

- [54] DRYER CONTROL SYSTEM AND METHOD
- [75] Inventors: **Ronald James Fowler**, Columbus;
Edward James Freeh, Worthington;
David Mark Koenig, Columbus, all
of Ohio
- [73] Assignee: **Industrial Nucleonics Corporation**,
Columbus, Ohio
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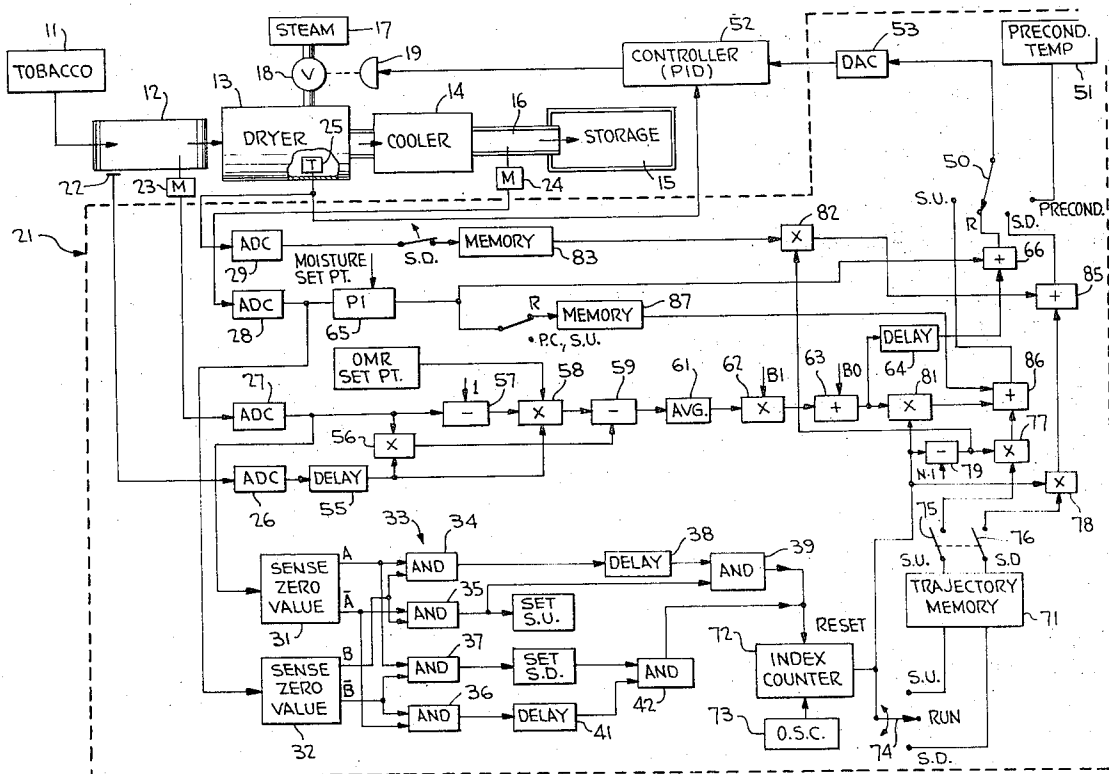
[57] **ABSTRACT**

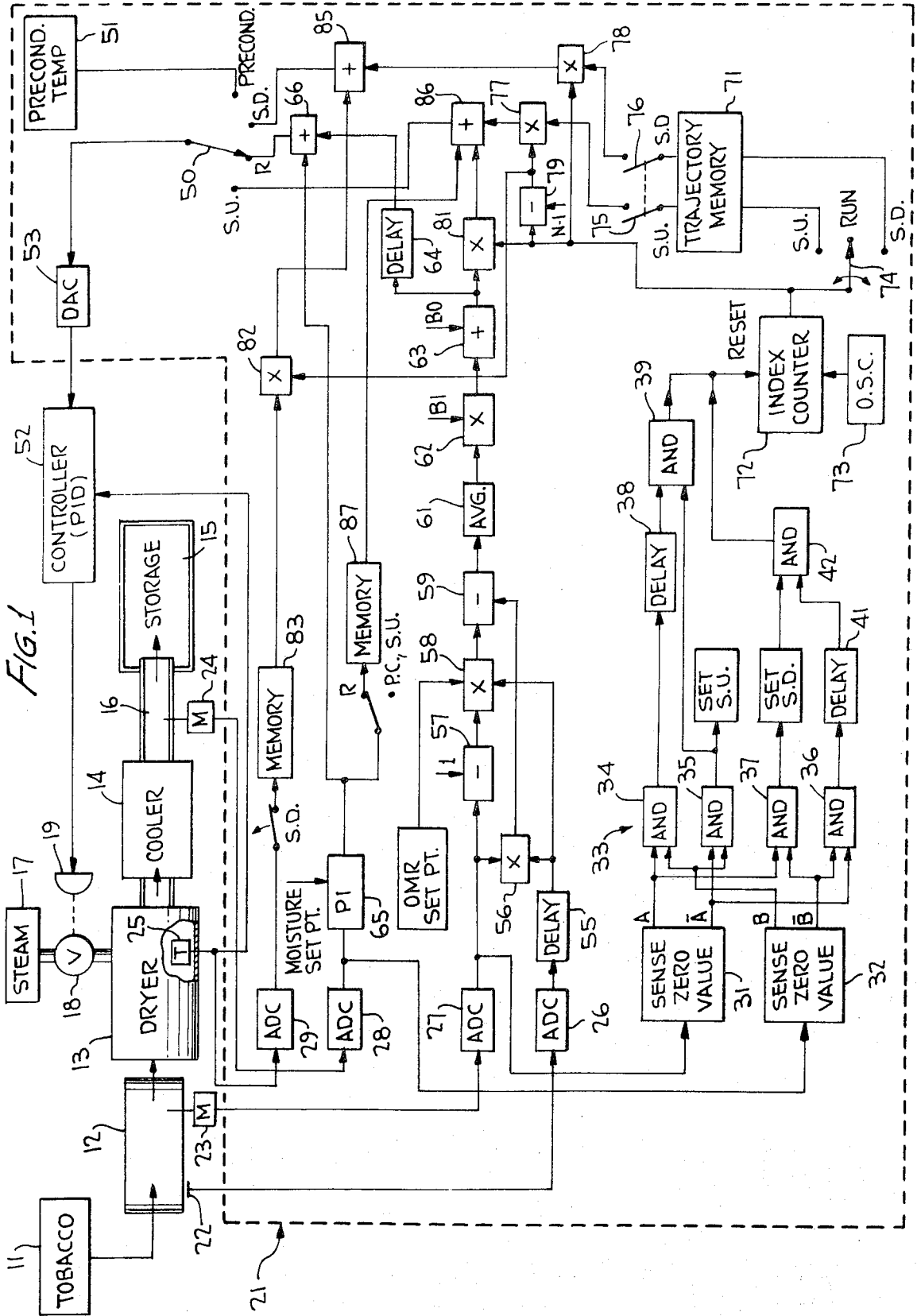
Moisture in tobacco flowing through a dryer is controlled so that it is maintained substantially at a desired amount during start up and shut down transitional periods of the tobacco flow through the dryer. Trajectories for the dryer drying rate during the start up and shut down periods are provided in a computer memory. During start up, an indication of the moisture and flow rate of the tobacco flowing into the dryer is derived to enable the amount of moisture expected to be removed by the dryer (dryer duty) to be calculated. When shut down commences the temperature of the dryer is derived and stored in the memory. During start up, the trajectory and dryer duty are time weighted so that a weighting factor for the trajectory decreases as the transitional period progresses and a weighting factor for the dryer duty increases as the period progresses and the two time weighted indications are combined to control the dryer drying rate. During shut down, the shut down trajectory and stored drying rate indication are time weighted so that a weighting factor for the trajectory increases as the period progresses and a weighting factor for the drying rate indication decreases as the period progresses and the two time weighted indications are combined to control the drying rate of the dryer.

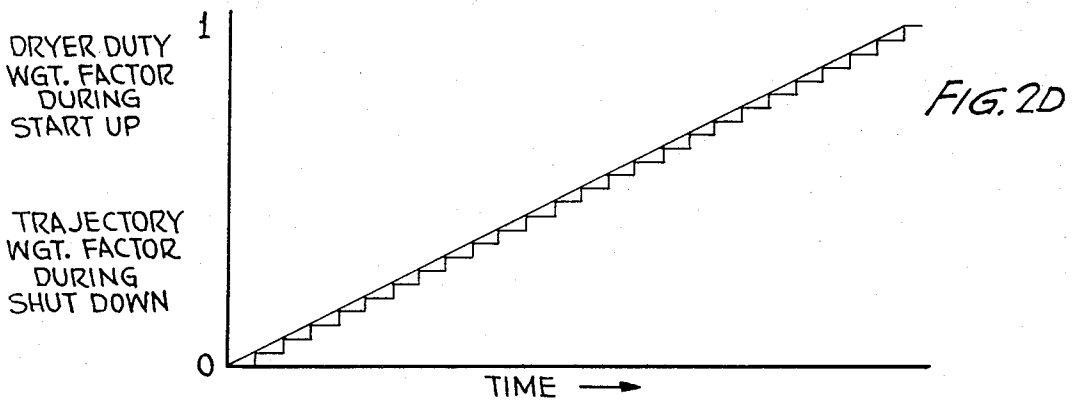
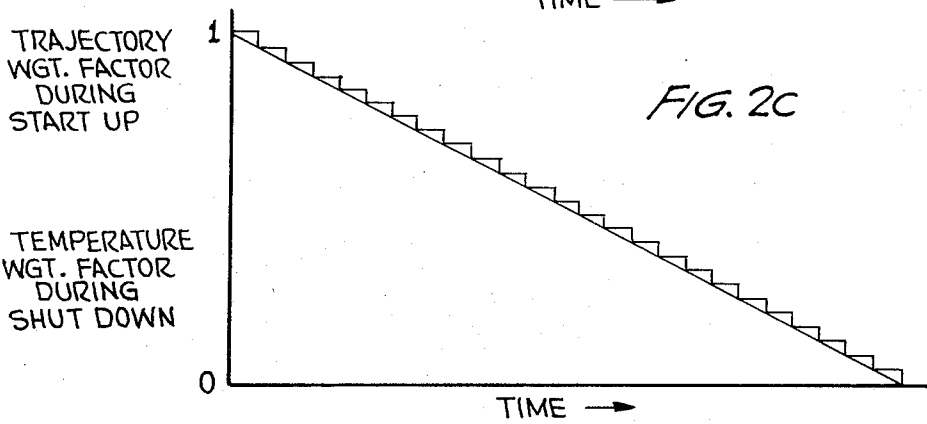
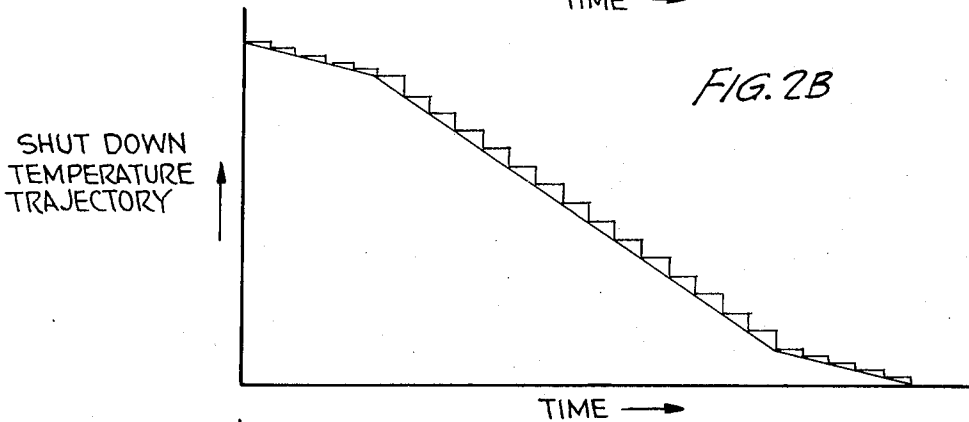
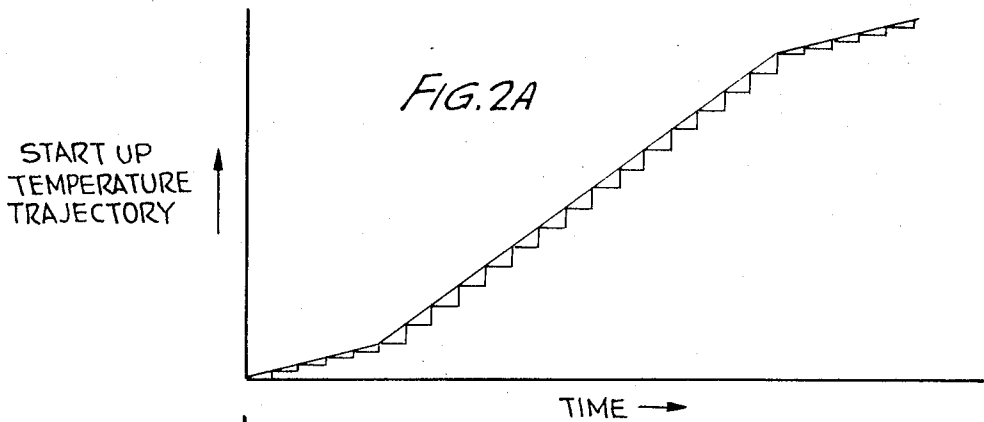
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Primary Examiner—William F. O'Dea
Assistant Examiner—Paul Devinsky
Attorney, Agent, or Firm—Allan M. Lowe et al.

11 Claims, 5 Drawing Figures







DRYER CONTROL SYSTEM AND METHOD**FIELD OF THE INVENTION**

The present invention relates generally to dryer control and more particularly to a controller wherein moisture of a material flowing through a dryer is maintained substantially at a set point value even though there is a substantial change in the dryer load.

BACKGROUND OF THE INVENTION

There are many systems and processes wherein a dryer is responsive to a mass of material flowing through the dryer and wherein it is desired to control the material moisture to a set point value. Examples of such systems and processes are in the tobacco, cotton, coffee, and nut processing industries.

When a substantial change in the load of such dryers occurs, moisture control to the set point value with existing controllers can be haphazard. For example, when dryers responsive to a material flow are initially supplied with material (start up) or the flow of material through such dryers is terminated (shut down), there is a tendency for the dryer to remove excess moisture from the material. If the mass of material that resides in the dryer at any one time is substantial, there is a resulting substantial economic loss, because over drying requires reprocessing of the material or because the material is completely ruined and cannot be reprocessed. Such losses can also occur if the supply, type, or moisture of material fed to the dryer changes considerably so that there is a substantial change in the dryer load. In the tobacco industry during each start up or shut down cycle of a typical cylindrical rotary drum dryer there may be up to 600 pounds of tobacco which require reprocessing because excess moisture is removed. Since start up and shut down cycles frequently occur numerous times during a day, the resultant economic loss is substantial.

SUMMARY OF THE INVENTION

In accordance with the present invention, moisture of a material emerging from a dryer of the above mentioned type is maintained approximately at a desired value even if there is a substantial change in the dryer load, as during start up or shut down. The result is achieved by providing a trajectory for the dryer drying rate during the transitional period of the substantial change. The trajectory is determined by factors such as the drying characteristics of the dryer and the dryer load, which in turn is a function of the flow rate and moisture of material through the dryer, and the type of material. Typically, the trajectory provides for a gradual change in the dryer drying rate during the transitional period. While the concept of gradually changing the drying rate of a dryer during the transitional period is disclosed in the prior art, we are unaware of any device actually utilizing the concept.

A significant improvement we have provided over the prior art device, wherein dryer drying rate is gradually varied during a transitional period, involves ascertaining a characteristic of the dryer, time weighting this characteristic, and combining the time weighted characteristic with a time weighted drying rate trajectory to control the dryer drying rate. Thereby, the dryer is smoothly controlled during the transitional period and the moisture of the material emerging from the dryer

remains close to the set point value throughout the transitional period.

For example, during start up, a trajectory is provided for the dryer drying rate, from an initial relatively low value to a final, relatively high value. The dryer duty associated with the material being fed to the dryer is monitored to derive an indication of what the dryer drying rate should be to enable the material which subsequently emerges from the dryer to be a specified set point moisture. At the beginning of the start up period, the process operation is most likely to be erratic, but toward the end of the start up or transitional period the computed dryer duty provides a relatively accurate indication of the desired dryer drying rate. The trajectory at the beginning of the start up transitional period has a relatively high probability of accurately controlling the dryer drying rate because the dryer load due to the material is not substantial. As the dryer becomes more loaded with the material, the material in the dryer has a greater effect on determining what the dryer drying rate should be. Thereby, during start up, time weighting functions are assigned to the trajectory and the dryer duty indication so that the weighting factor assigned to the trajectory decreases as the start up period progresses, while the weighting factor assigned to the dryer duty indication increases as the length of the period increases. The two time weighted indications are combined to derive a control signal for the dryer.

If the trajectory is not altered by time weighting, smooth transitions from start up to steady state (run) operation may not occur because the actual drying rate requirement of the dryer may differ significantly from that of the unaltered drying rate trajectory. The time weighting approach prevents under and over shoot of the dryer drying rate which could occur if only an unaltered trajectory were used. Overshoot is particularly disadvantageous because the product is overdried.

In the shut down transitional period, the opposite factors occur, whereby a characteristic of the dryer, such as its temperature, at the commencement of the shut down period is time weighted and combined with a time-weighted shut down trajectory. The time-weighting is such that the effect of the dryer characteristic decreases as the shut down period progresses, while the trajectory effect increases as the period length increases. The weighted trajectory and dryer characteristics are combined to derive a control signal for the dryer drying rate.

During shut down, the actual drying rate at the beginning of the shut down period may be less than the initial trajectory drying rate. If the drying rate trajectory were utilized under these circumstances, without time weighting, additional drying would occur to provide the opposite effect from that actually desired so that the product would be overdried. By time-weighting the indications of the actual drying rate at the beginning of shut down (e.g., dryer temperature at beginning of shutdown) and the drying rate trajectory, a smooth, monotonic transition in the drying rate occurs during the shut down period. Toward the end of the shut down period, when the trajectory effect is predominant over the temperature effect at the beginning of the shut down period, the dryer temperature is brought smoothly to a predetermined temperature without being influenced substantially by the dryer performance during normal running conditions.

During start up, an actual feedback loop cannot be provided because no material flows out of the dryer, whereby it is not possible to provide an indication of the deviation of the material moisture relative to a set point. However, according to a further feature of the invention, feedback is provided during start up by storing the error signal which subsisted during the immediately preceding processing interval. Since the dryer performance generally does not deviate materially from one shut down period to the following start up period, the prior error signal can usually be considered as an accurate measure of the amount of correction which should be applied during the next start up.

In one particular application of the invention, the dryer is utilized for enabling tobacco fed through it to have a predetermined moisture. However, it is to be understood that the principles of the invention are applicable to other types of material drying systems wherein material flows through the dryer and substantial changes occur in the load on the dryer.

It is accordingly, an object of the present invention to provide a new and improved system for and method of controlling a dryer for material that flows through the dryer so that a desired moisture content of the material is approximately maintained even though there is a relatively large change in the dryer load, e.g., as caused by a substantial change in the amount, type, or moisture of the material in the dryer.

Another object of the invention is to provide a new and improved system for controlling a dryer for material that flows through the dryer so that a desired moisture content of the material is approximately maintained during start up and shut down transitional periods of material flow through the dryer.

An additional object of the invention is to provide a new and improved system for and method of controlling a dryer for new material that flows through the dryer so that a desired moisture content of the material is approximately maintained during a start up transitional period of material flow through the dryer.

A further object of the invention is to provide a new and improved system for and method of controlling a dryer for material that flows through the dryer so that a desired moisture content of the material is approximately maintained during a shut down transitional period of material through the dryer.

An additional object of the invention is to provide a new and improved system for and method of controlling a dryer for material that flows through the dryer so that a desired moisture content of the material is approximately maintained even though there is a substantial change in the dryer load, wherein a predetermined characteristic of the dryer and an actual indication of the dryer duty during the period are combined to provide a smooth transition.

Another object of the invention is to provide a new and improved system for and method of controlling a dryer for material that flows through the dryer wherein prior indications of moisture error are utilized to assist in control during start up when no actual moisture error indications can be derived.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic, block diagram of one embodiment of the invention; and

FIGS. 2A-2D are graphic representations of start up trajectories and weighting factors utilized for the trajectories and for characteristics of the material in the dryer.

DETAILED DESCRIPTION OF THE DRAWING

Reference is now made to FIG. 1 of the drawing wherein there is illustrated a source 11 of relatively moist tobacco, typically having a moisture of 20 percent by weight, which is fed via a conveying system, including belt weigher 12, to a controlled dryer 13. Dryer 13 is of the type wherein tobacco flows into and out of it, and the tobacco flows through the dryer so that it is resident therein for a substantial time period; during normal (run) operation, material continuously flows through dryer 13 so that the rate of flow into the dryer approximately equals the flow rate of material out of the dryer. Typically, dryer 13 is of the rotary drum type. Material flowing from dryer 13 is conveyed to cooler 14, from which material flows to storage bin 15 via conveyor 16.

The drying rate of dryer 13 is influenced by the temperature thereof. To this end, dryer 13 is supplied with dry steam from source 17 via valve 18, the position (i.e., opening) of which is controlled by actuator 19.

The position of valve 18 is controlled by a local analog controller 52 which responds to a temperature transducer 25. The set point of controller 25 is furnished by computer control unit 21 in response to indications of various parameters indicative of the tobacco flowing into and out of dryer 13, as well as the dryer operating characteristics. The weight and moisture of tobacco supplied to dryer 13 are respectively monitored by belt weigher transducer 22, which functions in conjunction with belt weigher 12, and moisture transducer 23 which responds to the moisture of the tobacco on conveyor 12. Moisture of the conditioned tobacco flowing out of cooler 14 is monitored with a moisture transducer 24 that measures that tobacco on conveyor 16. Moisture transducers 23 and 24 can be of any well known type, such as infrared photoelectric transducers or dielectric transducers. The drying rate of dryer 13 is related to dryer temperature as measured by temperature transducer 25, located within dryer 13.

Computer control unit 21 is preferably a general purpose, cyclically operating digital computer that includes the usual input-output devices, memory, arithmetic unit and transfer buses. The computer is preferably programmed to perform a number of operations in sequence. The operations important to the calculation of the dryer control signal are indicated in FIG. 1 as boxes indicative of computer elements. Each of these operations is well known and can be performed by many existing general purpose computers. In the alternative, it is to be understood that a special purpose computer including each of the elements illustrated in computer control unit 21 can be employed.

The computer includes a number of alternative operational modes. Its particular mode of operation is responsive to the status of dryer 13, i.e., whether the dryer is in a start up, run, shut down, or precondition period. During start up and shut down, the dryer load changes since the amount of material in dryer 13 var-

ies. During run, dryer 13 is completely filled, but during precondition there is no material in the dryer, and it is maintained at predetermined temperature awaiting the flow of tobacco through it. The different operating modes of the system are represented in the diagram for computer control unit 21 as switches to simplify the presentation. It is to be understood, however, that in an actual general purpose computer there are no physical switches and that the switching functions are performed by conventional logic included in the computer.

It is the function of computer control unit 21 to determine the system mode of operation and drive a control signal for controller 52 in response to signals derived by transducers 22-25. To these ends, analog output signals of transducers 22-25 are respectively applied to analog-to-digital converters 26-29. While a different analog-to-digital converter is illustrated as being provided for each of the transducers, it is to be understood that only a single converter can be provided and multiplexed between the several transducers and the memory included within computer control unit 21. Analog-to-digital converters 26-29 respond for a predetermined time interval to average their input signals over the interval so that the signals derived from them can be considered as representative of the monitored quantity per unit length of time. The output signals of converters 26-29 are periodically sampled and supplied to the remainder of computer control unit 21.

The output signals of converters 27 and 28 are monitored to determine the dryer system operating mode since these converters respond to the presence or absence of tobacco flowing into and out of dryer 13. Zero output signals are derived by converters 27 and 28 only when there is no material flowing into and out of dryer 13; some finite signal value is derived from converters 27 and 28 in response to the flow of material into and out of the dryer. In response to both of converters 27 and 28 indicating that there is no material flowing into or out of dryer 13, the dryer is set to the precondition mode. In response to material flowing only into dryer 13 and no material emerging from the dryer, the dryer is in the start up mode. If material is flowing into dryer 13 and out of dryer 13, the dryer system is activated to the run mode; the system is activated to the shut down mode in response to material flowing out of dryer 13, to the exclusion of material flowing into the dryer.

To these ends, the output signals of converters 27 and 28 are respectively supplied to zero detecting elements 31 and 32. Zero detector elements 31 and 32 derive binary one signals in response to the sampled outputs of converters 27 and 28 having zero values. In response to any finite value being derived from converters 27 and 28, zero detecting elements 31 and 32 derive binary zero signals. Zero detector elements 31 and 32 are provided with true and complementary outputs, respectively indicated by \bar{A} and A and B and \bar{B} .

To determine the dryer operating mode, the output signals of detectors 31 and 32 are combined in logic element 33 in accordance with:

TABLE I

A	B	Dryer Mode
1	1	Precondition
0	1	Start Up
0	0	Run
1	0	Shut Down

To these ends, logic element 33 includes four AND elements 34-37 which respectively derive binary one outputs all during the precondition, start up, run, and shut down modes. AND element 34 has a pair of inputs respectively responsive to the \bar{A} and B outputs of zero detectors 31 and 32; AND element 36 has a pair of inputs respectively responsive to the \bar{A} and \bar{B} outputs of detectors 31 and 32; and AND element 37 has a pair of inputs respectively responsive to the A and \bar{B} outputs of zero detectors 31 and 32.

To detect the beginning or end of a transient period, a delay of one sample period is provided for the mode indicating signal which the system is leaving and the delayed signal is compared in an AND gate with a mode indicating signal for the dryer mode being entered. In particular, it is necessary to indicate the beginning of the start up and shut down transitional periods. To indicate the beginning of the start up period, the output signal of AND gate 34 is delayed by one cycle time in delay element 38, the output of which is combined in AND element 39 with the start up indicating output of AND gate 35. In response to a transition from the precondition mode to the start up mode, AND element 39 derives a binary one signal for one sample period to enable certain elements in the remainder of computer control unit 21 to be properly activated. To sense a transition from the run to the shut down mode, the output signal of AND element 36 is delayed by one sample period in delay element 41, the output of which is combined with the shut down indicating signal derived from element 37 in AND element 42. Thereby, AND element 42 derives a binary one signal during the cycle time beginning with the shut down interval.

With dryer 13 in the precondition mode, there is no load on the dryer so that the amount of control required is minimal. Thereby, a predetermined relatively low dryer temperature is maintained and the computer is activated so that a predetermined precondition temperature is read from memory element 51. To this end, a binary one signal derived from AND element 34, indicative of the precondition mode, activates switch element 50 to connect the predetermined temperature indication of memory element 51 to digital to analog converter 53. Controller 52 responds to the set point signal output of converter 53 to provide the requested temperature.

In run operation, the system is characterized by a feed forward loop responsive to the moisture and flow rate of tobacco supplied by belt 12 to dryer 13 and a feedback loop responsive to the percent moisture in the tobacco on conveyor 16. The feed forward signal, which is indicative of the dryer duty (the amount of drying which must be performed by the dryer to provide tobacco having a predetermined moisture) is derived by computing the moisture weight of the tobacco fed to the dryer and subtracting that weight from the desired moisture weight of the tobacco when it emerges from the dryer in accordance with:

$$JDY = (M1)(W1) - OMR(W1)(1-M1) \text{ where:}$$

$M1$ is the percentage moisture of the tobacco fed into dryer 13, as monitored by transducer 23;

$W1$ is the weight of the tobacco fed into dryer 13, as monitored by gauge 22; and

$OMR = M3/1 - M3$ is a set point of the desired fraction of the moisture weight ($M3$) in the total weight of the dried tobacco on conveyor 16.

For run control, the signal derived from converter 26 is delayed by the transport time between transducers 22 and 23 in delay element 55 so that the output of delay element 55 is time synchronized with the output of converter 27 and signals simultaneously derived by elements 27 and 55 are for the same mass of material flowing into dryer 13. To compute the weight of water represented by the outputs of converter 27 and delay element 55 at any one time, the weight and moisture percentage signals are multiplied together in multiplier element 56. The expected weight of the moisture for this mass of material is derived by determining the percentage of solid materials, exclusive of water, in the tobacco by subtracting the output of converter 27 from unity in subtraction element 56, the output of which is represented by $(1 - M1)$. The $(1 - M1)$ output of subtraction element 57 is multiplied in multiplier element 58 by a stored OMR set point signal in the computer memory and by the output of delay element 55; multiplier element 58 thereby derives an output signal commensurate with $(OMR)(W1)(1 - M1)$. The output of multiplier element 58 is indicative of the expected moisture weight of the considered mass of tobacco after it has emerged from dryer 13. The expected moisture weight indicating signal derived from multiplier 58 is subtracted from the input moisture weight indicating signal derived from multiplier element 56 in subtraction element 59.

The JDY indicating output signal of subtraction element 59, as expressed by Equation (1), is processed to derive a dryer control signal indicative of dryer load. Initially, the difference indication derived by element 59 is averaged in averaging element 61 over a number of sample periods, i.e., over a number of samples derived from the analog-to-digital converters, to remove relatively high frequency transients by a process which is somewhat similar to a low pass filter operation. The time averaged output signal of element 61, \overline{JDY} , is modified by a predetermined coefficient, B1, in multiplier element 62 which derives a signal that is combined with a predetermined constant, B0, indicative of the desired moisture of the conditioned tobacco on conveyor 16; the combining operation is performed by adder element 63 which derives an output signal in accordance with the linear, polynomial expression $B0 + B1(\overline{JDY})$. While the signal derived by element 63 is a linear polynomial of the quantity \overline{JDY} , the output signal could be a higher order polynomial, of any other suitable function. The signal derived by element 63 is indicative of a feed forward component of the set point temperature required to achieve the desired moisture of the conditioned tobacco on conveyor 16.

The feed forward component derived from adder element 63, reflecting the required drying rate of dryer 13, i.e. the dryer load, due to the moisture weight of tobacco fed to the dryer, is combined, after suitable delay in element 64, with an error indicating feedback component derived by a proportional-integral feedback loop which is responsive to the output signal of moisture gauge 24, as derived from analog-to-digital converter 28. The delay provided by delay element tuned in accordance with the dryer response characteristics. To derive the feedback component, the output of digital-to-analog converter 28, responsive to moisture gauge 24, is fed to proportional-integral element 65 of a well known type, which is also responsive to a digital moisture set point signal, which indicates the desired

moisture of the tobacco on conveyor 16. Proportional-integral element 64 derives an error signal indicative of the difference between the moisture set point signal and the output of converter 28 during each sample cycle of the converter, integrates the error signal, and adds the integrated error signal to the original error signal to derive the feedback component for the set point temperature of dryer 13.

The output signal of proportional-integral element 65 and the feed forward signal derived by delay element 64 are combined in adder element 66, the output of which is indicative of the set point value for the temperature of dryer 13. During the run mode, the output signal of adder 66 is connected via switch 50 to digital to analog computer element 53 which in turn provides an analog set point signal controller 52.

In accordance with the present invention, dryer 13 is controlled so that tobacco emerging from it is maintained approximately at a set point moisture during the transitional periods between the end of the precondition mode and the beginning of the run mode, i.e., the start up mode, and between the end of the run mode and the beginning of the precondition mode, i.e., the shut down mode. To this end, computer 21 includes in its memory start up and shut down trajectories which are stored in memory elements 71 and have dryer temperature versus time relationships as respectively indicated in FIGS. 2A and 2B. The trajectories of FIGS. 2A and 2B are mirror images of each other to simplify the presentation herein. However, the trajectories need not be mirror images of each other, but are synthesized to model the response of dryer 13 to expected dryer load variations during start up and shut down to achieve a predetermined moisture in the tobacco emerging from the dryer.

Typically, the shapes of the start up and shut down trajectories are determined by the dryer characteristics, assumed moisture of the tobacco in the dryer, the flow rate of tobacco through the dryer, the amount of tobacco in the dryer at the beginning or end of the transition, and the drying properties of the tobacco being treated. At the beginning and end of the trajectories illustrated in FIGS. 2A and 2B, the trajectory has a relatively small temperature versus time slope and a higher slope in the center portion of the transitional period. The initial temperature value of the start up trajectory and final temperature value of the shut down trajectory are equal to each other and the temperature at which the dryer 13 is maintained during the precondition mode, which subsists during the time interval between the end of the shut down mode and beginning of the start up mode. The maximum values of the two trajectories, at the end of the start up trajectory and beginning of the shut down trajectory, are average temperatures at which it is expected the dryer will be operating during the normal run mode. The time duration of the start up and shut down trajectories can be considered as constant because the time for material to be transported through the dryer is relatively constant. The trajectories of FIGS. 2A and 2B are nominal trajectories.

The trajectories illustrated in FIGS. 2A and 2B are constructed assuming identical changes in the volume of material flowing through dryer 13 during each start up and shut down period. The principles of the invention, however, are equally applicable to systems wherein there is a smaller change in the volume of the material. Also, if it is expected that the flow rate of ma-

terial through the dryer is subject to variations, the trajectory can be appropriately scaled as a function of time. If the material moisture or type of material changes, trajectories for these variables can be determined and stored. Working trajectories must be developed for each application considering the various factors described supra.

Each of the trajectories includes a number of discrete steps at which temperature remains constant during each scan period. Upon completion of each scan period, an index counter which controls readout of the trajectories is stepped and the temperature value associated with the trajectory may be changed; in the illustrated trajectories, it is assumed that a finite change occurs after each scan period.

The tobacco moisture is controlled to the approximate set point since the trajectories of FIGS. 2A and 2B have the greatest effect on dryer 13 when a minimum amount of tobacco is in the dryer, at the beginning of start up and the end of shut down; the trajectories have a minimum effect on dryer 13 when the dryer is almost fully loaded with tobacco, at the beginning of shut down and end of start up. Characteristics of the dryer operation respectively have the greatest and least effects when maximum and minimum amounts of tobacco are in the dryer. To these ends, time weighting functions (FIGS. 2C and 2D) are applied to the start up and shut down trajectories as well as to an indicated dryer characteristic. Each of the time weighting functions is similar to a straight line that varies from zero to one during the start up and shut down periods. The two time weighting factors include a number of discrete, equal amplitude levels, the number of which is equal to the number of scan periods in the transition period.

The time weighting factor of FIG. 2C, which varies from a maximum value of one to a minimum value of zero during the transitional period, is applied to the start up temperature trajectory of FIG. 2A such that the time weighting factor is multiplied by the temperature trajectory and the temperature trajectory thereby has a maximum effect at the beginning of the start up cycle, a minimum effect at the end of the start up cycle and is fifty percent effective in the center of the start up cycle. Similarly, the weighting factor function of FIG. 2D, wherein the weighting factor varies from zero to one from the beginning to the end of the transitional period is applied to the shut down trajectory in a multiplicative manner, whereby the final value of the shut down trajectory has virtually a 100 percent effect on the dryer, but the initial value of the trajectory has virtually zero effect.

The weighting factors of FIGS. 2C and 2D are also utilized to control the effect of the measured characteristics of the dryer operation during the transitional periods. In particular, during shut down, the time weighting factor of FIG. 2C is applied to an indication of the temperature of dryer 13 at the beginning of the shut down transition period and the weighting factor of FIG. 2D is applied to the moisture indication derived by adding element 63 during the start up mode.

The temperature magnitudes associated with the start up and shut down trajectories are stored in trajectory memory 71 and are derived from the memory during the appropriate start up or shut down mode. The memory locations are read out during the transitional periods in response to different locations in the memory being indexed by index counter 72, which is ad-

vanced once each sample period during the transitional periods by oscillator 73, which derives an output pulse at the beginning of each sample period. Index counter 72 includes a maximum count ($N - 1$) equal to the number of steps (N) minus one in the transitional periods; in the illustrated system and FIGS. 2A-D, N is assumed to be 25.

Index counter 72 is reset to a count of zero at the beginning of the start up and shut down periods. To this end, the counter includes a reset to zero input terminal which causes the counter to be reset to a zero count in response to a binary one input signal being applied thereto. Binary one signals are applied to the reset to zero terminal of counter 72 in response to the dryer mode shifting from precondition to start up, as indicated by a binary one output of AND element 39, or in response to the dryer shifting from a run to shut down mode, as indicated by a binary one output being derived by AND element 42. After counter 72 has been reset to zero, it is advanced by a count of one at the beginning of each sample period in response to an output signal of oscillator 73, whereby the counter state is indicative of the appropriate step in the transitional period.

The step indicating signal derived from counter 72 is applied selectively to start up and shut down inputs of trajectory memory 71 under the control of switching element 74, which is selectively connected between the output of the counter and the start up and shut down inputs of the trajectory memory. The temperature values of the start up and shut down trajectories are selectively read from the memory in response to closure of start up and shut down switching elements 75 and 76, respectively. Elements 74-76 are responsive to the mode indicating signals derived by AND elements 35 and 37. As the count of index counter 72 is advanced, the magnitudes of the signals fed through switching element 75 or 76 are varied in a predetermined manner, as illustrated for example, in FIGS. 2A and 2B.

To provide time weighting of the start up and shut down trajectories, the signals fed through switching elements 75 and 76 are respectively fed to multiplication elements 77 and 78. Second inputs supplied to multiplication elements 77 and 78 are indicative of the actual time position within the transitional period and the complement of the time position, as respectively illustrated in FIGS. 2C and 2D. To these ends, the shut down trajectory is multiplied in multiplier element 78 with the output of index counter 72 (illustrated in FIG. 2C), while multiplier element 77 responds to the start up trajectory as well as a signal indicative of $N - 1 - C$ (illustrated in FIG. 2D), as derived from subtraction element 79; subtraction element 79 is responsive to the count (C) derived from index counter 72 and a predetermined constant ($N - 1$) equal to the maximum count of counter 72. Thereby, the trajectory fed through switching element 75 is modified so that it is multiplied by a maximum amount toward the beginning of the start up cycle, but is multiplied by a minimum, almost zero value, toward the end of the cycle. Conversely, the shut down trajectory is modified in multiplication element 78 so that it is only slightly modified toward the beginning of the shut down period, but is decreased significantly toward the end of the shut down cycle.

The weighting factor signals applied to multiplication elements 77 and 78 are applied in parallel to modify the

monitored characteristics of dryer 13 which are indicative of dryer loading. During start up, the expected dryer loading factor, as represented by Equation (1) and derived from addition element 63, is modified in multiplication element 81 by the weighting factor variation indicated by FIG. 2C, as expressed by the output of index counter 72. During shut down, the complementary weighting factor signal, as indicated by FIG. 2D and derived from subtraction element 79, is multiplied in multiplier element 82 by a signal indicative of the dryer temperature at the beginning of the shut down period. To derive an indication of the temperature of dryer 13 at the beginning of the shut down period, the output of analog-to-digital converter 29 which reflects the temperature monitored by probe 25, is fed to memory element 83 via switching element 84. Switching element 84 is normally maintained in a closed condition so that memory 83 is updated after each sample period. However, during the shut down period, the output of AND element 36 causes switching element 84 to open, whereby during the duration of the shut down period memory 83 stores the temperature value of dryer 13 at the beginning of the shut down period.

During shut down, switching element 50 is controlled by the output of AND element 37 so that the shut down temperature set point signal is fed to digital to analog converter element 53. The set point signal derived by addition element 85 is responsive to the time weighted shut down trajectory and the time weighted temperature indication respectively derived from multiplication elements 78 and 82.

After the shut down period has been completed, switching element 50 is activated in response to the output of AND element 34 to feed the stored precondition temperature signal from memory element 51 to the digital to analog converter 53.

In response to the dryer mode being switched from the precondition to the start up mode, a binary one signal is derived from AND element 35, whereby switching element 50 is activated so that the output of addition element 86 is fed to element 53. AND element 86 responds to the time weighted start up trajectory derived from multiplication element 77 and the time weighted signal indicative of the dryer duty or load, as derived from multiplication element 81. Addition element 86 also responds to a residual feedback signal. An actual indication of the error cannot be divided during the start up interval because no material passes the moisture transducer 24 at any time during the start up interval.

The residual error indication is fed to addition element 86 by memory element 87 which is selectively responsive to the output of proportional-integral controller 65, as fed through switch 88. Switch 88 is maintained in a closed condition during the run mode in response to output signals of AND gates 36 and 37 being supplied thereto. During the precondition, start up and shut down modes, switch element 88 is open, whereby the signal stored in memory 87 is indicative of the error signal derived by proportional-integral control element 65 during the last step of the run mode. Since it is expected that the dryer error during the start up mode is generally similar to the dryer error during the immediately preceding operating period, the error signal stored in memory 87 provides a relatively accurate indication of the amount by which the time weighted tra-

jectory and moisture removal computation must be corrected during the start up mode.

While there has been described and illustrated one specific embodiment of the invention, it will be clear that variations in the details of the embodiment specifically illustrated and described may be made without departing from the true spirit and scope of the invention as defined in the appended claims. For example, the trajectories could be stored directly as time-weighted quantities, instead of being stored directly and multiplied by time-weighting factors.

We claim:

1. In a system for controlling a dryer for material that flows through the dryer so that a desired moisture content of the material is approximately maintained even though there is a significant change in the dryer load during a transitional period, means for providing a predetermined trajectory for the dryer drying rate during the transitional period, means for deriving an indication of the dryer performance during at least a portion of said transitional period, means for time weighting said trajectory and indication in opposite directions during said transitional period, and means for combining the time weighted trajectory and time weighted indication to derive a control signal for the dryer.

2. A method for controlling a dryer for material that flows through the dryer so that a desired moisture content of the material is approximately maintained even though there is a significant change in the dryer load during a transitional period comprising the steps of in a computer: storing a predetermined trajectory for the dryer drying rate during the transitional period, deriving an indication of said transitional dryer performance during at least a portion of the period, time weighting said trajectory and indication in opposite directions during the period; and controlling the dryer in response to concomitantly derived time weighted values of the trajectory and indication.

3. A method of controlling a dryer for material that flows through the dryer so that a desired moisture content of the material is approximately maintained even though there is a significant change in the dryer load during a transitional period including the steps of providing a predetermined trajectory for the dryer drying rate during the transitional period, said trajectory being determined by the dryer characteristics and the expected dryer load change during said transitional period, deriving an indication of the dryer performance during at least a portion of said transitional period, time weighting said trajectory and indication in opposite directions during said transitional period, and combining the time weighted trajectory and time weighted indication to derive a control signal for the dryer.

4. In a system for controlling a dryer for material that flows through the dryer so that a desired moisture content of the material is approximately maintained during a start up or shut down transitional period of flow the material through the dryer, means for providing a time weight trajectory for the dryer drying rate during the transitional period, said trajectory being determined by the drying characteristics of the dryer, the change of the material flow rate during the period and the change in the amount of material during said transitional period, means for deriving a time indication of the dryer performance during at least a portion of said transitional period, said trajectory and indication being time weighted in opposite directions during the period, and

means for combining said transitional time weighted trajectory and time weighted indication to derive a control signal for the dryer.

5 5. A method of controlling a dryer for material that flows through the dryer so that a desired moisture content of the material is approximately maintained during a start up or shut down transitional period of flow of the material through the dryer, comprising in a computer storing a predetermined trajectory for the dryer drying rate during the transitional period, said trajectory being determined by the drying characteristics of the dryer, the change of the material flow rate during said transitional period and the change in the amount of material during said transitional period, deriving an indication of the dryer performance during at least a portion of said transitional period, time weighting said trajectory and indication in opposite directions during said transitional period so that as the period progresses the effects of the weighting factors on said indication and said trajectory change in opposite directions; and concomitantly controlling the dryer in response to the time weighted trajectory and time weighted indication.

10 6. In a system or controlling a dryer for material that flows through the dryer so that a desired moisture content of the material is approximately maintained during a start up transitional period of flow of the material through the dryer, means for providing a time weighted trajectory for the dryer drying rate during the transitional period, said trajectory being determined by the drying characteristics of the dryer, the change of the material flow rate during said transitional period and the change in the amount of material during said transitional period, means for deriving a time weighted indication of the moisture of the material flowing into the dryer during said transitional the period, said trajectory and indication being time weighted during said transitional period so that a weighting factor for the trajectory decreases as said transitional the period progresses and a weighting factor for the indication increases as said transitional period progresses, and means for deriving a control signal for the dryer in response to the time weighted trajectory and indication.

15 7. The system of claim 6 further including means for storing a prior indication of a moisture feedback error, and wherein the control signal deriving means is responsive to the stored indication of a moisture feed-

back error.

8. The system of claim 6 wherein said moisture indicating deriving means includes means for deriving the indication as a function of the amount of water to be removed from the material while the material is resident in the dryer.

10 9. In a system for controlling a dryer for material that flows through the dryer so that a desired moisture content of the material is approximately maintained during a shut down transitional period of flow of the material through the dryer, means for providing a time weighted trajectory for the dryer drying rate during the transitional period, said trajectory being determined by the drying characteristics of the dryer; the change of the material flow rate during said transitional period and the change in the amount of material during said transitional period, means for deriving a time weighted indication of a drying characteristic of the dryer at the beginning of said transitional period, said trajectory and indication being time weighted during said transitional period so that a weighting factor given to the trajectory increases as said transitional period progresses and a weighting factor given to the indication decreases as the said transitional the period progresses, and means for combining the time weighted trajectory and indication to derive a control signal for the dryer.

15 10. The system of claim 9 wherein said drying characteristic deriving means includes means for deriving the indication in response to the temperature of the dryer.

20 11. In a system for controlling a dryer for material that flows through the dryer so that a desired moisture content of the material is approximately maintained even though there is a significant change in the dryer load during a transitional period, means for providing a time weighted trajectory for the dryer drying rate during the transitional period, means for deriving a time weighted indication of the dryer performance during at least a portion of said transitional period, said trajectory and indication being time weighted in opposite directions during said transitional period, and means for combining the time weighted trajectory and time weighted indication to derive a control signal for the dryer.

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