July 11, 1972 J. S. RICE 3,676,295

NONINTERACTING CONTROL OF MOISTURE AND FIBER CONTENT OF FIBROUS SHEET DURING MANUFACTURE

Filed Sept. 12, 1969 2 Sheets-Sheet 1

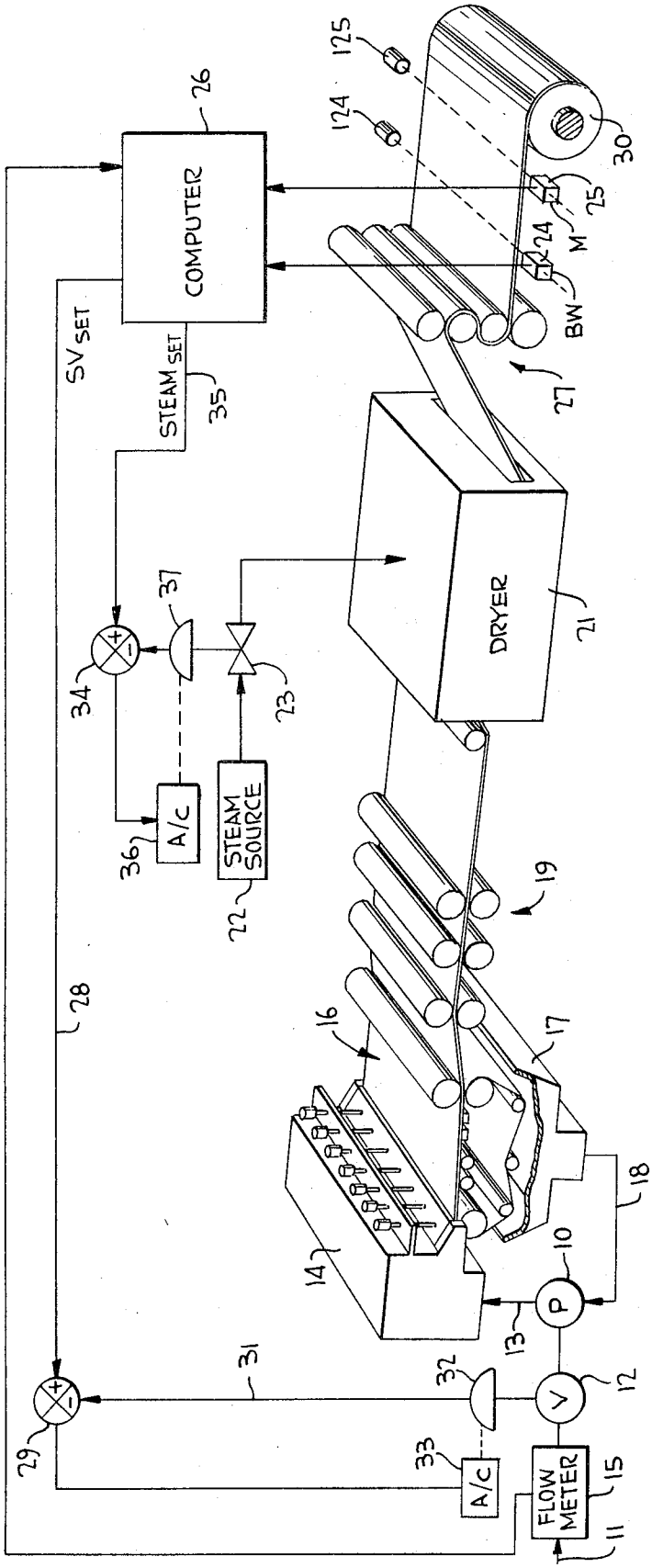


FIG. 1

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NONINTERACTING CONTROL OF MOISTURE AND FIBER CONTENT OF FIBROUS SHEET DURING MANUFACTURE

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FIG. 2

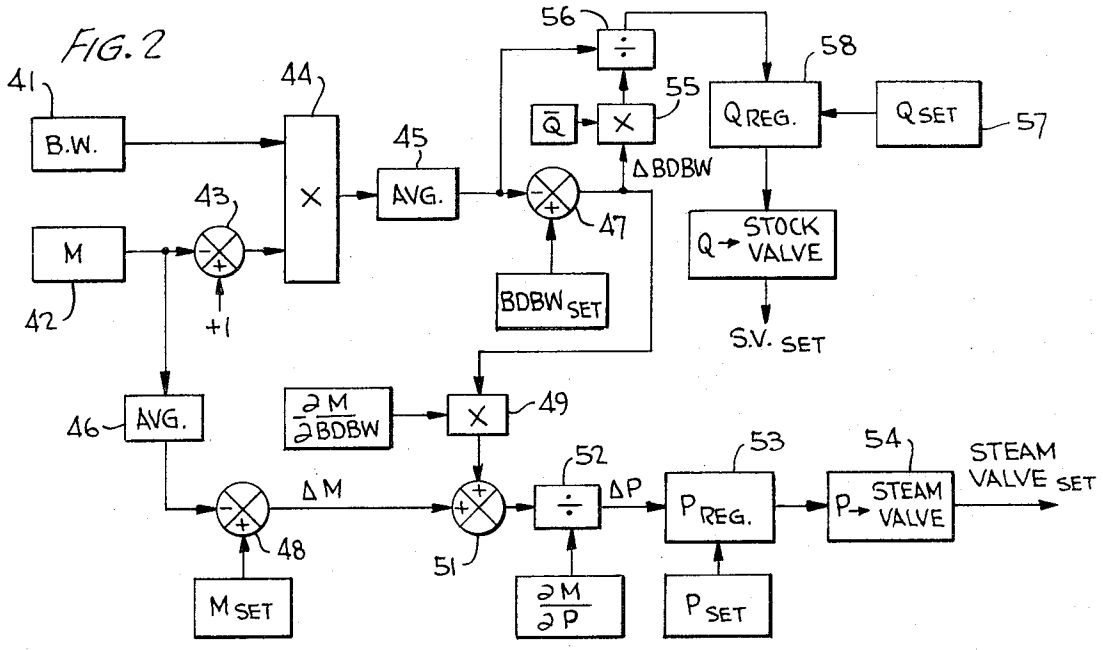
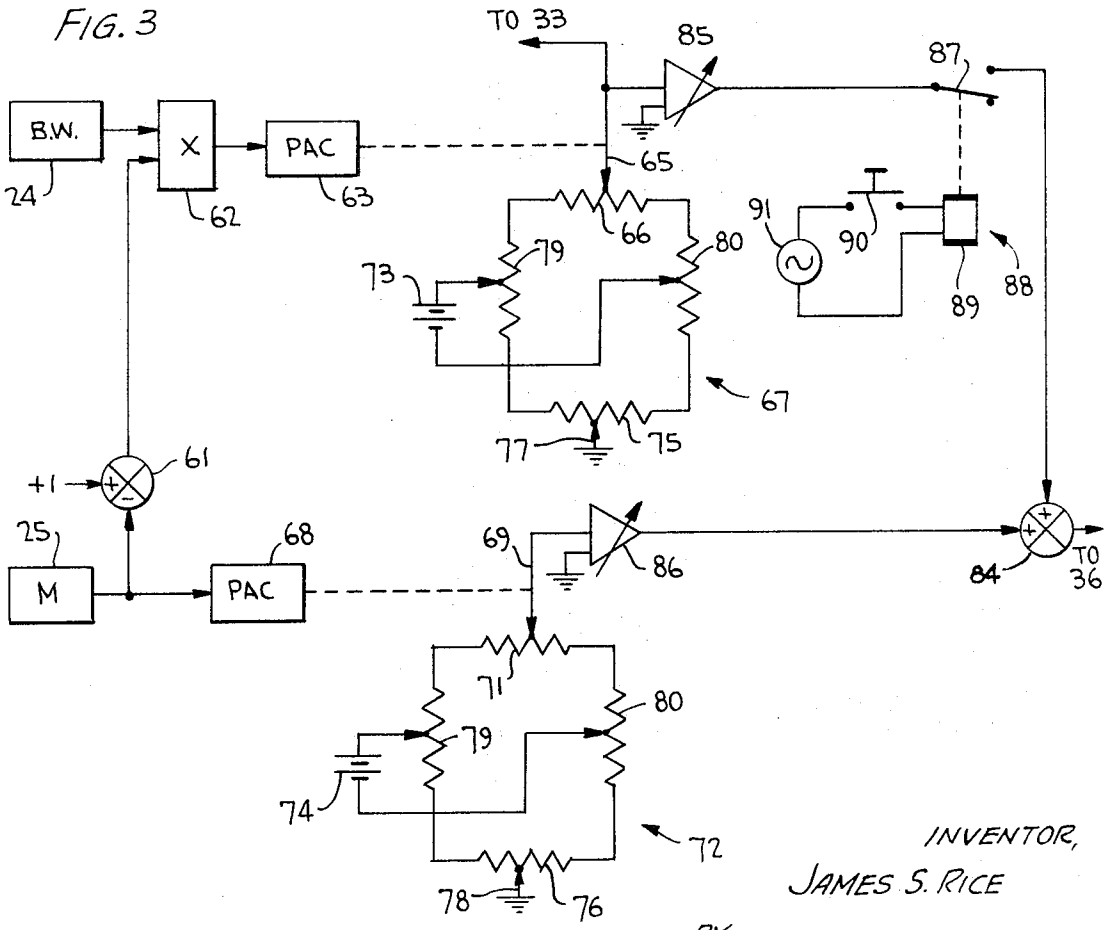


FIG. 3



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NONINTERACTING CONTROL OF MOISTURE AND FIBER CONTENT OF FIBROUS SHEET DURING MANUFACTURE

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U.S. Cl. 162—198 9 Claims

ABSTRACT OF THE DISCLOSURE

Moisture and fiber content of a fibrous sheet are controlled during manufacture by measuring the sheet moisture downstream of a dryer in the manufacturing machine, as well as the sheet fiber content. The fiber content and moisture measurements are combined to control the dryer drying rate in such a manner that changes in the rate at which fiber is fed to the machine are compensated for by changes in the dryer drying rate so that changes in the moisture content of the sheet are greatly minimized. The rate of fiber flow is controlled in response to an error signal for the sheet fiber content and the rate at which fiber is fed into the machine.

The present invention relates generally to control systems and methods for machines fabricating fibrous sheets and more particularly to a control system and method wherein sheet fiber and moisture content are controlled in a manner so that moisture variations normally induced in the sheet due to changes in the rate at which fiber is fed to the machine are compensated by controlling a dryer so that moisture in the sheet remains substantially constant.

Machines for fabricating fibrous sheets, such as paper, generally include a stock valve for controlling the flow of a fiber-water mixture into the machine and a dryer for removing water from the sheet after it has been formed. Concomitant or simultaneous control of the sheet moisture and fiber content in response to measurements of sheet basis weight, a parameter indicative of total sheet weight per unit area, and moisture has been proposed. Generally, the approach has been to control a steam pressure valve for the dryer in response only to a moisture signal and the stock valve only in response to total basis weight or bone dry basis weight content, a parameter indicative of dry fiber weight, i.e., total weight minus moisture. It has been found, however, that such concomitant controls do not enable the stock valve and dryer to be controlled on a noninteracting basis. Instead, corrections made to the sheet fiber weight affect the sheet moisture properties and a sheet having the desired moisture is not produced. If perfect noninteraction occurred, a change in the stock valve would have no effect on moisture of the sheet, and hence a noninteracting controller for a paper making machine is one in which a change in fiber flow rate would not be allowed to have an effect on moisture of the sheet, except for transient phenomena. It has also been found that variations in the sheet total basis weight, if corrected only by controlling the stock valve, cause a sheet having a moisture content different from a desired or target value to be produced.

A mathematical analysis of the dry fiber content per unit area or bone dry basis weight, as well as the moisture properties, of a sheet verifies the previously experimentally noted results. In particular, the bone dry basis weight, BDBW, and moisture M, of a paper sheet can be related to the pressure, P, of steam in the dryer and flow rate, Q, of fiber or stock through the stock valve in accordance with the functional relationships:

$$BDBW=BDBW(Q,P)$$

$$M=M(Q,P) \quad (1)$$

In response to incremental changes in the form of corrections to the fiber flow rate (ΔQ) and steam dryer pressure (ΔP), changes in bone dry basis weight ($\Delta BDBW$) and moisture (ΔM) occur and can be respectively represented as:

$$\Delta BDBW=\frac{\partial BDBW}{\partial Q}\Delta Q+\frac{\partial BDBW}{\partial P}\Delta P \quad (2)$$

and

$$\Delta M=\frac{\partial M}{\partial Q}\Delta Q+\frac{\partial M}{\partial P}\Delta P \quad (3)$$

where:

$\partial BDBW/\partial Q$ is the rate of change of bone dry basis weight with respect to fiber flow;

$\partial BDBW/\partial P$ is the rate of change of bone dry basis weight with respect to steam dryer pressure;

$\partial M/\partial Q$ is the rate of change of moisture with respect to fiber flow; and

$\partial M/\partial P$ is the rate of change of moisture with respect to steam dryer pressure.

For any grade and type of paper being manufactured, the partials $\partial BDBW/\partial P$, $\partial M/\partial Q$ and $\partial M/\partial P$ can be assumed constant, while the partial $\partial BDBW/\partial Q$ can be approximated as $BDBW/Q$. Since the fiber fed into a machine is controlled exclusively by the stock valve and the dryer has no effect thereon, the partial

$$\frac{\partial BDBW}{\partial P}=0$$

The partials $\partial M/\partial Q$ and $\partial M/\partial P$ are coefficients which can be experimentally determined for each machine and merely vary between grades and types of paper for most practical purposes and are thereby validly assumed constant for a particular set of machine parameters.

In accordance with the present invention, Equations 2 and 3 are solved for the values of ΔQ and ΔP to provide values for changes in the fiber flow rate and steam pressure necessary to fabricate a fibrous sheet wherein bone dry basis weight and moisture do not substantially interact with each other or have a minimal interaction and are reached without over or undershoot. The dryer steam pressure and fiber stock flow rate are varied in a coordinated manner so that changes in the fiber flow rate produce very small errors in the moisture content. In other words, if a sheet being manufactured does not have the correct fiber content but does have the desired moisture content, the solution of Equations 2 and 3 for ΔQ and ΔP gives the amount of correction to fiber flow rate and dryer drying rate to enable the fiber error to be corrected with a minimum change in the desired sheet moisture content. If only the fiber flow rate were corrected in response to a fiber error signal, without control of the drying rate, the total sheet weight would be excessively changed to produce overshoot of the moisture control.

Solving Equations 2 and 3, with appropriate substitutions, yields:

$$\Delta Q=\frac{\Delta BDBW}{\frac{\partial BDBW}{\partial Q}}=\frac{(\Delta BDBW)Q}{BDBW} \quad (4)$$

$$\Delta P=\left(-\frac{\partial M}{\partial Q}\cdot\Delta BDBW+\frac{\partial BDBW}{\partial Q}\cdot\Delta M\right)\div\left(\frac{\partial BDBW}{\partial Q}\cdot\frac{\partial M}{\partial P}\right) \quad (5)$$

For a particular steam dryer pressure, P,

$$\frac{\frac{\partial M}{\partial Q}}{\frac{\partial BDBW}{\partial Q}} = \frac{\partial M}{BDBW} \tag{6}$$

so that Equation 5 can be rewritten in accordance with:

$$\Delta P = \frac{-\frac{\partial M}{\partial BDBW} \cdot \Delta BDBW + \Delta M}{\frac{\partial M}{\partial P}} \tag{7}$$

According to a feature of the present invention, the setting of the stock valve is coordinated with the setting of the dryer steam valve in response to an error in the actual bone dry basis weight relative to the target or desired value therefor, multiplied by the flow of fiber through the stock valve divided by the actual bone dry basis weight. The ratio of the actual bone dry basis weight to the actual fiber stock flow is approximately equal to the coefficient $\partial BDBW/\partial Q$ in Equation 2, a variable which may be subject to greater changes than the remaining partial derivative coefficients of Equations 2 and 3.

I am aware of an article entitled "Designing and Tuning Digital Controllers," written by E. B. Dahlin et al., in the July 1968, "Instruments and Control Systems," pp. 11–15, wherein there is disclosed a system for preventing interaction between the fiber and moisture content of a sheet produced by a paper making machine. The present invention, however, provides results superior to those of systems developed in accordance with the Dahlin et al. article. In the Dahlin et al. article there is disclosed, in very broad terms, a system for controlling the dryer steam valve, as well as the stock valve, of a paper making machine in response to signals indicative of moisture and total basis weight of the formed sheet. In the present invention the steam valve is controlled in response to the moisture and bone dry basis weight, i.e., dry fiber content, of the sheet. By controlling the steam valve in response to moisture and bone dry basis weight, rather than total basis weight, the stock valve position can be controlled only in response to a bone dry basis weight error signal. In systems relying upon control in response to total basis weight and moisture, as disclosed by Dahlin et al., the stock valve, as well as the dryer steam valve, must be controlled in response to both moisture and total basis weight signals in addition to many parameters indicative of the machine characteristics. In particular, the stock and steam valves are both controlled in response to error signals for total basis weight and moisture, as well as machine parameters commensurate with rate of change of moisture with respect to dryer pressure, total basis weight with respect to dryer pressure, total basis weight with respect to stock flow rate, and rate of change of moisture with respect to stock flow. In the system developed by Dahlin et al., it was apparently felt that each of these machine parameters should be determined while the paper machine is in actual operation in response to perturbations actually applied to the machine. At the time such perturbations are applied to the machine no control is being performed and variations from property target values are intentionally introduced into the sheet being produced. Thereby, errors in sheet properties can arise due to two causes while the machine parameters are being determined. In the system of the present invention, where control is in response to bone dry basis weight and moisture, only three machine parameters are employed. As indicated supra, these parameters are rate of change of moisture with respect to bone dry basis weight, rate of change of moisture with respect to dryer pressure and rate of change of bone dry basis weight with respect to stock flow. For any particular grade of paper, I have found that the two moisture rates of change can be determined with sufficient accuracy on an a priori basis to enable accurate closed loop control to be performed and that $\partial BDBW/\partial Q$ can be accurately

approximated as the ratio of actual bone dry basis weight to stock flow. Therefore, a paper machine controlled in accordance with the present invention does not require time consuming periodic perturbation, which can cause errors in sheet properties, to determine machine characteristics. Further, problems of controller implementation are substantially reduced because fewer terms are required and the need to constantly update all of the machine parameters does not exist.

I have been informed that systems actually built utilizing the total basis weight approach described in the Dahlin et al. article are subject to problems of transients and poor regulation. It is likely that these problems arise because the stock valve is controlled in response to two error signals, viz: total basis weight and moisture, which may interact to produce overshoot or undershoot of moisture and basis weight. It has been found in a system actually constructed in accordance with the present invention that these problems are substantially reduced, apparently because only the bone dry basis weight error signal controls the stock valve and is employed in combination with the moisture error to control the steam valve. Controlling in response to the bone dry basis weight error is significant even though moisture and total basis weight measurements are usually combined to derive a signal indicative of bone dry basis weight. To the casual observer, it might appear that the bone dry basis weight error is merely a combination of the moisture and total basis weight errors. This is not the case, however, because of the multiplicative relationship between total basis weight and moisture. To derive an accurate indication of bone dry basis weight error, bone dry basis weight should be determined by combining the moisture and total basis measurements and subtracting the calculated bone dry basis weight value from a set point or target value therefor.

In a system of the type disclosed by Dahlin et al., the total basis weight and moisture signals resulting from a scan of the gauge across the sheet width are averaged to derive signals which are compared with target values therefor to derive the total basis weight and moisture errors. If the sheet being scanned has relatively great variations in dry fiber weight across its width, these may not be reflected in the control actions derived from the total basis weight and moisture errors because of the multiplicative nature by which total basis weight and moisture are combined to obtain bone dry basis weight. In accordance with another aspect of the present invention, total basis weight and moisture measurements made in each of a plurality of cross-sheet zones in response to scanning gauges are combined to derive a measure of bone dry basis weight in each zone. The bone dry basis weight indications for the several cross-sheet zones are averaged to derive an accurate indication of sheet fiber weight across the sheet width scanned to enable relatively error free noninteracting control of the sheet moisture and fiber content to be attained.

It is accordingly an object of the present invention to provide a new and improved system and method for concomitantly controlling the moisture and fiber content of a fibrous sheet during manufacture.

Another object of the present invention is to provide a new and improved system for and method of concomitantly controlling the fiber and moisture content of a fibrous sheet in a coordinated manner so that changes in the rate at which fiber is fed to the machine do not substantially affect the sheet moisture.

A further object of the present invention is to provide a system for and method of manufacturing a fibrous sheet wherein changes in the rate at which fiber is fed to the machine do not substantially affect the sheet moisture content and only a single variable indicative of a sheet parameter is required to control the fiber flow rate.

Still another object of the present invention is to provide a new and improved system for the method of con-

trolling the fiber and moisture content of a fibrous sheet in resopnse to signals derived from scanning gauges by concomitantly controlling a dryer steam valve and fiber stock valve so that changes in the rate at which fiber is fed to the machine do not substantially affect the moisture content of the sheet.

Still another object of the invention is to provide a noninteracting system for controlling the moisture and fiber content of a fibrous sheet during formation wherein the stock valve setting is controlled in response to measured dry fiber weight and the dryer steam valve is controlled in response to measured dry fiber weight and moisture.

Still another object of the present invention is to provide a noninteracting system for controlling the moisture and fiber content of a sheet wherein a stock valve is controlled in response to dry fiber weight and the flow rate of fiber through the valve.

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

FIG. 1 is a block diagram of a system in accordance with a preferred embodiment of the present invention;

FIG. 2 is a flow diagram indicative of the operations performed by the computer of FIG. 1; and

FIG. 3 is a circuit diagram of another embodiment of the apparatus which can be included within the computer of FIG. 1.

Reference is now made to FIG. 1 of the drawings wherein there is illustrated a machine for producing a fibrous sheet, such as paper, controlled in accordance with an embodiment of the present invention. In the fibrous sheet producing machine, a mixture of water and fiber is fed through conduit **11** from a fiber and water source (not shown). From conduit **11**, the fiber-water mixture is fed through stock valve **12** to pump **10** and conduit **13** which is connected to the inlet of headbox **14**. The fiber flow rate through stock valve **12** and conduit **11** is monitored by flow meter **15**, the output of which is an electrical signal proportional in amplitude to the mass flow rate of the mixture flowing from conduit **11** through stock valve **12**. Because there is a relatively constant and predetermined percentage of fiber in the mixture fed through conduit **11**, the output signal of flow meter **15** at any instant is correlated with the fiber flow rate through stock valve **12**.

Downstream of headbox **14** is Fourdrinier wire **16**, which receives a jet of fiber-water slurry emerging from the headbox slice and removes sufficient water from the slurry in a manner well known to those skilled in the art to form a sheet on the wire. Water removed from the mixture on wire **16**, generally referred to as white water, is fed from catch basin **17** through conduit **18** into conduit **13**, downstream of stock valve **12**, via pump **10**.

The sheet formed on wire **16** is fed to water removing press rollers **19**, downstream of which is steam dryer **21**. Dryer **21** is heated by steam from source **22** fed to the dryer at a controlled pressure through steam valve **23**. The relatively moisture-free paper sheet emerging from dryer **21** is polished and smoothed by calender rollers **27**. The sheet emerging from rollers **27** is the finished product that is fed to take-up roll **30**.

Between rollers **27** and roll **30** are scanning basis weight and moisture gauges **24** and **25**, respectively. Gauges **24** and **25** are respectively periodically scanned by motors **124** and **125** across the entire width of the sheet emerging from rollers **27** to derive signals indicative of the total weight of the sheet per unit area, a term referred to as basis weight, and percentage of moisture in the sheet.

The instantaneous signals derived by gauges **24** and **25** for different cross-sheet locations of the gauges, as well as the stock flow signal derived by flow meter **15**, are fed to computer **26** which derives analog set point signals for stock valve **12** and steam pressure valve **23** on leads **28** and **35**, respectively. The stock valve set point signal is fed to difference node **29**, where it is compared with a signal on lead **31** indicative of the actual position of stock valve **12**, as derived from valve actuator **32**. The resulting difference signal derived by node **29** activates automatic controller **33** to drive stock valve **12** to the position indicated by the set point signal on lead **28**. Difference node **34** similarly responds to the steam set point signal derived by computer **26** on lead **35** and the steam valve **23** position, as indicated by actuator **37** therefor to activate automatic controller **36** for steam valve actuator **37**.

Computer **26** responds to the analog signals derived by gauges **24** and **25**, as well as flow meter **15**, to actuate stock valve **12** and steam pressure valve **23** so that a noninteracting control between the sheet fiber or bone dry basis weight and moisture is achieved. To this end, computer **26** responds to gauges **24** and **25** to derive signals indicative of the average bone dry basis weight and moisture content for one scan of gauges **24** and **25** across the width of the sheet, i.e., profile average signals for bone dry basis weight and moisture. The computer responds to these average value signals, as well as the fiber flow rate signal derived from meter **15** and preprogrammed signals in a memory thereof to solve Equations 4 and 7 for incremental changes in the fiber flow and steam pressure changes to achieve noninteracting moisture and bone dry basis weight control of the sheet being formed. From the solution of Equations 4 and 7, the positions of stock valve **12** and steam pressure valve **23** are determined and the set points for these valves are derived on leads **28** and **35**, respectively.

Computer **26** can take the form of an analog computer, special purpose digital or general purpose digital computer. In a preferred embodiment of the invention actually built and constructed, computer **26** is a general purpose digital computer having an analog-to-digital and digital-to-analog input-output elements, as well as the usual memory, arithmetic unit and transfer buses.

The memory of computer **26** is programmed to solve Equations 4 and 7 in a step-by-step manner, described infra in conjunction with FIG. 2. In addition, the memory includes prestored values indicative of partial derivative coefficients for the particular paper making machine for each grade and type of paper to be fabricated. The coefficients are determined on an experimental, a priori basis and are commensurate with the rate of change of change of moisture with respect to bone dry basis weight ($\partial M/\partial BDBW$) and rate of change of mositure with respect to steam pressure ($\partial M/\partial P$). For any particular grade or type of paper being fabricated, the coefficients $\partial M/\partial P$ and $\partial M/\partial BDBW$ can be considered as constant and are stored in tabular form in the computer memory and retrieved therefrom in response to signals fed into the computer indicative of the grade and type of paper being formed. The memory of computer **26** includes a sufficient number of bit locations to store instantaneous values of total basis weight and moisture as derived from gauges **24** and **25** as they scan across the sheet. In addition, the computer memory includes a listing of initial set point or target values for bone dry basis weight and moisture for each particular grade and type of paper being formed. Initial set points for stock valve **12** and steam valve **23** are stored in the memory for each grade and type of paper formed by the machine. Adequate space is provided in the memory for storing measured values of stock flow through meter **15** to enable the average stock flow to be computed with the same periodicity as the average moisture and bone dry basis weight quantities. The memory of computer **26** is sufficiently large to store the results of computations performed by the arithmetic unit of the computer, and is pre-

loaded with nonlinear table look-up functions relating calculated values of flow through stock valve **12** and steam pressure valve **23** to set points for the stock valve and steam pressure valves.

To provide an understanding as to the manner by which computer **26** responds to the input signals from gauges **24** and **25** and flow meter **15** and stored signals in the memory thereof to solve Equations 4 and 7, attention is now directed to the flow diagram of FIG. 2. The output signals of total basis weight and moisture gauges **24** and **25** are periodically converted into digital signals as the gauges scan across the sheet and stored in the memory of computer **26**. After gauges **24** and **25** have been scanned across the width of the sheet, the memory of computer **26** stores a pair of signals for each of a multiplicity of transverse positions of the sheet, as indicated by blocks **41** and **42**, respectively.

The stored values of total basis weight and moisture are combined in the computer arithmetic unit to derive a signal indicative of the sheet bone dry basis weight at each transverse sheet position. To this end, each moisture signal (M) **42** is subtracted from one in the computer arithmetic unit and the resultant difference is returned to a different memory slot for each transverse position, an operation indicated by node **43**. The resultant $(1-M)$ difference signals for each transverse position are combined with the total basis weight signal (BW) **41** for the corresponding transverse sheet positions in a multiplicative manner in the computer arithmetic unit, the output of which is returned to a different memory location for each transverse sheet position and is indicative of sheet bone dry basis weight at the different transverse positions, operations indicated in the flow diagram by box **44**.

After the bone dry basis weight for each cross sheet position is calculated and stored in memory, the average bone dry basis weight for the entire width of the sheet is calculated, an operation indicated by box **45**. To this end, the different cross sheet position bone dry basis weight signals are read out in seriatim and accumulated in a register in the computer memory. The accumulated result is divided by the number of cross sheet positions from which data are taken. A similar averaging operation is performed on stored moisture signals derived from the several cross sheet locations from which data are taken, an operation indicated by box **46**. The stored cross sheet or profile averages for bone dry basis weight and moisture, the operations of boxes **45** and **46**, respectively, are compared with target or set point values for bone dry basis weight and moisture stored in the computer memory and retrieved in response to command signals indicative of grade and type of paper being manufactured. The comparisons are performed by subtracting the calculated average values from the stored target values in the computer arithmetic unit, operations indicated by summing nodes **47** and **48**, respectively. The difference between the average bone dry basis weight and moisture signals and the set points therefor, ΔBDBW and ΔM, respectively, are error signals which are returned to appropriate memory slots.

From the stored, calculated values of ΔM and ΔBDBW, as well as the stored coefficients of $\partial M/\partial BDBW$, the change in steam pressure valve setting, ΔP, is calculated. To this end, the memory location storing ΔBDBW is multiplied in the computer arithmetic unit with the stored value of

$$-\frac{\partial M}{\partial BDBW}$$

an operation indicated by box **49**. The resultant product is stored in a register of the computer arithmetic unit and added to the value of ΔM retrieved from the computer memory, an operation indicated by summing node **51**. The

$$\left(\Delta M-\frac{\partial M}{\partial BDBW}\Delta BDBW\right)$$

signal is returned to the computer memory location previously storing ΔM and is then divided in the arithmetic unit by the coefficient $\partial M/\partial P$ stored in memory to derive a ΔP signal, an operation indicated by box **52**. The ΔP signal remains in a register in the computer arithmetic unit and is algebraically combined therein with a value for steam dryer pressure previously stored in the computer memory and retrieved therefrom, an operation indicated by box **53**. The result of operation **53**, indicative of desired steam pressure for dryer **21** (P), is returned to the same memory location as the one where the previous desired steam dryer pressure value was stored. The initial value for desired steam pressure is loaded into the selected memory location at the beginning of the run for a particular type and grade of paper as an initial value for P_{SET} from a read only portion of memory containing a priori determined values thereof. In response to an operator selecting a particular type and grade of paper to be manufactured, the a priori detremined value of desired steam pressure is read from the read only section of memory to the memory location associated with operation **53**. As the machine operations occur, the initial value of desired steam dryer pressure set into the memory location associated with operation **53** is incremented in a positive or negative direction in response to the ΔP signal resulting from the division operation indicated by box **52**.

From the steam pressure indicating signal stored in the memory location associated with operation **53**, a steam pressure to steam valve position table look-up is performed in the memory to derive a digital output signal indicative of the set point for steam valve **23**, an operation indicated by box **54**. The steam valve setting is coupled to a digital-to-analog converter, the output of which is derived on line **35** to control the position of valve **23** in a manner described supra.

The set point for stock valve **12** is calculated by computer **26** in accordance with Equation 4 in response to the stored values in the computer memory indicative of calculated average bone dry basis weight, bone dry basis weight set or target point, average stock flow through stock valve **12** and the previous setting of the stock flow rate. To this end, the error value of bone dry basis weight, ΔBDBW, derived during operation **47**, is retrieved from memory and combined with the value in memory indicative of the computed average value for fiber flow ($\overline{Q}$) through stock valve **12** over the same time period as gauges **24** and **25** scanning across the sheet. This operation indicated by box **55**, is multiplicative and performed by the computer arithmetic unit in time sequence with the operations involved in determining the steam valve set point. The product $(\overline{Q}\cdot\Delta BDBW)$ is fed from the arithmetic unit to a memory location of computer **26**, subsequently retrieved from memory to the arithmetic unit and divided by the bone dry basis weight previously computed and stored during operation **45**. The division operation yielding the quotient

$$\left(\frac{\Delta BDBW\cdot\overline{Q}}{BDBW}\right)$$

is performed by computer **26** in the arithmetic unit thereof and the result is transferred back to the computer memory, operations indicated by box **56**. The quotient computed and stored during operation **56** is a signal having a magnitude and polarity indicative of the change in stock flow (ΔQ) through valve **12** necessary to provide noninteraction between the moisture and bone dry basis weight of the sheet being formed.

The quotient stored during operation **56** next increments the set point (Q) for the value of fiber flow through stock valve **12** stored by the computer memory. The incrementing operation **58** is performed in the computer arithmetic unit and the result is returned to the computer memory at the same place as where the previous value for the sheet fiber content was stored. In the same manner as described supra with regard to steam pressure, the

initial value for the sheet fiber content for the particular grade and type of paper being formed is retrieved from a read only section of memory and fed into the memory location associated with operation **58**. Each new value for flow rate derived during operation **58** is fed to the computer memory and utilized therein as an index for a table look-up relating the stock valve **12** position with the calculated value for fiber flow rate. The resultant of the table look-up operation is transformed to the computer digital-to-analog converter output and is fed via line **28** to drive stock valve **12** in the manner indicated supra.

After each scan of gauges **24** and **25** across the width of the sheet, computer **26** responds to a start signal to perform each of the previously mentioned operations in one second or less. Thereby, the stock and steam valve signals on leads **28** and **35** are substantially simultaneously derived and the stock and steam valves **12** and **23** are substantially simultaneously or concomitantly controlled in a coordinated manner so that changes in the rate at which fiber is fed through stock valve **12** to headbox **14** do not substantially affect the moisture in the sheet.

Reference is now made to FIG. 3 of the drawings wherein there is illustrated still another embodiment of the system of the present invention. In the embodiment of FIG. 3, an analog computer type system is utilized in place of the digital computer described in conjunction with FIG. 2. A further distinction between the systems of FIGS. 2 and 3 is that the flow rate through stock valve **12** is not monitored and individual coefficients for the various machine parameters are not provided. Instead, a number of settings are manually inserted, depending upon experimental results derived from operating the system.

Referring now more particularly to FIG. 3, the instantaneous signals derived by basis weight and moisture gauges **24** and **25** are combined to derive a bone dry basis weight signal. To this end, the D.C. analog output of moisture gauge **25** (a signal magnitude M) is subtracted from a D.C. voltage indicative of unity in difference node **61**, the output of which is fed to analog multiplier **62**, also responsive to the instantaneous output of basis weight gauge **24** (a signal magnitude BW). The product output of multiplier **62**, a D.C. signal proportional to $BDBW = BW\,(1-M)$, is fed to profile averaging computer **63**.

Profile averaging computer **63** responds to the instantaneous bone dry basis weight input signal thereof for the duration of a scan of gauges **24** and **25** across the width of the sheet and upon completion of the gauge scan, derives a constant output signal, in the form of a shaft position. The rotational position of the shaft is indicative of the average value of bone dry basis weight for the scan. Similarly, the output of moisture gauge **25** is averaged over a scan of the gauges across the width of the sheet being manufactured by profile averaging computer **68**. Upon the completion of each scan of gauges **24** and **25** across the sheet, profile averaging computer **68** produces a shaft rotation having a position commensurate with the average value of moisture gauge **25** while the gauge is scanning across the sheet.

The shaft rotation outputs of profile averaging computers **63** and **68** respectively drive sliders **65** and **69** of potentiometers **66** and **71**, included in bridges **67** and **72**. Bridges **67** and **72** are driven by floating D.C. power supplies **73** and **74**, respectively, and include target or set point potentiometers **75** and **76**. Sliders **77** and **78** of potentiometers **75** and **76** are both grounded and manually set to positions corresponding with set point, i.e., target values for bone dry basis weight and moisture, respectively.

To adjust the range of voltages applied to bridges **67** and **72** by power supplies **73** and **74**, each bridge includes potentiometer **79** and **80** having manually adjusted sliders. The slider settings of potentiometers **80** are adjusted in accordance with the low range of bone dry basis weight and moisture for a particular grade of paper being fabricated, while the settings of potentiometers **79** in the bridges correspond with the highest value for bone dry basis weight and moisture for the grade of paper being manufactured.

The bipolarity signals derived from taps **65** and **69**, respectively indicative of bone dry basis weight error and moisture error are combined linearly in summing node **84**. To this end, the D.C. voltages at sliders **65** and **69** are fed through variable gain D.C. amplifiers **85** and **86**, set in accordance with the desired degree of compensation to provide noninteracting bone dry basis weight and moisture control. The gain of amplifier **85** corresponds directly with the amount of compensation required to attain noninteracting bone dry basis weight and moisture control of the sheet being manufactured. The gain setting of amplifier **85** is dependent upon the relationship between changes in moisture and fiber content for the type and grade of paper made by each particular paper machine, as well as the transport lags from stock valve **12** and dryer **21** to the location of gauges **24** and **25**. These parameters are determined on an empirical basis to control the gain of the amplifier in such a manner as to provide the desired results. While the gain of amplifier **85** is adjusted to enable an output signal of sufficient magnitude to be derived to achieve a one-to-one relationship between bone dry basis weight and moisture compensation. Without amplifier **85**, the range of values between the bone dry basis weight and moisture compensation is limited to approximately 0.2 to 1.

With the system in normal operating condition, the outputs of amplifiers **85** and **86** are added together in summing node **84**, the output of which directly drives automatic controller **36** for steam valve **23**. In normal operation, contacts **87** of relay **88** are closed in response to energization of relay coil **89** by the closure of manual switch **90** which connects A.C. supply **91** to coil **89**. Switch **90** is activated to the open circuit condition to open contacts **87** only when the paper machine is in a start-up condition, while a grade change is being performed or if something appears to be malfunctioning in the interaction control system.

The output voltage of summing node **84** is applied directly to the automatic controller **36** for valve **23** because it is a measure of the actual deviation of the pressure change of the steam valve, thereby eliminating set point comparator **34** of FIG. 1. In a simliar manner, stock valve **12** is controlled in response to the deviation of measured bone dry basis weight relative to the target value thereof, as monitored by the voltage between potentiometer slider **65** and grounded slider **77** of bridge **67**. To this end, the voltage at slider **76** is fed directly to automatic controller **33** and set point comparator **29** is not employed.

While there have been described and illustrated several specific embodiments of the invention, it will be clear that variations in the details of the embodiments specifically illustrated and described may be made without departing from the true spirit and scope of the invention. For example, flow meter **15** can be eliminated in systems wherein the position of valve **12** can be accurately correlated with the actual fiber flow rate through conduit **11**. In addition, the position controllers for valves **12** and **23** can be replaced by feedback controllers responsive to measurements of stock flow through valve **12** and the pressure of steam fed by source **22** to the dryer. In such instances, flow meter **15** and a pressure transducer in the line between source **22** and dryer **21** are provided and the outputs thereof are combined with target values for stock flow and steam pressure calculated by computer **26** to derive error signals that control stock valve **12** and steam valve **23**.

A further possible change, having particular application with regard to feedback control of valve **12** in response to an error signal derived in response to the output of flow meter **15** and a calculated value for fiber flow rate, involves determining the value of ΔQ in response to the

set points for BDBW and Q, rather than the calculated values of $\overline{BDBW}$ and $\overline{Q}$. Since the set points for BDBW and Q do not generally deviate by a great amount from the calculated average values thereof, the value of ΔQ determined in this manner is frequently sufficiently accurate for control with the present system. Using the set points for BDBW and Q in determining the value of ΔQ has the advantage of faster settling time when the system is starting or while a grade change is taking place. In systems wherein stock flow error is calculated, the steam pressure target value can be computed in accordance with

$$\Delta P = \frac{-\frac{\partial M}{\partial Q}\Delta Q + \Delta M}{\frac{\partial M}{\partial P}} \quad (8)$$

rather than Equation 7 supra. The equivalency between Equations 7 and 8 results from the equality of

$$\frac{\partial M}{\partial Q}\Delta Q \text{ and } \frac{\partial M}{\partial BDBW}\Delta BDBW$$

Still a further possible change to the system is that the values of bone dry basis weight moisture and total basis weight measured or calculated at the different cross-sheet zones need not be stored for the entire period while the gauge is scanning across the sheet. In particular, the value of total basis weight for each zone can be discarded after bone dry basis weight for the zone has been calculated. The values of bone dry basis weight and moisture for the several zones can be accumulated as the gauges scan across the sheet and the total values thereof divided by the number of zones after the scan has been completed. If it is desired to average out certain property changes in the sheet along its length, the average property values from several scans can be averaged together to derive the moisture and bone dry basis weight error signals, rather than averages derived from a single scan of the gauges.

I claim:

1. A system for controlling the moisture and fiber content of a fibrous sheet formed by feeding a mixture of water and fiber to a fibrous sheet forming machine including a dryer comprising measuring means for deriving a first signal indicative of the dry fiber weight of a formed sheet, measuring means for deriving a second signal indicative of the moisture content of the sheet downstream of the dryer, means combining said first and second signals for deriving a dryer control signal, means responsive to the first signal for deriving a control signal for the rate of fiber flow to the machine concomitantly with the derivation of the dryer control signal, means for controlling the drying rate of the dryer in response to said dryer control signal, and means for controlling the rate of fiber flow to the machine responsive to said fiber flow rate control signal.

2. The system of claim 1 further including measuring means for deriving a third signal indicative of the rate of fiber flow to the machine, and means responsive to said first and third signals for deriving said control signal for the rate of fiber flow to the machine.

3. The system of claim 2 wherein said dryer control signal deriving means includes means responsive to errors between the measured fiber weight and moisture content of the sheet and target values therefor.

4. The system of claim 3 wherein said fiber flow rate control signal deriving means includes means responsive to errors only between the measured fiber weight of the sheet and a target value therefor.

5. The system of claim 1 wherein said dryer control signal deriving means includes means responsive to errors between the measured fiber weight and moisture content of the sheet and target values therefor.

6. The system of claim 5 wherein said fiber flow rate control signal deriving means includes means responsive to errors only between the measured fiber weight of the sheet and a target value therefor.

7. The system of claim 1 wherein said fiber flow rate control signal deriving means includes means responsive to errors only between the measured fiber weight of the sheet and a target value therefor.

8. The system of claim 1 wherein said fiber content measuring means includes a moisture gauge and a total basis weight gauge scanning across at least a portion of the sheet width together, means responsive to the scanning gauges at corresponding cross sheet portions to derive a measure of dry fiber weight for individual cross sheet portions, means responsive to the scanning gauge responsive means and the scanned moisture gauge for separately averaging the fiber weight and moisture content of the sheet for a predetermined length across the sheet width.

9. A method of controlling the fiber and moisture content of a fibrous sheet formed by feeding a mixture of water and fiber to a fibrous sheet forming machine including a dryer comprising providing a measurement of the moisture content of the sheet downstream of the dryer, providing a measurement of the dry fiber weight of the formed sheet, providing a dryer control signal which is a function of both said moisture and dry fiber weight measurements, and controlling the dryer in response to said dryer control signal concomitantly with controlling the rate at which fiber is fed to the machine in a coordinated manner so that changes in the rate at which fiber is fed to the machine do not substantially affect the moisture content of the sheet.

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