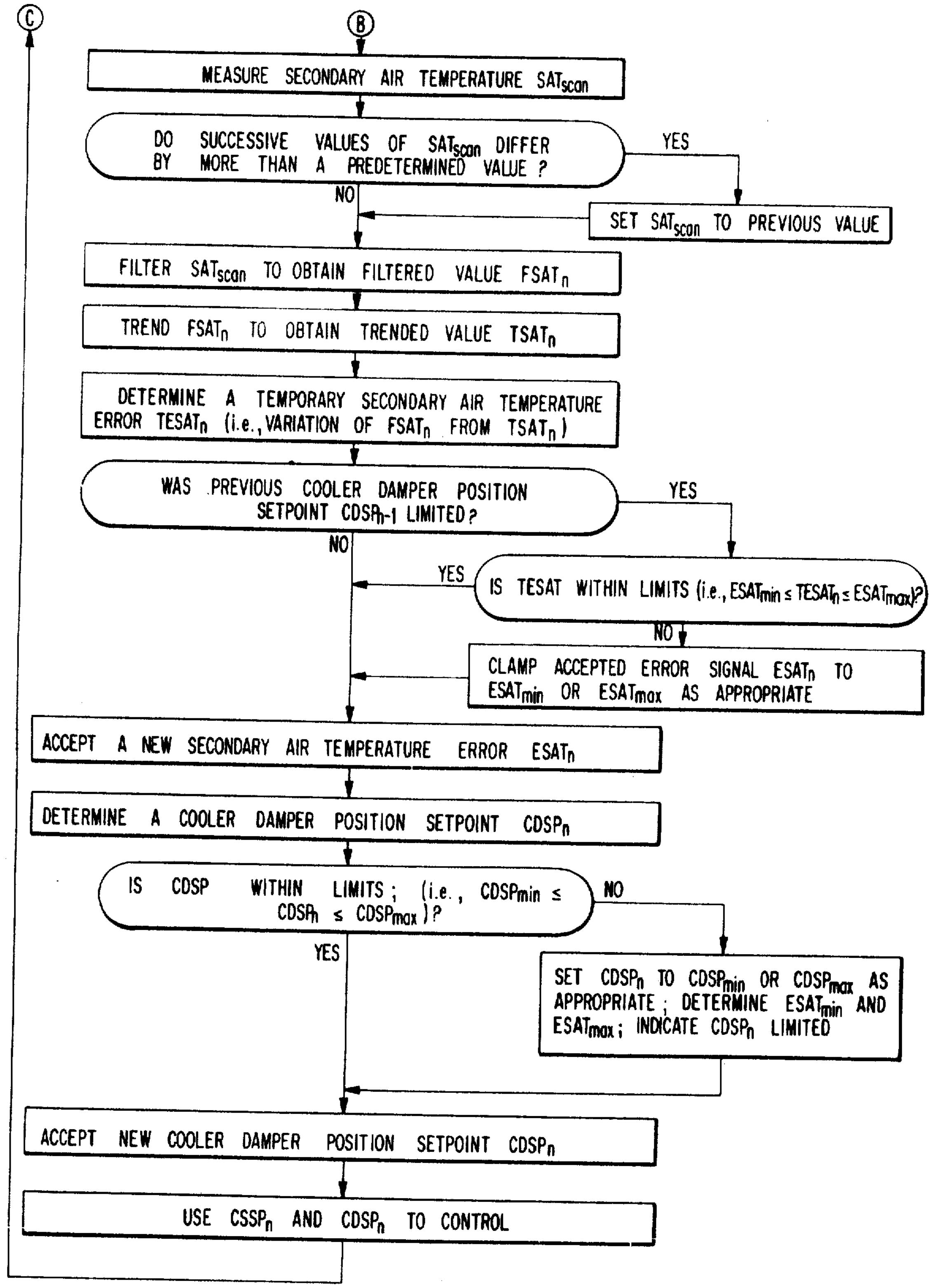
C
B
MEASURE SECONDARY AIR TEMPERATURE SAT_{scan}
DO SUCCESSIVE VALUES OF SAT_{scan} DIFFER BY MORE THAN A PREDETERMINED VALUE ?
YES
NO
SET SAT_{scan} TO PREVIOUS VALUE
FILTER SAT_{scan} TO OBTAIN FILTERED VALUE $FSAT_n$
TREND $FSAT_n$ TO OBTAIN TRENDED VALUE $TSAT_n$
DETERMINE A TEMPORARY SECONDARY AIR TEMPERATURE ERROR $TESAT_n$ (i.e., VARIATION OF $FSAT_n$ FROM $TSAT_n$)
WAS PREVIOUS COOLER DAMPER POSITION SETPOINT $CDSP_{n-1}$ LIMITED ?
YES
NO
YES
IS TESAT WITHIN LIMITS (i.e., $ESAT_{min} \leq TESAT_n \leq ESAT_{max}$)?
NO
CLAMP ACCEPTED ERROR SIGNAL $ESAT_n$ TO $ESAT_{min}$ OR $ESAT_{max}$ AS APPROPRIATE
ACCEPT A NEW SECONDARY AIR TEMPERATURE ERROR $ESAT_n$
DETERMINE A COOLER DAMPER POSITION SETPOINT $CDSP_n$
IS CDSP WITHIN LIMITS ; (i.e., $CDSP_{min} \leq CDSP_n \leq CDSP_{max}$)?
NO
YES
SET $CDSP_n$ TO $CDSP_{min}$ OR $CDSP_{max}$ AS APPROPRIATE ; DETERMINE $ESAT_{min}$ AND $ESAT_{max}$; INDICATE $CDSP_n$ LIMITED
ACCEPT NEW COOLER DAMPER POSITION SETPOINT $CDSP_n$
USE $CSSP_n$ AND $CDSP_n$ TO CONTROL

FIG. 3B

METHOD AND APPARATUS FOR ROTARY KILN CONTROL

BACKGROUND OF THE INVENTION

This invention relates to the production of end products in rotary kilns and, in particular, to an improved method and apparatus for controlling and regulating the operation of rotary kilns to provide stable kiln operation.

Typical rotary kilns employed in the production of Portland cement are steel cylinders 8 to 25 feet in diameter and between 100 and 700 feet long. The cylinders are lined with refractory brick and inclined 2° to 3° from the feed end to the discharge end. The steel cylinder is supported at spaced points and rotated through a gear drive by an electrical motor at speeds in the order of 20 to 120 revolutions per hour. Cement raw material, such as finely ground limestone, clay or shale intermixed in the desired proportions and either in the form of a finely ground slurry or a dry pulverized, intermixed material are fed into the upper or feed end of the rotary kiln.

During rotation of the kiln, the raw materials move slowly down the kiln at a rate which is a function of the kiln rotational speed and pass through successive zones known as the drying or chain zone, the preheating zone, the calcining zone and the clinkering or burning zone. If the raw materials enter the feed end of the kiln in the form of a wet slurry, the moisture is evaporated in the chain zone which may extend for 25 percent of the kiln length. Chains are suspended from the kiln to contact the slurry and serve as a heat exchanger to drive off moisture. The drying or chain zone is not necessary in a kiln which is specifically adapted to use only a dry mix. As the materials move down the kiln, they are slowly heated by a stream of hot gases which are produced by a burner positioned at the lower or discharge end of the kiln and which flow counter to the direction of material movement in the kiln. A fan at the feed end of the kiln creates a slightly negative pressure in the kiln and draws the hot combustion gases produced by the burner through the kiln to heat the raw materials moving in the opposite direction, causing the raw materials to undergo successive changes due to the steadily increasing temperature of the materials.

The temperature of the dried raw materials increases until the calcining temperature is reached at which time carbon dioxide is liberated from the raw materials, changing the carbonates to oxides. The calcining zone occupies the major portion of the kiln length. The temperature of the material changes little within the calcining zone since the calcining reaction is endothermic and requires heat. A measurement of the material temperature within this zone gives little indication of the degree of calcination. At a point down the kiln where calcination is complete, a large temperature difference exists between the solid materials and the counterflowing hot gases. Thus, when calcination is complete, the temperature of the solid material begins to increase rapidly to the point where the exothermic clinkering reactions are initiated. The heat generated by these chemical reactions causes the solid material temperature to rapidly increase 700°–800° F. The clinkering or burning zone is near the discharge end of the kiln and the material remains at or near the high temperature until it leaves the kiln and is thereafter cooled. The degree of completion of the chemical reaction in the clinkering or burning zone depends upon the feed composition, the temperature in this zone and the residence time of an increment of feed within the zone.

The kiln must be controlled in such a manner as to produce a clinker product having a satisfactorily quality and preferably a uniform quality. The variables over which a kiln operator has immediate control and which directly influence the kiln operation are the kiln feed rate, i.e., the rate at which the raw materials are fed into the upper end of the kiln, the kiln rotational speed, the fuel rate, i.e., the rate at which fuel is injected into the kiln and burned, and the exit gas rate, i.e., the rate at which the combustion gases and other gaseous kiln products are drawn through the kiln and exhausted from the feed end into the atmosphere. In addition, the kiln operator also has control over the cooling of the materials after they are discharged from the kiln. Usually, the materials are discharged onto a movable grate through which cooling air is forced and transmitted along the movable grate to a conveyor for further processing. The kiln operator has immediate control over the rate at which cooling air is forced through the material and the operating speed of the movable grate. The kiln operator attempts to select values for each of these control variables which will result in stable kiln operation producing a desirable product at the required product volume.

One primary control approach is that of maintaining conditions in the burning zone or clinkering zone constant. To this end, control systems sense parameters such as burning zone temperature and other kiln temperatures, torque required to rotate the kiln and others to regulate the rate of fuel input to the kiln or the speed of the kiln. In this manner, the effects of process disturbances are minimized and kiln stability is greatly improved. Such stability minimizes kiln operating cost by producing a more uniform product and increasing the efficiency of the equipment. For example increased kiln stability increases the kiln-lining life and thereby reduces the frequency at which the refractory lining has to be replaced in the kiln.

Therefore, it is an object of this invention to provide a control system which improves stability in a rotary kiln.

Another object of this invention is to provide a control system which is compatible with and complements other kiln control systems for improving kiln operating stability.

Yet another object of this invention is to provide a control system for improving rotary kiln stability by stabilizing kiln-lining temperature.

SUMMARY

In accordance with one aspect of this invention, the kiln-lining temperature and heat transfer characteristics of materials on a cooling grate are analyzed and the measurements implemented to control the depth of materials on the grate to maintain a constant kiln-lining temperature. A secondary control function includes measurement of the air temperature leaving the material to control the air flow through the materials.

The subject matter of the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The above and further objects and advantages of this invention may be better understood by reference to the following description taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram depicting a rotary cement kiln embodying and utilizing the present invention;

FIG. 2 is a block diagram illustrating a control system incorporating the invention and employed to control the operation of the rotary cement kiln of FIG. 1;

FIG, 3, FIG. 3A and FIG. 3B are flow diagrams illustrating the operation of the control system of FIG. 2.

DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

Referring to FIG. 1, a typical rotary cement kiln with its associated equipment is schematically illustrated. Rotary cement kiln **10** has at its upper or feed end a kiln feed hopper **11** and a kiln feed pipe **12** for feeding blended raw materials **13** into the upper end of kiln **10**. The raw materials normally include Al_2O_3, SiO_2, Fe_2O_3, $MgCO_3$ and $CaCo_3$ plus small amounts of K_2O, Na_2O and sulfur. The blended raw materials or feed may be in the form of a dry powder or a slurry and may be preheated in a heat exchanger utilizing the kiln exit gases. The specific embodiment shown is particularly adapted for use with slurry mixtures. Chains **16** are suspended along the kiln length from the feed end **14** to remove moisture from the slurry. Such chains could be used to preheat a dry mixture but are not necessary for dry mixtures. Kiln **10**, inclined downward at an angle of approximately 3° from feed end **14** to discharge end 15, is rotated by an electric motor 20 shown here driving a pinion gear 21 that engages a ring gear 22 encircling and attached to kiln 10. As kiln 10 is rotated by kiln drive motor 20 through gears 21 and 22, the kiln rotation causes the raw materials or feed to slowly cascade forward, the rate of forward progress of the feed within kiln 10 being approximately proportional to kiln rotational speed. Motor 20 is normally controlled to drive kiln 10 at a predetermined constant rotational speed.

At the discharge end of the kiln, a fuel supply line 25 and a primary air-supply line 26 are connected to a fuel-air mixing chamber 27 which injects a high-energy flame 30 into kiln 10. Natural gas, pulverized coal, oil or combinations thereof may be employed as fuel, the fuel being fed into line 25 from a suitable source. The primary air is forced through line 26 and into chamber 27 by fan 28.

The interior of kiln 10 is lined with a refractory material (not shown in detail) generally designated by numeral 29 which is capable of absorbing heat from flame 30 and transmitting it to the gases and feed travelling through kiln 10. The combustion gases and other gaseous kiln products are drawn through the kiln by an induced draft fan 31 which exhausts the gases through a dust collector and stack 32. Induced draft fan 31 creates a slightly negative pressure in the kiln drawing secondary air from clinker cooler 35 through the kiln. The gases emerging from feed end 14 of kiln 10 pass through a series of dust collectors 37 which recover the dust and an exit gas damper 38. The dust may be reintroduced to the kiln through a conduit 33 to a dust feeder 34.

As the feed proceeds slowly down the kiln, it is heated by hot gases flowing counter to it and also by the heated refractory walls of the kiln. The temperature of the dry feed increases until the calcining temperature is reached. At this point, the calcium carbonate $CaC0_3$ and the magnesium carbonate $MgC0_3$ begin to decompose, forming Ca0 and Mg0. The released carbon dioxide CO_2 joins the combustion gas and is drawn from kiln 10 by fan 31. The zone of kiln 10 where this reaction occurs is called the calcining zone. This reaction continues over a major portion of the kiln length. The temperature of the feed changes very little within this zone since the calcining reaction is endothermic and requires heat. A measurement of feed temperature within this zone will not give a meaningful indication of the degree of calcination of the feed.

At the point in kiln 10 where calcination of the feed is complete, a large temperature difference exists between the feed and the combustion gases and therefore a rapid increase in feed temperature results. The temperature at which the exothermic clinkering reaction occurs is reached quickly and the heat generated by the clinkering reaction causes the temperature of the feed to increase still further to the point where the solids become partially liquefied. The clinkering reaction for the formation of $(CaO)_2\cdot(SiO_2)$, $(CaO)_3\cdot(Al_2O_3)$ and $(CaO)_4\cdot(ABTLO_3)\cdot(Fe_2O_3)$, which are the crystalline compounds that determine the physical properties of the cement, occurs rapidly. The resulting partly fused mass of varying size continues to move down the burning zone of the kiln and remains near its maximum temperature until it nears discharge end 15 of the kiln. While at this temperature, most of the remaining CaO combines with the $(CaO)_2\cdot(SiO_2)$ to form $(CaO)_3\cdot(SiO_2)$. The degree of completion of this clinkering reaction depends upon the feed composition, the temperature in the burning zone and the residence time of an increment of feed within the zone.

As the hot clinker material approaches the end of the kiln, it begins to lose some of its heat to the incoming secondary air. At the exit end of the kiln, the clinker drops onto the travelling grate 40 usually reciprocated by a motor 41. Air is blown through grate 40 by fan 42 to cool the clinker. Part of the resulting heated air becomes secondary air which is drawn through kiln 10 by fan 31, the remainder being exhausted by fan 43 through dust cyclone 44 to the atmosphere. The cooled clinker is transported by conveyor 45 to grinding apparatus (not shown) which pulverizes the clinker to form cement.

A number of sensors are provided to monitor various parameters of kiln operation and to generate electrical signals representing the values of these parameters. These signals are employed by the control system of the invention to affect the improved kiln stabilization. As illustrated in FIG. 1, control system 50 has a signal coupled thereto from undergrate pressure sensor 51 on line 52 indicating the air pressure in the chamber under movable grate 40. A kiln-lining temperature-sensing device 53, for example a thermocouple, is provided near the discharge end 15 of the kiln to provide a signal transmitted to control system 50 on line 54 indicating the kiln-lining temperature at that point. Another temperature sensing device 55 is located to measure the average temperature of the secondary air passing from the material on grate 40 to the kiln. This sensor is coupled to control system 50 by line 56. Control system 50 utilizes the information concerning kiln operation provided on lines 52, 54 and 56 to produce control signals on lines 60 and 61. The control signal on line 60 represents a cooler speed set point and is applied to controller 62 to control the speed of motor 41 and therefore the depth of material on grate 40. The control signal on line 61 represents a cooler damper set point signal and is applied to controller 63 to control positioners 47 and, thereby, the position of dampers 46. Varying the position of the individual dampers 46 thereby varies the flow rate of cooling air from fan 42 through grate 40 and the material thereon. Controllers 62 and 63 are standard analog controllers as known in the art and will not be described in detail.

FIG. 2 illustrates the details of control system 50 shown in FIG. 1. Referring to FIG.2, the signal on line 54 representing the temperature of the kiln lining is applied to check logic 70 as measured by the kiln-lining temperature-sensor 53. The signal on line 54 LTP_{scan} is constantly being applied to check logic 70 which compares successive values of signal LTP_{scan}. When two successive values differ by more than a given value, it is assumed that a disturbance exists or that the temperature measuring device has failed and the former, or earlier, value of LTP_{scan} is used. An alarm function may be initiated if such differential values continue to exist. The functions of check logic 70 may be conveniently performed in a digital computer with successive values of LTP_{scan} being stored in the computer memory. Check logic 70 thereby serves to mask momentary or short term disturbances and to sense the failure of the kiln-lining-temperature-measuring device 53.

Filtering and smoothing of signal LTP_{scan} to remove noise and other signal variations unrelated to the kiln-lining temperature is performed in filter 71. The output signal of filter 71 is $FLTP_n$. The filtering action of filter 71 is described in the equation:

$$FLTP_n = FLTP_{n11} + K_{ltp}(LTP_{scan} - FLTP_{n11})$$

Where

$FLTP_n$ is the new filtered value,

$FLTP_{n11}$ is the last filtered value,

LTP_{scan} is the present scan value, and

K_{ltp} is the filter constant.

The function of filter 71 may conveniently be performed in a digital computer with signals $FLTP_n$, $FLTP_{n11}$ and LTP_{scan} and constant K_{ltp} being stored in the computer memory. This calculation is performed at short intervals to insure that $FLTP_n$ represents the current condition of the kiln-lining temperature thereby forming an accurate basis for control action. K_{ltp} is selected to be small enough to eliminate noise and other unrelated disturbances on the signal, but not so small as to damp out the signal.

Output signal $FLTP_n$ of filter 71 is applied to summing amplifier 72. A kiln-lining-temperature setpoint signal LTSP is also applied to summing amplifier 72. The kiln-lining-temperature setpoint represented by LTSP is controlled by the operator and generated by means of a potentiometer, a value stored in a digital computer or equivalent means. Typical kiln-lining-temperature setpoint values for a particular kiln used in the cement process will be based upon past experience.

Summing amplifier 72 is of the type well known in the art and provides a temporary kiln-lining-temperature error $TELTP_n$ proportional to the difference between the lining temperature setpoint LTSP and the present filtered value of the kiln-lining temperature represented by signal $FLTP_n$, as expressed by the equation:

$$TELTP_n = LTSP - FLTP_n$$

Temporary kiln-lining-temperature error $TELTP_n$ is positive if the present filtered value of kiln-lining-temperature $FLTP_n$ is less than the lining-temperature setpoint LTSP. The error $TELTP_n$ is negative if the present filtered value of kiln-lining-temperature $FLTP_n$ exceeds the lining-temperature setpoint LTSP. The function of summing amplifier 72 may conveniently be performed in a digital computer.

Temporary kiln-lining-temperature error signal $TELTP_n$ is applied to proportional windup logic 73. Proportional windup logic 73 is used in conjunction with setpoint generator 74 and pressure limit logic 75 to substantially eliminate adverse effects caused by proportional windup of the control system which occurs when a two-mode control algorithm is implemented.

Various types of windup occur when control algorithms are implemented in nonlinear systems, as is known in the art. Proportional windup occurs in a control system which implements a control algorithm on an incremental basis. Proportional or reset windup will occur when either of the normally utilized two- or three-mode control algorithms are implemented with the type of windup being dependent upon the particular control algorithm. If either proportional or reset windup are encountered, the process will not respond properly. Therefore, both proportional and reset windup problems must be overcome if a control system is to be effective. Either proportional or reset windup can be eliminated by the proper selection of the control algorithms. In this particular embodiment, two-mode control algorithms which eliminate reset windup are utilized; and means for eliminating the resulting proportional windup problems are disclosed. Equivalent means could be utilized to eliminate reset windup if the control algorithm were selected initially to eliminate proportional windup.

Proportional windup logic 73 responds to an indication from pressure limit logic 75 that the previous control signal was limited. Such a limiting action indicates that the control system was operating outside its effective range and that proportional windup could be encountered in this control action. Proportional windup logic 73 responds to such an indication to substantially eliminate adverse effects. Such compensation is necessary because setpoint generator 75 generates an output control signal which is a function of a two-mode control algorithm. The output signal from setpoint generator 74 is examined by pressure limit logic 75 to determine whether the control signal will place the system into a proportional windup range. Pressure limit logic 75 is coupled to proportional windup logic 73 to indicate, therefore, whether a proportional windup problem existed on the previous control action. If such a condition did exist, proportional windup logic 73 would clamp $TELTP_n$ to a limit determined by pressure limit logic 75 during the previous control action. As a result, the output of proportional windup logic 73 represented by signal $ELTP_n$ is generated in accordance with the following relationships:

$ELTP_n = TELTP_n$ if $ELTP_{min} \leq TELTP_n \leq ELTP_{max}$,

$ELTP_n = ELTP_{min}$ if $TELTP_n < ELTP_{min}$

$ELTP_n = ELTP_{max}$ if $TELTP_n > ELTP_{max}$

where

$ELTP_n$ is the present error function to be used as a control variable, and

$ELTP_{min}$ and $ELTP_{max}$ are process dependent limits.

The function of proportional windup logic may be conveniently performed in a digital computer with signals $ELTP_n$, $ELTP_{n-1}$ and $TELTP_n$ and limits $ELTP_{min}$ and $ELTP_{max}$ being stored in computer memory.

The resulting error signal $ELTP_n$ is applied to setpoint generator 74 which determines a temporary undergrate-pressure setpoint signal $TUGPSP_n$ in accordance with two-mode control algorithm:

$$TUGPSP_n = UGPSP_{n-1} - K_1 ELTP_n + K_2 ELTP_{n-1}$$

Where

$TUGPSP_n$ is the new temporary undergrate-pressure setpoint,

$UGPSP_{n-1}$ is the previous undergrate-pressure setpoint,

$ELTP_n$ is the present kiln-lining-temperature error, and

$ELTP_{n-1}$ is the previous kiln-lining-temperature error.

K_1 and K_2 are controller constants which are determined in accordance with the following equations:

$$K_1 = K_2 + 100(R)(T)/(PB) \text{ and}$$
$$K_2 = 100/(PB)$$

Where

R is the resets per minute for the setpoint generator,

T is the calculation interval in minutes, and

PB is the proportional band figure for the setpoint generator which is a function of the setpoint generator gain.

The function of setpoint generator 74 may be conveniently performed in a digital computer with signals $TUGPSP_n$, $UGPSP_{n-1}$, $FLTP_n$ and $ELTP_{n-1}$ and constants K_1 and K_2 being stored in computer memory.

The output of setpoint generator 74 represented by $TUGPSP_n$ is applied to pressure limit logic 75 to be compared with the previous undergrate-pressure setpoint signal $UGPSP_{n-1}$. Pressure limit logic 75 determines whether the calculated change in the undergrate-pressure setpoint would require the prevention of proportional windup by examining both the previous cooler speed setpoint and undergrate-pressure limits. If no undergrate-pressure setpoint change will result or if the control system senses the proportional windup condition and the proposed change would tend to cause the system to move further into proportional windup, the previous undergrate-pressure setpoint is used (i.e., $UGPSP_n = UGPSP_{n-1}$). Otherwise, $UGPSP_n$ is set equal to $TUGPSP_n$ and is compared against limits $UGPSP_{min}$ and $UGPSP_{max}$. If $UGPSP_n$ is limited, limits for kiln-lining-temperature error signal $ELTP_n$ are determined; and the fact that the undergrate-pressure setpoint has been limited is recognized. The limits and limit indication are fed back to proportional windup logic 73 for use in the succeeding control action. Therefore, the output of pressure limit logic 75 may be represented by the following relationships:

$UGPSP_n = UGPSP_{n-1}$ if $TUGPSP_n = UGPSP_{n-1}$ or if

$CSSP_n$ at a maximum or minimum limit and

$TUGPSP_n$ would decrease or increase the setpoint respectively, otherwise

$UGPSP_n = TUGPSP_n$ if $UGPSP_{min} \leq TUGPSP_n \leq UGPSP_{max}$,

$UGPSP_n = UGPSP_{min}$ if $TUGPSP_n < UGPSP_{min}$, and

$UGPSP_n = UGPSP_{max}$ if $TUGPSP_n > UGPSP_{max}$

The function of pressure limit logic 75 may be conveniently performed in a digital computer with the signals $UGPSP_n$, $TUGPSP_n$ and $UGPSP_{n-1}$ and the constant limits $UGPSP_{min}$ and $UGPSP_{max}$ being stored in computer memory.

As specifically shown, the output signal $UGPSP_n$ is coupled through a delay circuit 76, whose output, therefore, represents the previous value for the undergrate-pressure setpoint, $UGPSP_{n-1}$. It is also possible to obtain and utilize the signal $UGPSP_n$ directly; however, system stability and the embodiment adapted for implementation in a computer is simplified if the delay is incorporated. Such a delay may be conveniently implemented by a digital computer with signals $UGPSP_n$ and $UGPSP_{n-1}$ being stored in the computer memory.

The previous undergrate-pressure setpoint signal $UGPSP_{n-1}$ is applied to summing amplifier 80 to determine a temporary undergrate-pressure error represented by $TEUGP_n$. The other input to summing amplifier 80 is obtained from undergrate-pressure sensor 51, illustrated in FIG. 1, which generates a signal UGP_{scan} on line 52. This signal is constantly being applied to check logic 81 which compares successive values of signal UGP_{scan} to determine if a disturbance or sensor failure has occurred. An alarm function may be initiated if a failure exists. As check logic 81 produces the earlier value of UGP_{scan} if the earlier and present values differ by more than a predetermined value, check logic 81 serves to mask momentary disturbances and sense failures of the measurement circuitry. The functions of check logic **81** may, like check logic **70**, be conveniently performed in a digital computer.

The output signal of check logic **81** is applied to filter **82**. Filter **82** smooths signal UGP_{scan} and removes noise and other signal variations unrelated to the undergrate pressure. The output signal of filter **82** is $FUGP_n$ and is generated in response to

$$FUGP_n = FUGP_{n11} + K_{ugp}(UGP_{scan} - FUGP_{n11})$$

Where

$FUGP_n$ is the new filtered value,

$FUGP_{n11}$ is the last filtered value,

UGP_{scan} is the present scan value, and

K_{ugp} is the filter constant.

The function of filter **82**, like filter **70**, may also conveniently be performed by a digital computer with the signals $FUGP_n$, $FUGP_{n11}$ and UGP_{scan} and the filter constant K_{ugp} being stored in computer memory. This calculation is also performed at short intervals to insure that $FUGP_n$ represents the current condition of the undergrate pressure thereby forming an accurate basis for control action. K_{ugp} is selected to be small enough to eliminate noise and other unrelated disturbances, but not so small as to damp out the signal.

Output signal $FUGP_n$ is a filter value representing the air pressure under the grate. This air pressure is a function of the depth and porosity of materials on the grate and the characteristics of the fan or source of cooling air. As the characteristics of the cooling air source are substantially constant, air pressure variations under the grate are primarily a function of variations in the depth and porosity of the materials. Further, the temperature of the cooling air leaving grate will vary in accordance with heat transferred to the cooling air as it passes through the materials, the initial heat in the cooling air being substantially constant. Further, the heat transfer from the materials is a function of the material depth and porosity. Therefore, changes in the filtered signal $FUGP_n$ represent changes in the heat transfer characteristics of the material on the grate and the heat transferred to the kiln from the cooler can be varied by changing the depth of material on the grate.

Output signal $FUGP_n$ is applied to summing amplifier **80** where it is combined with the previous setpoint signal $UGPSP_{n11}$ from delay circuit **76** to obtain temporary undergrate-pressure error signal $TEUGP_n$ in accordance with the equation:

$$TEUGP_n = UGPSP_{n11} - FUGP_n$$

Temporary undergrate-pressure signal $TEUGP_n$ is positive if the present filtered value of undergrate pressure represented by $FUGP_n$ is less than the pressure setpoint represented by $UGPSP_{n11}$. The error signal is negative when the present filtered value $FGUP_n$ is greater than the setpoint signal. Summing amplifier **80** may also be implemented in a digital computer.

Temporary undergrate-pressure error signal $TEUGP_n$ is applied to proportional windup logic **83**. Proportional windup logic circuit **83** responds to previous indications that the system is in a proportional windup range to eliminate adverse effects. The output signal from controller **84** is examined by speed limit logic **85** to determine whether it will place the control system in a proportional windup range. Speed limit logic **85** is coupled back to proportional windup logic **83** to indicate, therefore, whether a proportional windup problem existed on the previous control action. If such a situation did exist, proportional windup check logic **83** clamps $EUPG_n$, representing the undergrate-pressure error to limits determined by speed limit logic if the error signal $TEUGP_n$ exceeds those limits. As a result, the output of proportional windup logic **83** is represen ed by signal $EUGP_n$ which is generated in accordance with the following relationships:

$$EUGP_n = TEUGP_n \text{ if } EUGPmin \leq TEUGP_n \leq EUGP_{max},$$
$$EUGP_n = EUGP \text{ if } TEUGP_n < EUGP_{min}, \text{ and } EUGP_n = EUGP_{max} \text{ if } TEUGP_n < EUGP_{max},$$

$EUGP_n$ is the present error function to be used as a control variable, and

$EUGP_{min}$ and $EUGP_{max}$ are process dependent limits.

The function of proportional windup logic **83** may be conveniently implemented in a digital computer with signals $TEUGP_n$ and $EUGP_n$ and limit signals $EUGP_{min}$ and $EUGP_{max}$ being stored in computer memory.

The resulting error signal $EUGP_n$ is applied to controller **84** which generates a temporary speed setpoint signal $TCSSP_n$ in accordance with the two-mode control algorithm

$$TCSSP_n = CSSP_{n11} - K_3 EUGP_n + K_4 EUGP_{n11}$$

Where

$TCSSP_n$ is the new temporary cooler speed setpoint signal,

$CSSP_{n11}$ is the last cooler speed setpoint signal,

$EUGP_n$ is the present error function, and

$EUGP_{n11}$ is the previous error function.

K_3 and K_4 are controller constants which are determined in accordance with the following equations:

$$K_3 = K_4 + 100\,(R)(T)/(PB) \text{ and}$$
$$K_4 = 100/(PB)$$

Where

R is the resets per minute for the controller,

T is the calculation interval in minutes, and

PB is the proportional band figure for the controller which is a function of the controller gain.

Controller **84** may be conveniently implemented with a digital computer with signals $TCSSP_n$, $CSSP_{n11}$, $EUGP_n$ and $EUGP_{n11}$ and constants K_3 and K_4 being stored in computer memory.

The output signal $TCSSP_n$ from controller **84** is applied to speed limit logic **85 1** compares $TCSSP_n$ with predetermined maximum and minimum constant values $CSSP_{max}$ and $CSSP_{min}$ to determine if proportional windup will be encountered. $CSSP_{min}$ is therefore representative of the lower end of the effective speed control range while $CSSP_{max}$ represents the upper end. If either constant is exceeded, $TCSSP_n$ is clamped. Also $EUGP_{min}$ and $EUGP_{max}$ are determined. They represent the undergrate-pressure errors for present process conditions while will take the control system to proportional windup. Both error limit signals $EUGP_{min}$ and $EUGP_{max}$ and the indication that proportional windup exists are fed back to proportional windup logic **83**. If $TCSSP_n$ lies within the acceptable range, then $CSSP_n$ is set equal to $TCSSP_n$. Therefore, the output of speed limit logic **85** may be represented by the following relationships:

$$CSSP_n = TCSSP_n \text{ if } CSSP_{min} \leq TCSSP_n \leq CSSP_{max}$$
$$CSSP_n = CSSP_{min} \text{ if } TCSSP_n < CSSP_{min}$$
$$CSSP_n = CSSP_{max} \text{ if } TCSSP_n > CSSP_{max}$$

Where

$CSSP_n$ is the present cooler speed setpoint signal, and

$CSSP_{min}$ and $CSSP_{max}$ are constant limits indicating the lower and upper proportional windup points.

The function of speed limit logic **85** may be conveniently performed in a digital computer with signals $TCSSP_n$ and $CSSP_n$ and constant limits $CSSP_{min}$ and $CSSP_{max}$ being stored in computer memory.

Cooler speed setpoint signal $CSSP_n$ is then transferred back to the kiln and instrumentation on line **60** to cause controller **62**, shown in FIG. **1**, to adjust the speed of motor **41** accordingly. Controller **62** is a conventional analog controller which is known in the art. Adjusting the speed of motor **41** varies the material depth on movable grate **40**. If the motor speed increases, the depth of materials decreases. Such a control action occurs when the lining temperature represented by LTP_{scan} exceeds the setpoint signal LTSP. As the depth of materials decreases, less heat is transferred from this material to the kiln thereby tending to decrease the kiln-lining temperature. Likewise, if the kiln-lining temperature becomes cool, motor **41** moves grate **40** more slowly allowing a buildup of materials on grate **40** with the result that heat transfer at the kiln discharge end increases. This causes an increase in the kiln-lining temperature. Hence the action of this control system tends to stabilize the kiln-lining temperature with the result that the thermal stability of the overall system is increased.

Still further increased thermal stability can be obtained by altering the position of the dampers **46** in response to the average secondary air temperature as measured by sensor **55** shown in FIG. **1**. Sensor **55** generates a signal SAT_{scan} on line **56** which represents the temperature of the secondary air entering kiln **10**. The signal SAT_{scan} is initially transferred to check logic **90** which compares successive values. When two successive values differ by more than a given value, it is assumed that a disturbance exists or that the temperature sensor **55** has failed; and the former, or earlier, value of SAT_{scan} is used. An alarm function may also be initiated if such differential values continue to exist. The functions of check logic **90** may conveniently be performed in a digital computer, with successive values of SAT_{scan} being stored in computer memory. Check logic **90** thereby serves to mask momentary short term disturbances and to sense the failure of secondary air-temperature measuring device **55**.

Filtering and smoothing of the signal SAT_{scan} to remove noise and other signal variations unrelated to the kiln-lining temperature is performed in filter **91**. The output signal of filter **91** is $FSAT_n$. The filtering action of filter **91** is described in the equation:

$$FSAT_n = FSAT_{n-1} + K_{sat}\,(SAT_{scan}\ 31\ FSAT_{n-1})$$

Where

$FSAT_n$ is the new filtered value,
$FSAT_{n-1}$ is the last filtered value,
SAT_{scan} is the present scan value, and
K_{sat} is the filter constant.

The function of filter **91** may conveniently be performed in a digital computer with signals $FSAT_n$, $FSAT_{n-1}$ and SAT_{scan} and constant K_{sat} being stored in computer memory. This calculation is performed at short intervals to insure that $FSAT_n$ represents the current condition of the secondary air-temperature thereby forming an accurate basis for control action. K_{sat} is selected to be small enough to eliminate noise and other unrelated disturbances, but not so small as to damp out the signal.

OUtput signal $FSAT_n$ of filter **91** is applied to summing amplifier **92** where it is compared with a trended secondary air temperature signal $TSAT_n$ from trend filter **93**. Trend filter **93** produces a filtering action as described by equation

$$TSAT_n = TSAT_{n-1} + K_{tsat}(FSAT_n - TSAT_{n-1})$$

Where

$TSAT_n$ is the new trended temperature value,
$TSAT_{n-1}$ is the last trended temperature value,
$FSAT_n$ is the present filtered value, and
K_{tsat} is the filter constant.

The function of trend filter **93** may be conveniently performed in a digital computer with signals $TSAT_n$, $TSAT_{n-1}$, and $FSAT_n$ and filter constant K_{tsat} being stored in computer memory.

A trended-air-temperature value is utilized as a base for determining errors rather than a constant setpoint signal. This allows the secondary air-temperature control loop to control the air temperature but not to override the cooler speed control loop. Hence, the setpoint signal represented by trend-air-temperature signal $TSAT_n$ factors in variations caused by control actions of the cooler speed control loop and responds to short term disturbances.

Summing amplifier **92** is of the type well known in the art and may be implemented in a digital computer. Summing amplifier **92** provides a temporary error signal $TESAT_n$ proportional to the difference between the secondary air-temperature setpoint signal $TSAT_n$ and the present filtered value of secondary air temperature represented by signal $FSAT_n$ as expressed by the equation

$$TESAT_n = TSAT_n - FSAT_n$$

The temporary secondary-temperature error signal $TESAT_n$ is applied to proportional windup logic circuit **94**. Proportional windup logic **94**, like proportional windup logic **83**, responds to previous indications that the system is in proportional windup to eliminate adverse effects. The output signal from controller **95** is examined by damper check logic **96** to determine whether the control signal will place the system in a proportional windup range. Damper limit logic **96** is coupled back to proportional windup **94** to indicate, therefore, whether a proportional windup problem existed on the previous control action. If such a situation did exist, proportional windup check logic **94** clamps $ESAT_n$ to limits determined by damper limit logic **96** if the present error signal $TESAT_n$ exceeds those limits. As a result, the output of proportional windup logic **94** represented by signal $ESAT_n$ is generated in accordance with the following relationships:

$$ESAT_n = TESAT_n \text{ if } ESAT_{min} \leq TESAT_n \leq ESAT_{max},$$
$$ESAT_n = ESAT_{min} \text{ if } TESAT_n < ESAT_{min}, \text{ and}$$
$$ESAT_n = ESAT_{max} \text{ if } TESAT_n > ESAT_{max}$$

Where

$ESAT_n$ is the present error function to be used as a control variable, and

$ESAT_{min}$ and $ESAT_{max}$ are process dependent limits.

The functions of proportional windup logic **94** may conveniently be performed in a digital computer with signals $ESAT_n$ and $TESAT_n$ and limits $ESAT_{min}$ and $ESAT_{max}$ being stored in computer memory.

The resulting error signal $ESAT_n$ is applied to controller **95** which generates a cooler damper position setpoint signal $TCDSP_n$ in accordance with the two-mode control algorithm

$$TCDSP_n = CDSP_{n-1} - K_5 ESAT_n + K_6 ESAT_{n-1}$$

Where

$TCDSP_n$ is the new temporary cooler damper position setpoint signal,

$CDSP_{n-1}$ is the last cooler damper position setpoint signal,

$ESAT_n$ is the present error function, and

$ESAT_{n-1}$ is the previous error function.

K_5 and K_6 are controller constants which are determined in accordance with the following equations:

$$K_5 = K_6 + 100(R)(T)/(PB) \text{ and}$$
$$K_6 = 100(PB)$$

Where

R is the resets per minute for the controller,
T is the calculation interval in minutes, and
PB is the proportional band figure for the controller gain.

The function of controller **95** may conveniently be performed in a digital computer with signals $TCDSP_n$, $CDSP_{n-1}$, $ESAT_n$ and $ESAT_{n-1}$ and constants K_5 and K_6 being stored in computer memory.

The output signal $TCDSP_n$ from controller **95** is applied to damper limit logic **96** which compares $TCDSP_n$ with predetermined maximum and minimum constant values $CDSP_{max}$ and $CDSP_{min}$ to determine if proportional windup will be encountered. $CDSP_{min}$ therefore represents a value of $TDCSP_n$ which will move the dampers to a minimum position; $CDSP_{max}$ indicates the value of $TCDSP_n$ will open the dampers to a maximum position. If either constant is exceeded, $TCDSP_n$ is clamped. Also $ESAT_{min}$ and $ESAT_{max}$ are determined. The represent the errors for the present process conditions which will just take the process control system to proportional windup. Both error signal limits and the indication that proportional windup exists are fed back to proportional windup logic circuit **94**. If $TCDSP_n$ lies within the acceptable range, then $CDSP_n$ is set equal to $TCDSP_n$. Therefore, the output of damper logic circuit **96** may be represented by the following relationships:

$$CDSP_n = TCDSP_n \text{ if } CDSP_{min} \leq TCDSP_{max},$$
$$CDSP_n = CDSP_{min} \text{ if } TCDSP_n \leq CDSP_{min}$$
$$CDSP_n = CDSP_{max} \text{ if } TCDSP_n \geq CDSP_{max}$$

Where

$CDSP_n$ is the present cooler damper position setpoint, and

$CDSP_{min}$ and $CDSP_{max}$ are constant limits indicating the proportional windup range limits.

Damper limit logic **96** may be conveniently implemented in a digital computer with $CDSP_n$ and $TCDSP_{n-1}$ and constant limits $CDSP_{min}$ and $CDSP_{max}$ being stored in computer memory.

Cooler damper position setpoint signal $CDSP_n$ is then transferred back to the kiln and instrumentation on line **61** to cause an analog controller **63** or equivalent shown in FIG. **1** to adjust to the position of dampers 46 accordingly. As shown the controller 63 produces an output signal which is applied to an intermediate positioner 47 which controls the position of each damper. Both controller 63 and positioner 47 are known in the art.

By adjusting the position of dampers 46, air flow through grate 40 can be altered independently of the variations due to control actions from the cooler grate speed control loop. However, sustained changes in the operating conditions caused by control actions from the cooler speed control loop are factored into the secondary air-temperature control loop by trending the setpoint signal as a function of actual process temperature. Assuming a constant bed depth, the secondary air-temperature control loop opens the dampers as secondary air temperature increases and closes the dampers as the temperature decreases. Changes in secondary air temperature caused primarily by speed variations of motor 41 are reflected as corresponding changes in the trended secondary air-temperature setpoint. As a result, variations, in the sensed secondary air temperature will be nullified so the the secondary air-temperature control loop will take no action.

FIGS. 3, 3A and 3B (hereinafter FIG. 3) illustrate a flow chart of the operation of a control system such as that shown in FIG. 2 which is especially adapted for implementation by a digital computer. Signal UGP_{scan} representing the undergrate pressure and, hence, the depth of material on the grate, is checked to determine whether successive values differ by more than a predetermined value. The previous value of UGP_{scan} is saved and used if the difference exceeds the predetermined value. The signal is filtered periodically to obtain a filtered value $FUGP_n$ and compared to the previously calculated undergrate pressure setpoint $UGPSP_{n11}$ and a temporary undergrate-pressure error signal $TEUGP_n$ is generated representing the difference between $UGPSP_{n11}$ and $FUGP_n$.

If the previous cooler speed was not limited, a temporary cooler speed setpoint signal $TCSSP_n$ is calculated. However, if the previous cooler speed setpoint signal was limited indicating that proportional windup could exist, the error signal $TEUGP_n$ is compared with previously determined limits $EUGP_{min}$ and $EUGP_{max}$. If $TEUGP_n$ lies between or equals the limits, $TEUGP_n$ becomes the error signal $EUGP_n$; if not, $EUGP_n$ is set equal to the appropriate limit value $EUGP_{min}$ or $EUGP_{max}$. Then $EUGP_n$ is used to determine the temporary cooler speed setpoint. The temporary cooler speed setpoint is checked against limits $CSSP_{min}$ and $CSSP_{max}$ which represent the range of effective control for the particular apparatus. If within or equal to the limits, the calculated setpoint $TCSSP_n$ becomes the effective setpoint $CSSP_n$; otherwise, the output signal is limited to the maximum or minimum values. When limiting occurs, $EUGP_{min}$ and $EUGP_{max}$ are calculated as those values which will, under the present process conditions, cause an output of $CSSP_{min}$ or $CSSP_{max}$ respectively. These signals are stored in a digital computer until the next control action. When limiting occurs, an indication of the fact is made.

The next series of steps in the control system operation outlined in FIG. 3 is that of measuring the kiln-lining temperature. Signal LTP_{scan} representing the kiln-lining temperature is checked to determine whether successive values differ by more than a predetermined value. The previous value of LTP_{scan} is saved and used if the difference exceeds the predetermined value. The signal is filtered periodically to obtain a filtered value $FLTP_n$ and compared with the desired kiln-lining temperature represented by setpoint signal LTSP. The resulting error signal $TELTP_n$ is used to determine a temporary undergrate-pressure setpoint signal $TUGPSP_n$ if the previous value of the undergrate-pressure setpoint signal $USPSP_{n11}$ was within limits. If it was not, then the error signal is compared with temperature error limits $ELTP_{min}$ and $ELTP_{max}$ generated during the previous control action and set to those limits as appropriate. Therefore, either the actual kiln-lining temperature or a limiting value will be used as an error signal $ELTP_n$ to calculate a temporary undergrate-pressure setpoint signal $TUGPSP_n$.

The value of the temporary undergrate-pressure setpoint signal $TUGPSP_n$ is examined to determine whether it will be used as the new undergrate-pressure setpoint signal $UGPSP_n$. If the temporary and previous setpoint signals are equal (i.e., $TUGPSP_n = UGPSP_{n11}$) the temporary setpoint signal becomes the control variable. If there is a difference in the two values, then the magnitude and direction of the resulting control action is examined to determine whether a control action generated from implementing $TUGPSP_n$ would place the process into proportional windup. If it would not, then the temporary setpoint signal is used as a control variable $UGPSP_n$; if such control action would cause proportional windup, then the control variable is set to $UGPSP_{min}$ or $UGPSP_{max}$ which are constant limits. When such limiting occurs, new lining temperature error limits $ELTP_{min}$ and $ELTP_{max}$ are calculated; and an indication of limiting is made.

If the secondary air-temperature control loop were not utilized, the control system would utilize the value of cooler speed setpoint signal $CSSP_n$ to adjust the system. Where however, such a control loop is utilized, the control system then measures the secondary air temperature and generates a signal SAT_{scan}. Successive values of SAT_{scan} are checked to determine whether they differ by a predetermined value. If they do, the earlier value is saved and used. The signal is filtered periodically to obtain a filtered value $FSAT_n$. This signal is trended to obtain a trended secondary air-temperature signal $TSAT_n$. These signals are compared and a temporary error signal $TESAT_n$ representing the difference between the trended and filtered secondary air temperatures is obtained. If the previous cooler damper setpoint signal did not drive the dampers to a limiting position, the difference between the trended and filtered secondary air temperatures is utilized as a control signal $ESAT_n$. However, if the previous control signal did cause proportional windup, the error or difference signal is utilized only if it does not exceed limits calculated on the previous control action. If the newly calculated difference does exceed one limit, that limit is utilized.

Once the secondary air-temperature difference signal $ESAT_n$ has been selected, a new cooler damper position setpoint signal $TCDSP_n$ is generated. If it is within the limits of damper position, it becomes the cooler damper position setpoint signal $CDSP_n$. Otherwise either the limit $CDSP_{min}$ or $CDSP_{max}$ is utilized. When a limit is required, an indication of proportional windup is made and new values for the temperature difference limits $ESAT_{min}$ and $ESAT_{max}$ are calculated. These are the limits which will cause the calculated value of the cooler damper position setpoint signal to reach the minimum or maximum limits respectively. Therefore, either the calculated value or a limit is used as the cooler damper position setpoint signal $CDSP_n$. At this point, the control system of FIG. 3 would cause both the values of $CSSP_n$ and $CDSP_n$ to be transmitted to the controllers 60 and 63 respectively shown in FIG. 1. After a predetermined interval, the control system of FIG. 3 would be implemented again to determine new setpoint values in accordance with the present operation of the kiln.

As indicated previously, the control system described herein tends to stabilize the thermal characteristics of a rotary cement kiln by controlling the kiln-lining temperature at the discharge end and the temperature of the air entering the kiln. Primarily, the control system will regulate the depth of discharged materials on a cooler grate to thereby vary the heat transfer from the materials to the kiln lining. Long term variations in the secondary air temperature are not effective to alter the damper positions because the control action is dependent upon a trended temperature value as a setpoint. However, damper position is controlled to compensate for short term changes in the secondary air temperature. It will be recognized by those skilled in the art that many modifications may be made to the various embodiments of the disclosed system without varying the true spirit and scope of the invention. Therefore, it is the object of the appended claims to cover all such modifications and variations which are within the true spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A control system for rotary kiln apparatus including a kiln lining desirably maintained at a predetermined temperature and cooling apparatus including movable grate means adapted to receive materials from a discharge end of the kiln and a source of cooling air, said control system comprising means for indicating the kiln-lining temperature at the discharge end and means for indicating the heat transfer characteristics of discharged materials on the movable grate and control means responsive to said kiln-lining temperature measuring means and said characteristic indicating means and adapted for controlling said movable grate means so as to maintain the kiln-lining temperature at the predetermined value.

2. A control system as recited in claim 1 wherein said characteristic indicating means includes means operably coupled to said grate means for sensing the air pressure under said grate means.

3. A control system as recited in claim 2 wherein variable speed drive means are operably connected to said movable grate means, said control means including means responsive to said kiln-lining temperature means and the predetermined temperature value for determining the temperature difference and means coupled to said temperature difference means for generating a signal representing the desired grate means pressure as a function of the temperature difference and means responsive to said desired grate-pressure generating means and said grate-pressure sensing means for determining the pressure difference and means responsive to said pressure-difference generating means for producing a speed control signal, said variable speed drive means being responsive to the speed control signal

4. A control system as recited in claim 3 wherein said source of cooling air includes controllable means for transferring the cooling air through the grate and material on the grate, said control means additionally comprising means for measuring the cooling air temperature after the cooling air passes through the material and means responsive to said measurement of air temperature for controlling said source of cooling air.

5. A control system as recited in claim 4 wherein said source of cooling air comprises a fan and damper means for controlling air flow to the grate, said control means being responsive to said air temperature sensing means for generating a predetermined air temperature and means responsive to said air temperature sensing means and said predetermined temperature signal generating means for controlling said damper means.

6. A method for controlling a rotary kiln apparatus including a kiln lining desirably maintained at a predetermined temperature and cooling apparatus including movable grate means adapted to receive materials discharged from a discharge end of the kiln and a source of cooling air comprising the steps of measuring the kiln-lining temperature at the discharged end, analyzing the heat transfer characteristics of the discharged materials on the movable grate and, in response to said kiln-lining-temperature-measuring and heat transfer characteristic analyzing steps controlling the movable grate means so as to maintain the kiln-lining temperature at the predetermined value by varying the amount of materials on the grate means.

7. A control method as recited in claim 6 wherein said analyzing the heat transfer characteristics includes the step of measuring the air pressure under the grate means caused by discharged materials, thereon,

8. A control method as recited in claim 7 wherein the grate means may be moved at variable speeds to thereby vary the amount of materials thereon, said control method including the additional steps of determining the difference between the measured kiln-lining temperature and the desired kiln-lining temperature and, in response thereto determining an undergrate-pressure setpoint and varying the movable grate speed so as to maintain the actual undergrate pressure equal to the undergrate-pressure setpoint.

9. A control method as recited in claim 8 wherein said cooling air source includes means for controlling cooling air flow through the grate means, said control method additionally comprising the steps of measuring the temperature of the air after it exits from the material and responding to said measurement for controlling the quantity of cooling air passing through the grate.

10. A control system as recited in claim 9 wherein said source of cooling air includes controllable damper means and a fan, the controllable damper means controlling the air flow through the material, said control method additionally comprising the step of determining a desired air temperature from measured air temperatures and, in response to a difference therebetween, controlling the damper positions to maintain the measured air temperature at the desired air temperature.