

[54] **METHOD OF CONTROLLING A DRIER LIMITED PAPER MACHINE**[75] Inventor: **Erik B. Dahlin**, Saratoga, Calif.[73] Assignee: **Measurex Corporation**, Cupertino, Calif.[22] Filed: **May 20, 1974**[21] Appl. No.: **471,228****Related U.S. Application Data**

[63] Continuation of Ser. No. 233,937, March 13, 1972, abandoned.

[52] **U.S. Cl.** **162/198; 162/252; 162/253; 162/256; 162/258; 162/259; 162/263; 162/DIG. 6**[51] **Int. Cl.** **D21f 1/08; D21f 7/00; D21f 9/00**[58] **Field of Search** **162/198, 263, 252, 253, 162/254, 259, 256, 258, 342, DIG. 6**[56] **References Cited****UNITED STATES PATENTS**

3,165,438	1/1965	Dennis et al.	162/340 X
3,649,444	3/1972	Futchur	162/198
3,687,802	8/1972	Rummel et al.	162/198
3,703,436	11/1972	Rice	162/198

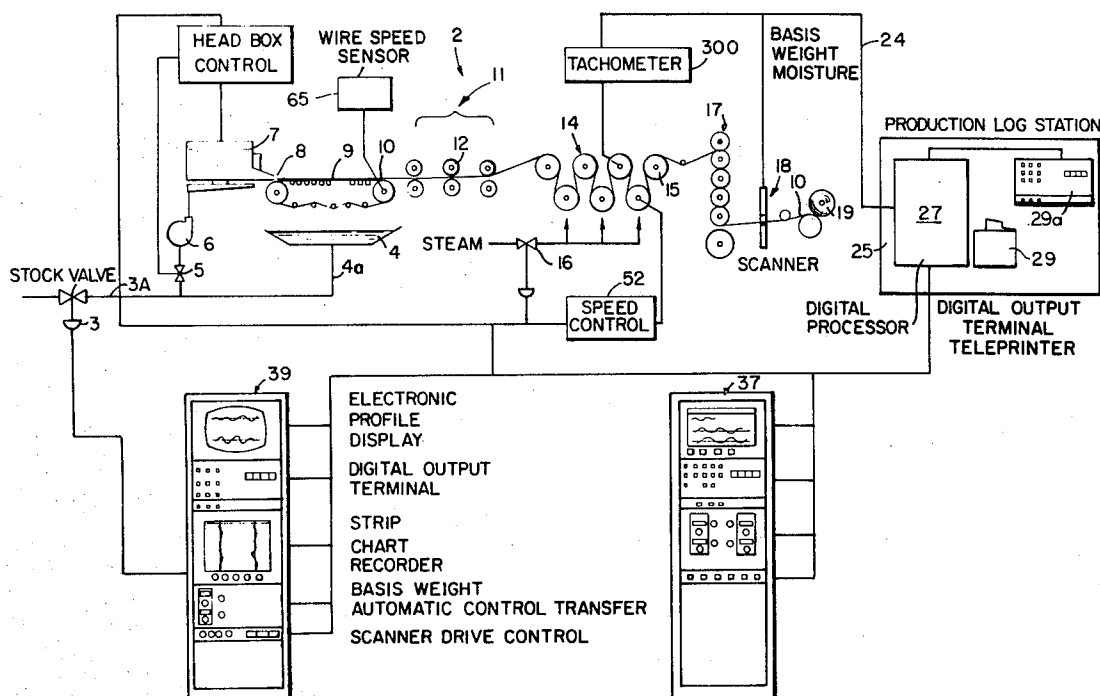
Primary Examiner—S. Leon Bashore

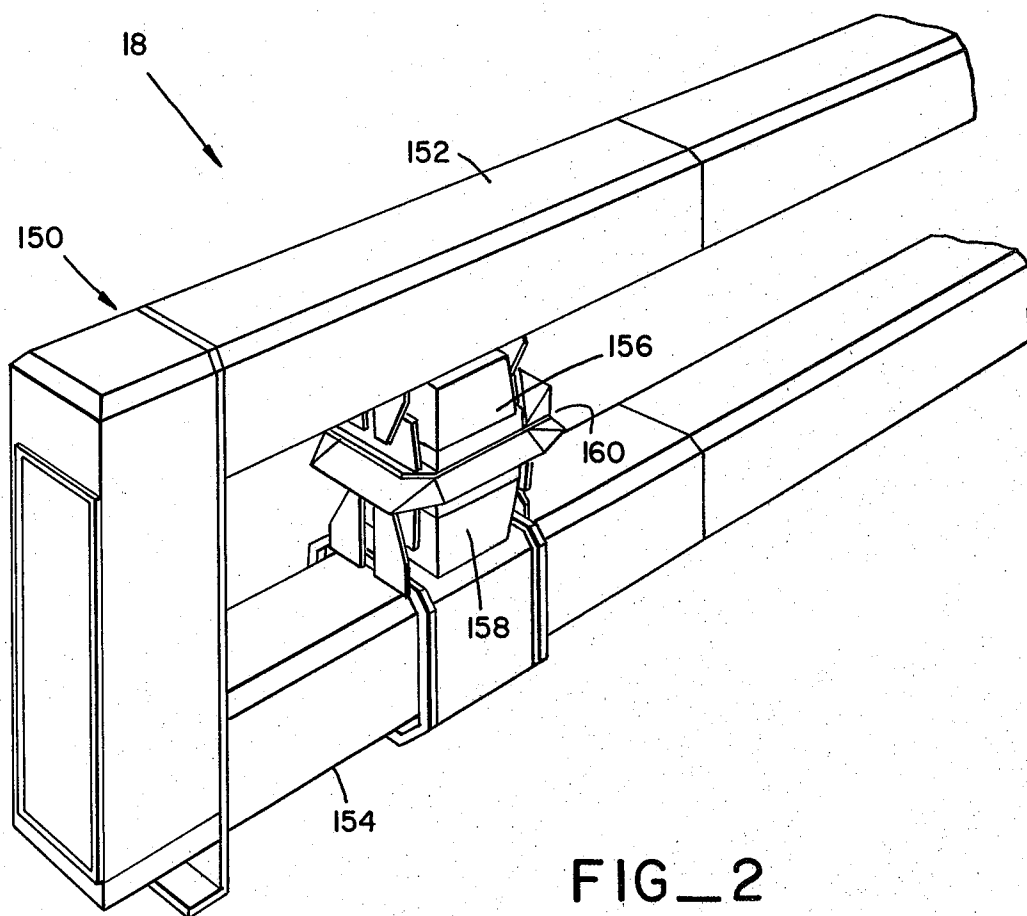
Assistant Examiner—M. Steven Alvo

Attorney, Agent, or Firm—Flehr, Hohback, Test, Albritton & Herbert

[57] **ABSTRACT**

A method of paper machine drier limited control wherein grade changes are executed in a continuous feedback manner. One control loop drives conditioned weight from one value to another value via action on stock flow while a second control loop maintains moisture at a constant value via action on master speed. The conditioned weight and moisture control loops are coordinated so that a control action in one loop will not upset the controlled variable in the other loop. The change in conditioned weight is also coordinated with a corresponding change in the headbox slice opening. Changes in master speed necessary to maintain a constant moisture content are fed forward to a headbox jet-to-wire ratio control loop so that the headbox head may be adjusted for speed changes to keep the jet-to-wire ratio constant. An additional coupling is made between the jet-to-wire ratio control loop and the slice opening so that the fiber concentration of the jet is not thrown out of control by head changes and the rotational velocity of the rectifier rollers is controlled to eliminate pressure differentials at the slice.

1 Claim, 5 Drawing Figures



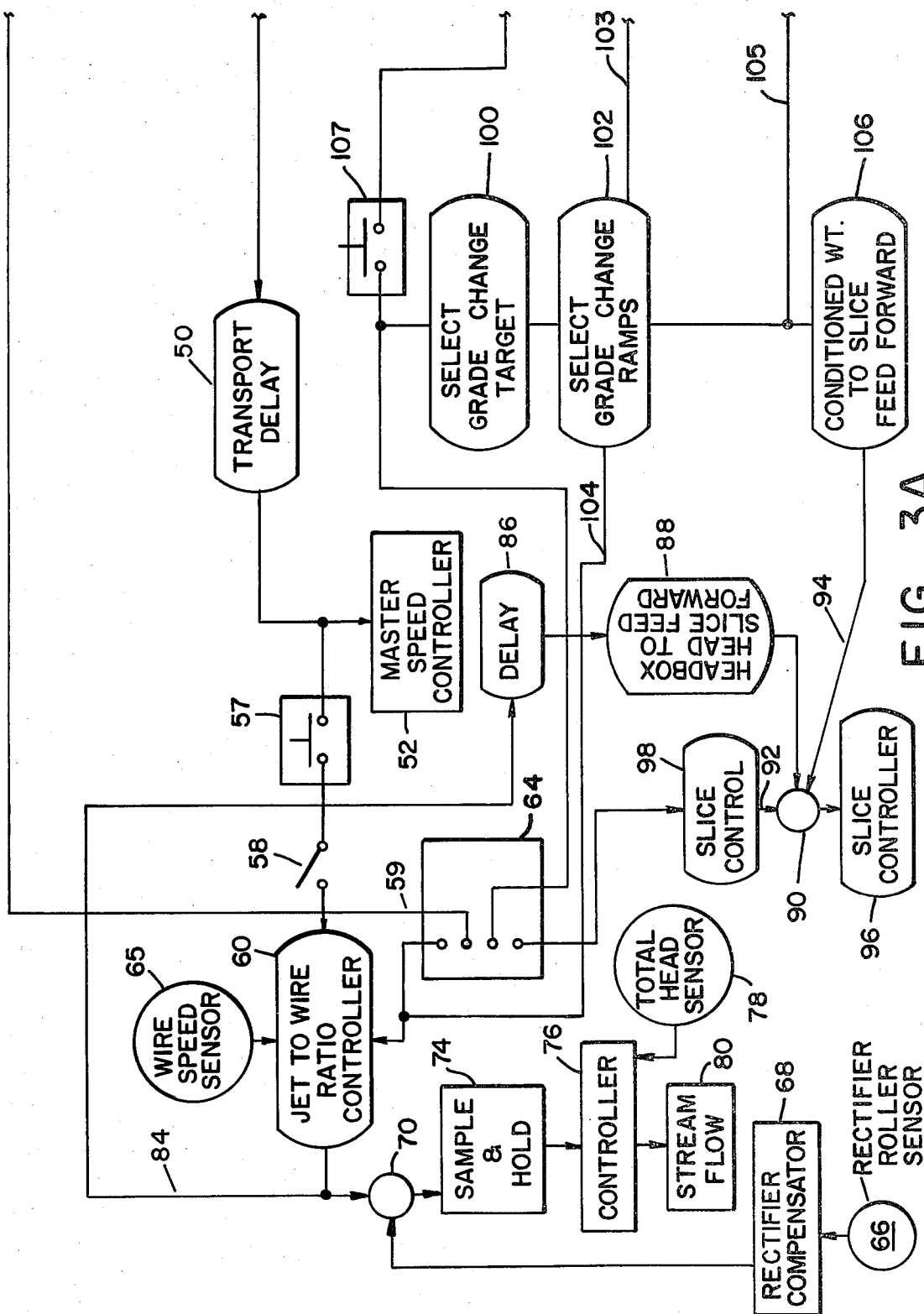


FIG - 3A

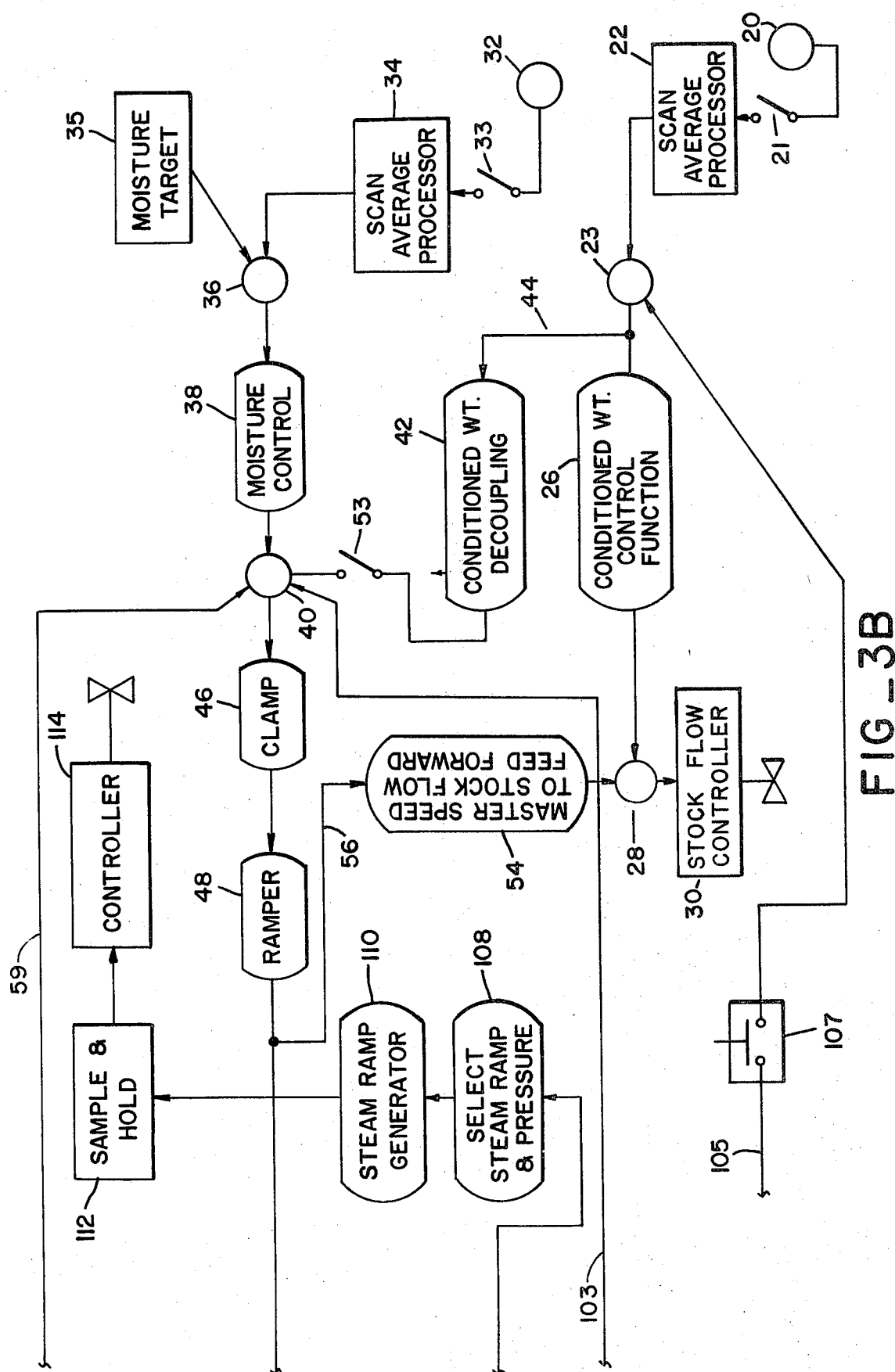
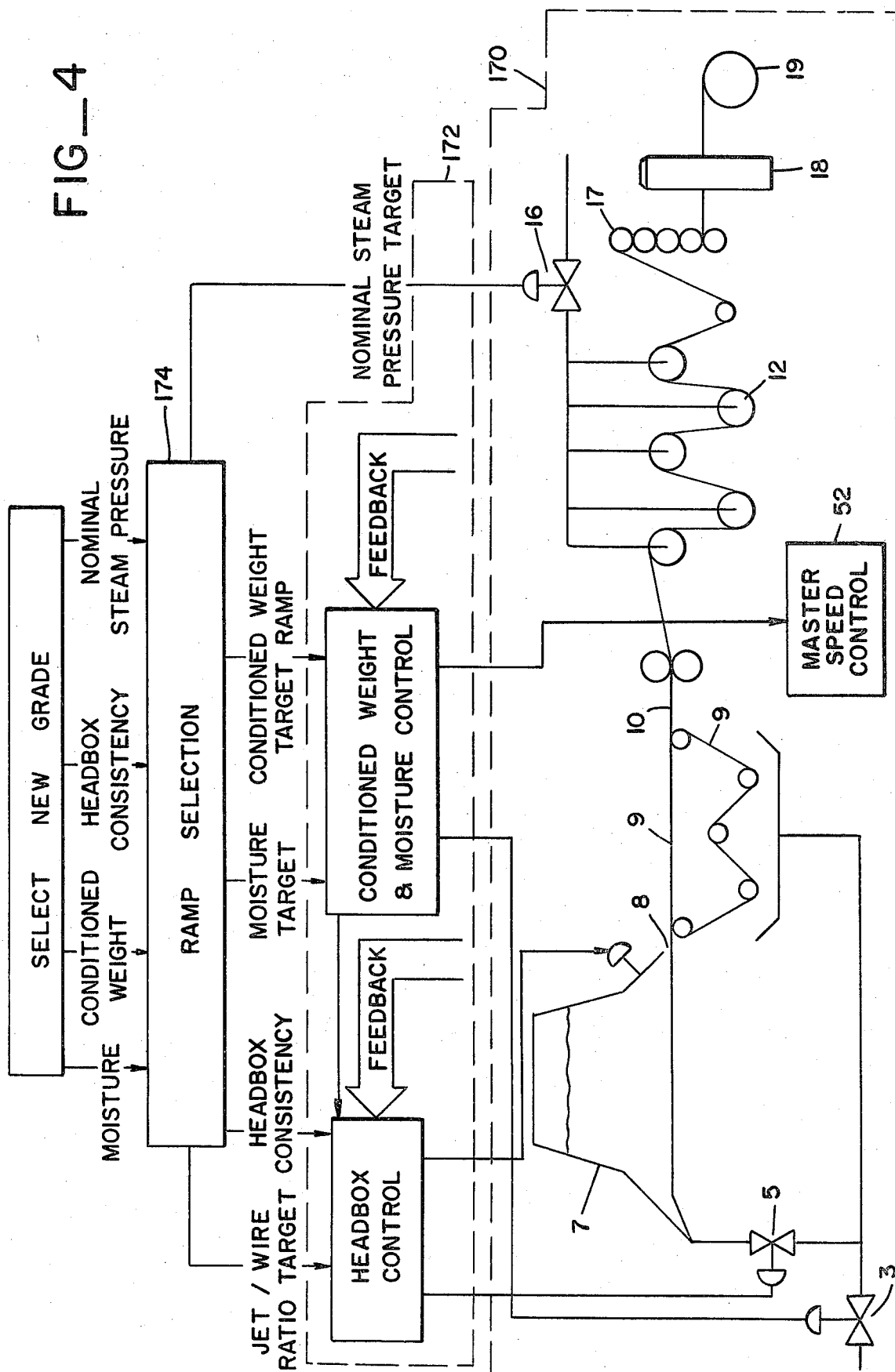


FIG-4



METHOD OF CONTROLLING A DRIER LIMITED PAPER MACHINE

This is a continuation of application Ser. No. 233,937 filed Mar. 13, 1972, and now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates to the digital control of paper making machines. More particularly it relates to a feedback control system for changing the grade of paper and an improved method of controlling a paper machine headbox.

The process of paper making utilizes logs as the basic raw material. The logs have their bark removed, are cut into chips, and then are converted to pulp. Pulp to be used for white paper is then bleached whereas unbleached pulp may be used for such products as paper bags. After bleaching, pulp streams of different compositions and properties are blended together to produce a sheet with the desired properties. The blended stream is then sent to refiners which consist of counter rotating disks or cones between whose surfaces the pulp slurry is pumped. The refiner disks cut the fibers and rupture the outer cell walls to expose the softer inner materials. This increases the surface area of the pulp and to some degree the strength of the paper product.

The product from the refiner, called stock, is then mixed with white water and passed through a stream flow valve into a headbox. The headbox transforms the incoming flow of pulp into a wide jet stream about one inch deep. This is done by allowing the water to escape or jet from the bottom of the headbox through a long narrow opening called the "slice". The jet discharges on top of and parallel with a moving wire screen, often called a fourdrinier wire (hereafter called the wire). The speed of the jet and wire are controlled to run at nearly the same velocity. However, a slight differential in the two speeds causes a certain amount of fiber orientation and thus improves the paper quality. Thus, it is critically important to control the jet speed to wire speed ratio (hereafter called jet-to-wire ratio). Water passes through the wire but leaves the majority of the fiber behind as a wet web. The water that passes through the wire is called white water and is collected and again mixed with the stock flow as mentioned earlier. The next step in the process is that of pressing water out of the web. In this way the solids content is increased from about 20% to about 40%. Following pressing, the sheet passes through a steam heated dryer section from which the sheet emerges at about 95% solids. In other words, the moisture content is a critical parameter with small deviations around 5% making considerable differences in both the properties of the paper product and the economies of production. Thus, moisture content must be carefully controlled.

The paper sheet passes from the dryer section to a "calendar stack" where the thickness uniformity is improved and a surface finish is imparted to the paper. Finally, the paper is wound on a reel.

Paper making machines start with the headbox and end with the reel. They are very expensive and to be economical must be run as continuously as possible. As with other expensive production equipment, unscheduled down time or slow downs on the paper machine are very costly. In maximizing the output of a paper machine, one significant area ripe for improvement is in time lost in changing the grade of the paper. Grade here refers to the basis or conditioned weight of the

paper being made where conditioned weight and basis weight are two very similar ways of describing the weight of fiber content per unit area of paper produced. Due to pulp input limitations, grade changes usually require commensurate speed changes as well as changes in many other variables. Because of this complexity, reducing the unproductive time in a grade change is a formidable task and requires a very sophisticated control scheme that includes special headbox controls not heretofore available. The present invention fills this gap in paper machine control.

The application of process control techniques to paper making has been going on for some time now. These techniques have developed from a point where human operators were watching meters and adjusting valves through analog feedback control to the present. Recently digital feedback control has replaced analog control for many applications. The process of replacing analog control with digital control started in situations where the control schemes were relatively simple and the advantages quite clear. Progressively more difficult applications were switched over from analog to digital control. The present invention is directed at two complex and interrelated problems that have not been solved - grade change and headbox control.

In the past the general approach for handling grade changes was to move the actual process variables such as machine speed, stock flow, headbox head, and steam along complex trajectories that were predetermined from process models. The procedure started with the development of accurate process variable trajectories using data logging, curve fitting and similar techniques. When a grade change was required, the machine was taken off control and the various process variables were carefully moved from their initial set point to their final set point along the previously determined trajectories. After the process variables reached their final values, the machine was brought back on control and good paper again made. Because little or no feedback information is used in controlling the change, this approach just described is called open loop grade change control.

There are, however, several drawbacks to the open loop approach. To start with, severe process transients may develop if the process variable trajectories are not accurate. Thus considerable effort must be put into the development of process models. But even after the investment is made to get good models, there are still problems. In particular, all models depend on some assumptions. As long as the assumptions are realistic, they cause no great harm. But all too often conditions change so that one or more of the assumptions are no longer valid. For example, pulp from a different tank may be introduced while a grade change is taking place. Unless the pulp from the new tank has nearly the same properties as that from the old tank, the assumptions may be far off. And, pulp often varies considerably from tank to tank due to such things as the use of a different kind of wood or a different percentage of used paper. Thus, the projected variable trajectories may be thrown far off due to no greater disturbance than a change in pulp characteristics.

As a result of these possibilities, the grade change must be made very slowly to allow time for human intervention. Otherwise there is a risk of having to abort midway through a grade change or even a risk of sheet break. Since all of these alternatives are quite expensive

sive in production time lost, an improved method of changing grade is needed.

Furthermore, the open loop schemes usually require very expensive instrumentation. For example, they require a control valve in the white water line and a flow meter in either the stream flow line or the white water line. Since these lines are on the order of 30 inches in diameter, the instrumentation therefor is very expensive.

Since a grade change requires a movement of the headbox parameters, coordination of grade change with headbox control is critical. In particular, the jet-to-wire ratio and headbox fiber concentration must be accurately controlled, both during grade change and during normal regulatory operation. The prior art schemes have done poorly in this regard.

Thus it is an object of this invention to provide a faster method of implementing grade changes.

Another object of the invention is to provide a method of grade change control that reduces the risk of sheet breaks.

Still another object of the invention is to provide a method of grade change control that greatly reduces the required investment in instrumentation.

Another object of the invention is to provide a method of grade change capable of immediately adjusting to a change in pulp.

Another object of the invention is to provide an improved method of grade change control that accurately coordinates grade change and headbox control.

Another object of the invention is to provide a headbox control method that accounts for the impact of recitifier rollers.

Another object of the invention is to provide a manual speed feed forward without upsetting moisture or conditioned weight.

Finally, it is an object of this invention to control grade changes by moving the condition weight of the paper from one value to another while maintaining moisture content constant by adjusting stock flow, speed, jet-to-wire ratio, and headbox fiber concentration.

SUMMARY OF THE INVENTION

The present invention broadly achieves the foregoing objectives of paper machine control by first determining the actual scan average value of moisture, comparing this value with a moisture target value, and utilizing the error signal therefrom to manipulate master speed so that moisture content is maintained within specifications. Similarly the actual scan average value of conditioned weight is compared with a conditioned weight target, and the error signal therefrom is utilized to manipulate stock flow such that conditioned weight remains within specifications. Crosscoupling is provided between conditioned weight error signals and master speed so that changes in the error signal will not upset moisture. Likewise crosscoupling is provided between moisture error signals and stock flow so that changes in the moisture error signals will not upset conditioned weight. The moisture error signal modified by the crosscoupling signal is coupled to the headbox control loop wherein the total headbox head is controlled by manipulating stream flow where the objective is to maintain a constant jet-to-wire ratio. Finally the headbox head control loop is coupled to the headbox slice

such that changes in the head do not affect the pulp fiber concentration of the paper sheet.

According to another aspect of the invention, an automatic grade change is achieved by ramping the targets of the control system parameters from their pre-grade change value to their respective new grade change values such that master speed target is moved no faster than some predetermined rate. In the non-dryer limited mode, steam to the dryer section is also ramped along a predetermined trajectory.

BRIEF DESCRIPTION OF THE DRAWING

A preferred embodiment of the invention will now be explained in detail in conjunction with the drawing wherein:

FIG. 1 is a schematic showing the interaction between a conventional paper machine and applicant's invention.

FIG. 2 is a partial perspective view of a paper machine sheet scanner that may be used for detecting average values of conditioned weight and moisture.

FIG. 3A is the first part of a systems diagram of a control scheme for a paper machine according to the present invention.

FIG. 3B is the second part of 3A. Taken together FIGS. 3A and 3B are one complete figure.

FIG. 4 is a schematic showing automatic grade change control.

According to one aspect of the invention, control is concentrated on two parameters - conditioned weight and moisture content. The control objective is to maintain moisture at a constant value and either keep conditioned weight constant or cause it to move on a particular trajectory depending on whether operation is in a regulatory or grade change mode. Steam in the dryer section is maintained constant at its maximum value. Thus, the process is called dryer limited. Control is achieved under these conditions by manipulating speed and stock flow. But the movement of speed and stock must be synchronized so that both the moisture and conditioned weight requirements are met simultaneously. This is accomplished by decoupling speed changes from conditioned weight changes. That is, adjustments in speed to compensate for a moisture error are not allowed to upset conditioned weight. Likewise adjustments in stock flow are not allowed to upset moisture. By upset is meant that in theory changes in one parameter will have no impact whatsoever on the other. In practice there probably is some disturbance but it is lost in the noise of the measuring gauges. Furthermore, this is achieved in spite of strong process coupling between these variables.

As an aid in understanding the invention, the paper making process and a control system therefor are briefly described with the aid of FIG. 1. A more elaborate description is provided in U.S. Pat. No. 3,757,122 issued Sept. 4, 1973 and entitled "Basis Weight Gauging Apparatus, System and Method Using a Digital Count". Referring now to FIG. 1, raw stock is supplied to paper machine 2 via stock valve 3 and line 3A. White water from collection reservoir 4 is drained via line 4a, mixed with raw stock and supplied through stream valve 5 and fan pump 6 to head box 7. The pulp and white water mixture jets from head box 7 through slice 8 on top of and parallel with wire 9. Water passes through wire 9 and is collected by reservoir 4. However, the majority of fiber is left behind to form a wet

web 10. After leaving wire 9, web 10 is passed through press 11 consisting of a plurality of rollers 12 which removes much of the water from web 10 and essentially converts it to a sheet of wet paper. Thereafter the paper sheet passes into a dryer section 14 consisting of a plurality of rollers 15 through which steam is supplied via steam control valve 16. The steam heats the rollers and consequently evaporates much of the water in the paper sheet so that the paper emerging from dryer section 14 has the desired moisture content. The paper passes dryer section 14 to a calender stack 17. Thereafter the sheet passes through scanner 18 and is wound on reel 19.

Scanner 18 is shown in more detail in FIG. 2. Referring now to FIG. 2, scanner 18 consists generally of a frame 150 having a pair of spaced upper and lower parallel beams 152 and 154 that extend laterally across the sheet of paper 10 being produced by paper machine 11. Upper and lower heads 156 and 158 contain sensors and are moveably mounted to frame 150 and are adapted to scan the entire width of the paper sheet which passes through a gap 160 between the two heads. Within the heads are conditioned weight and moisture sensors which may be of conventional design well known in the art or as described in application, Ser. No. 861,588, filed Sept. 29, 1969 and now U.S. Pat. No. 3,641,349 issued Feb. 8, 1972, entitled Apparatus for Measuring the Amount of Substance that is Associated with a Base Material and Method Therefore. This application is assigned to the assignee of the present invention. As the heads traverse the paper sheet, both conditioned weight and moisture are continuously measured and supplied to the rest of the system.

In particular, signals indicative of conditioned weight and moisture are supplied via data channel 24 to production log station 25 that includes a digital processor 27 having an I/O device 29 and a digital output terminal 29a attached thereto. I/O device 29 provides communication interface between processor 27 and operators while digital output terminals 29a provides real time information in digital format on the measurements being made.

Output signals from processor 27 are supplied via data channel 31 to consoles 37 and 39 that may contain various displays and input command devices as shown and described in more detail in the above referenced application.

Referring now to FIG. 3, the conditioned weight signal from conditioned weight sensor 20 in scanner heads 156 and 158 is supplied through data interrupt 21 to scan average processor 22. Since the control method is usually implemented with a digital computer, data interrupt would commonly be a program controllable connection to sensor 20, and the various signals would be in digital form. Scan average processor 22 determines the average value of conditioned weight across an entire scan of scanner 18. When data interrupt 21 is figuratively closed, the scan average signal is compared at summing unit 23 with a target conditioned weight signal supplied via data path 24 (FIG. 1). The resulting error signal is supplied to conditioned weight control function 26 which generates the primary command signal for adjusting stock flow controller 30 such that conditioned weight is kept on target. Conditioned weight control function 26 is a well known relationship that takes the following form:

$$\frac{\Delta SF}{\Delta CWE} = K_1 \frac{1 + a_1 Z^{-1} + a_2 Z^{-2}}{1 + b_1 Z^{-1} + b_2 Z^{-2} + \dots + b_n Z^{-n}}$$

Where:

ΔSF = change in stock flow

ΔCWE = change in conditioned weight error signal

n = Integer(δ_h/δ_s)

δ_h = transport delay between stock valve and reel

δ_s = time between control actions

K_1 = gain constant

Z = Z transform

a_1, a_2 = constants

b_1, b_2 = constants

The moisture signal generated by the moisture sensor in heads 156 and 158 and converted to digital form is shown figuratively as originating at point 32. This signal is supplied via data interrupt 33 to scan average processor 34. The scan average signal is supplied to summing unit 36 where it is compared with a moisture target signal 35. The resulting error signal is supplied to moisture control function 38 which generates the primary command signal for adjusting the paper machine master speed such that moisture is kept on target. By master speed is meant the speed at which sheet 10 passes through the paper machine. This control function is well known and takes the following form:

$$\frac{\Delta MS}{\Delta MOI E} = K_2 \frac{1 + c_1 Z^{-1} + c_2 Z^{-2}}{1 + d_1 Z^{-1} + d_2 Z^{-2} + \dots + d_n Z^{-n}}$$

Where:

ΔMS = change in paper machine master speed

$\Delta MOI E$ = change in moisture error signal

K_2 = gain constant

c_1, c_2 = constants

d_1, d_2 = constants

The command signal from moisture control function 38 is supplied to summing unit 40 where it is combined with a conditioned weight decoupling signal.

This signal is generated by conditioned weight decoupling function 42 from the conditioned weight error signal supplied via data path 44. Functionally, the decoupling signal compensates for any impact that a change in conditioned weight may have on moisture, and thereby makes it possible to take control action on conditioned weight without having to worry about upsetting moisture control. Mathematically decoupling function 42 takes the following form:

$$\frac{\Delta MS}{\Delta CWE} = K_3 \frac{1 + e_1 Z^{-1} + e_2 Z^{-2}}{1 + f_1 Z^{-1} + f_2 Z^{-2} + \dots + f_n Z^{-n}}$$

Where:

K_3 = gain constant

e_1, e_2 = constants

f_1, f_2 = constants

The output of summing unit 40 is supplied to a conventional clamp function 46 which restricts the permissible change in master speed to predetermined magnitudes. The output of clamp 46 is supplied to ramp function 48 which specifies the maximum single step at which the speed control equipment should be driven and the time separation between those steps. Together, clamp 46 and ramper 48 protect the sensitive and ex-

pensive speed drive mechanism from excessive control action.

The output of ramper 48 is supplied via transport delay 50 to master speed controller 52. Delay 50 is necessary to synchronize the impact of a change in speed with a change in stock flow as seen at the scanner. Since the propagation time through the process is less for a control action on speed than for a control action on stock, an artificial delay must be added in the speed control path to make sure that the impact of speed and stock flow changes reach the scanner at the same time. Master speed controller 52 translates the command signal from delay 50 into the appropriate hardware action so that the paper machine master speed is changed accordingly.

To achieve decoupling between a control action on speed and conditioned weight, the output of ramper 48 is supplied not only to master speed controller 52 but also to master speed to stock flow feed forward control function 54 via data path 56. This function supplies an output command signal to summing unit 28 that adjusts stock flow so that conditioned weight will not be affected by an adjustment of master speed. Mathematically, decoupling function 54 takes the following form:

$$\frac{\Delta SF}{\Delta MS} = K_1$$

Where:

K_1 = gain constant

This system, called a decoupled dryer limited controller, provides total noninteractive control. That is, moisture target adjustments can be made without upsetting conditioned weight, and conditioned weight target adjustments can be made without upsetting moisture.

Stock flow controller 30 and master speed controller 52 may be direct digital control units or analog controllers whose set points are controlled by the command signals supplied thereto.

In the regulatory mode, it is sometimes undesirable to change speed frequently because the speed drives tend to wear. In this case, control action on speed is restricted to 1 in N scans. However, control action on stock flow need not be and is not restricted. Because of this difference, conditioned weight decoupling function 42 must either be deactivated or restricted to operate only when control action on speed is permissible. This restriction is symbolized by switch or data interrupt 53 which is closed every N scans. Of course, the function of switch 53 may be accomplished by a programming routine.

According to another aspect of the invention, control is performed on the headbox where the jet-to-wire ratio and the pulp fiber concentration are the dependent control variables. The jet-to-wire ratio is the ratio of the water velocity coming out of the headbox slice to the velocity of the fourdrinier wire. In controlling this variable, the jet velocity coming from the headbox slice is controlled by manipulating the head in the headbox. By head is meant the total pressure on the fluid at the slice location. This pressure is determined from the height of the pulp-water column and the air pressure over the liquid surface.

In controlling the jet-to-wire ratio, it is convenient to use cascaded control. That is, fluctuations in total head

pressure are regulated by an analog controller acting on stream flow and the controller set point is determined by the basic control scheme.

The basic control scheme for jet-to-wire ratio utilizes four independent variables. The first is a change in the master speed command signal supplied to master speed controller 52 from delay 50. Clearly, any change in this command signal will cause a change in the wire speed, and without a compensating change in jet velocity the jet-to-wire ratio would be altered. To handle this problem the output of transport delay 50 is supplied through manual disconnect 57 and data interrupt 58 to jet-to-wire ratio controller 60. Manual disconnect 57 enables the operator to disconnect links in the controlling program, such as the link between master speed and the headbox, at his discretion. Data interrupt 58 again illustrates the requirement that speed changes be initiated only every N scans.

The second input variable to be accounted for is the jet-to-wire ratio target which is supplied to controller 60 from manual entry station 64. Manual entry station 64 is a general purpose data entry and data display panel where various control variables may be entered, modified or displayed.

The third independent variable to be accounted for is wire speed. This variable must be considered in addition to master speed since the operator can change the draw, that is, the velocity difference between two sections of the paper machine, at his discretion. It is important that the operator be able to adjust the draw to minimize the chance of a paper sheet break. But if a change in draw is made between the master speed section and the wire, it will cause a change in wire speed, and any change in wire speed impacts the jet-to-wire ratio. Consequently, the wire speed is measured by wire speed sensor 65 whose output signal is supplied directly to jet-to-wire ratio controller 60.

The jet-to-wire ratio controller 60 transfer function is derived in the following manner. First the jet-to-wire ratio is defined as:

$$J = \frac{V_j}{V_w} \quad (5)$$

Where:

J = jet-to-wire ratio

V_j = jet velocity of the stock from the slice

V_w = wire velocity

From classical fluid mechanics theory it can be shown that:

$$V_j = 2gH \quad (6)$$

Where

g = acceleration due to gravity

H = total headbox head

To accommodate master speed changes, a new variable V_c is defined as:

$$V_c = V_w + V_m \quad (7)$$

Where:

V_m = change in master speed

By substituting equations (6) and (7) into (5), and solving for H , one gets:

$$H = \frac{(JV_c)^2}{2g} \quad (8)$$

From equation (8) the target for the total head controller is defined as:

$$T_H = H = \frac{(JV_c)^2}{2g} \quad (9)$$

and

$$\Delta T_H = \frac{(TV_c)^2}{2g} - H_F$$

Where:

H_F = previously determined target for total head control

The output of jet-to-wire ratio controller 60 is defined by equation (9).

The fourth independent variable that must be accounted for is the rectifier roller velocity. Rectifier rollers in the headbox modify the flow pattern in the headbox and generate a pressure differential at the slice opening that can be positive or negative. The rectifier roller velocity is detected by detector 66 and is supplied to rectifier compensator function 68 which generates an output signal of the following form:

$$H_e = H_e^{nom} + c_1 (V_e - V_e^{nom}) \quad (10)$$

Where:

H_e = head loss due to rectifier roller speed

H_e^{nom} = nominal head loss due to rectifier roller speed

c_1 = constant

V_e = measured rectifier roller speed

V_e^{nom} = nominal rectifier roller speed

This signal is summed with the output of jet-to-wire ratio controller 60 at summing unit 70 so that the actual target signal for the headbox controller is:

$$T_H' = \frac{1}{2g} (JV_c)^2 + H_e$$

If the rectifier rollers are creating a positive pressure differential at the slice opening, then the output signal from rectifier roller compensator 68 will subtract from the output of controller 60, and vice versa.

The output signal from summing unit 70 is supplied to sample and hold device 74. This device, in effect, holds the output of summing unit 70 and supplies it to analog controller 76 which operates on stream flow valve 80 to maintain the total head on target. In so doing, the actual head as detected by head sensor 78 is compared with the total head target, T_H . Any difference therebetween causes control action on stream flow valve 80 to reduce the difference. A separate control loop exists for controlling the air pressure over the liquid in the headbox. Thus clearly it would also be possible to tie into this loop to aid in controlling the jet velocity. However, controlling the stream flow valve is believed to be a superior scheme.

As can be seen from equation (11), the set point for controller 76 will be changed by either a change in J or in V_c . Any wire speed change resulting from a master speed change, ΔV_m , will have been accompanied by a feedforward to stock flow via master speed to stock feedforward function 54. Consequently, if the slice area A_j remains constant, then the headbox consistency C_h will remain constant. Thus any wire speed change due to a change in master speed need not be accompa-

nied by control action on the slice to keep C_h constant.

If, however, a change in wire speed occurs that is not due to a change in master speed, the head set point, T_H , will also change to maintain a constant jet-to-wire ratio. But this will cause a change in the flow rate, F_j , from the slice. Since the changed flow rate is not accompanied by a corresponding change in fiber supplied to the headbox, it is necessary to change the slice opening so that the flow rate is returned to its previous value. Headbox consistency C_h is thereby maintained at a constant value. Quantitatively the relationships are derived as follows:

The flow at the slice F_j is defined as:

$$F_j = A_j V_j \quad (12)$$

Where:

A_j = slice area

V_j = slice exit velocity

The dry weight at the reel is given by:

$$DW_r = \frac{Ch F_j r \gamma Re}{100 W V_w \alpha} \quad (13)$$

Where:

Ch = head consistency in %

r = the fraction of fiber retained on the wire

δ = the density of the fiber

W = the width at the slice

Re = the number of square feet per ream

α = the shrinkage factor, i.e., width at reel/width at slice

From equations (5), (12), (13) it follows that:

$$Ch = \frac{DW_r W_{load}}{A_j Jr Re \gamma} \quad (14)$$

differentiating equation (14)

$$\Delta A_j = \frac{-A_j \Delta Ch}{(Ch \& \Delta Ch)} \quad (15)$$

where Ch is computed from equation 13 and ΔCh is the desired change in consistency entered from manual entry station 64. The relationship of equation (15) is implemented by slice control unit 98.

To decouple headbox consistency from changes in jet-to-wire ratio target or wire speed changes, feedforward is utilized. The output of jet-to-wire ratio control unit 60 is supplied via data path 84 through delay 86 to headbox head to slice feedforward functional unit 88. Analytically the feedforward relationship is derived as follows:

Since conditioned weight is constant, F_j is required to remain constant. Thus by differentiating equation (12) it follows that:

$$A_j \Delta V_j + V_j \Delta A_j = 0 \quad (16)$$

From equation (6) it follows that:

$$\Delta V_j = \frac{g}{V_j} \Delta H \quad (17)$$

Combining equation (5), (16) and (17) one gets the correct relationship for unit 88:

$$\Delta A, \frac{-A_g}{(JV_w)^2} \Delta H$$

For changes in master speed, the headbox head to slice feedforward is disabled since any change in master speed is synchronized with a stock flow change via master speed to stock flow feedforward unit 54. Thus, fiber concentration is maintained at a constant value without adjusting the slice opening.

A manual speed feedforward feature is supplied from manual entry station 64 via data path 59 to summing junction 40. The purpose of this function is to make a speed change without upsetting conditioned weight or moisture. This capability is particularly useful since speed changes are made quite frequently by the operator. By coupling the speed change through summing unit 40, the impact on conditioned weight thereby is minimized due to the crosscoupling via master speed to stock flow and via the jet-to-wire ratio and fiber concentration crosscoupling.

Another aspect of the invention is the automatic control of grade change. The objective of automatic grade change control is to drive the paper machine from one conditioned weight to another while either holding moisture constant or moving it only slightly. On occasion a grade change may require that both conditioned weight and moisture be moved significantly. As mentioned in the background of the invention, the old approach to grade change was to directly move the process control variables from one set point to another very slowly along some predetermined trajectory. The present invention in contrast moves the targets of the control system. This distinction, of moving the control system targets rather than the actual process control variables, is significant in that the former approach allows the sophisticated control system to remain in operation and effect a speedy and smooth grade change. In initiating a grade change, it would be desirable to change the control targets instantaneously from their initial value to their final value. However as mentioned previously, such action would destroy the sensitive drive mechanisms on most machines. To avoid this problem, the present invention moves the master speed target on a ramp whose slope may be any value up to a predetermined maximum above which the speed drive would be damaged. As an aid in conceptualizing automatic grade change, it is useful to refer to FIG. 4. There it can be seen that grade change involves three basic levels. The first is level 170 which consists of the paper machine and its associated control parameters such as the stock valve, the stream flow valve, slice opening, master speed control, and steam among others. The second level is the control system 172 as was described in detail in connection with FIG. 3. The third level is ramp selection and movement 174.

As can be seen, the first step is to select a new grade change. This may be done by entering a code number on manual entry station 64 in FIG. 3. By so doing, a new set of grade data which includes conditioned weight, headbox consistency, steam pressure and moisture targets are automatically fetched from a table.

The new targets for moisture and conditioned weight in turn define the nominal target values for jet-to-wire ratio, master speed, slice opening, and stock flow. The targets for these control parameters are then moved from their original value to their new value.

As described earlier, the movement of master speed must be restricted below some maximum rate. But below this level it may be moved as desired. If grade change is to be made as quickly as possible, the movement of conditioned weight target is made as a step function and control of the master speed done via ramper 48 and clamp 46 in FIG. 3. All other targets are also moved as a step. If, however, a slower grade change is desired, then the conditioned weight target may be moved on a ramp having the desired slope. Typically several ramping routines are available in storage, and the operator may select one. When a slower than maximum grade change is selected, the other control targets such as moisture and headbox consistency are usually, but not necessarily, moved in one step.

The movement of the control targets in turn causes the process variables to be changed as described in connection with FIG. 3. For example, control on speed and stock flow from moisture and conditioned weight scan average are accomplished just as in the case of drier limited control. However, the restrictions on regulatory movement of master speed are now removed. That is, for switches 33 and 53, N is set equal to 1.

In FIG. 3, the grade change is illustrated by select grade change target 100 and select grade change ramps 102. The ramped conditioned weight signal is supplied via data path 105 and switch 107 to summing unit 23 where it is a command on the basis weight target.

During a grade change, the fiber concentration in the headbox must also be moved to a new value in accordance with the new conditioned weight. Accordingly, the slice opening target value is ramped in conjunction with the conditioned weight. This operation is illustrated as conditioned weight to slice feedforward function 106, the output of which is supplied via data path 94 to summing unit 90. The stepped or ramped moisture target is supplied via data path 103 to summing unit 40, and the stepped or ramped jet-to-wire ratio target is supplied via data path 104 to jet-to-wire ratio controller 60.

If the paper machine is operating in a dryer limited mode when the grade change is initiated, there will be no command signal to steam. If, however, the paper machine is not operating in a dryer limited mode when the grade change is initiated, i.e., steam to the dryer section is less than maximum, then the set point for steam is moved on a ramp in conjunction with the target for the conditioned weight. The steam pressure set point is moved from its pregrade change value to a nominal value for the new grade. Thus, in the non dryer limited mode, when a grade change is initiated, a final set point value for steam is fetched from a table, and an appropriate ramp function is selected to move the steam target from its pregrade change value to its post grade change value. This step is illustrated at 108. The steam set point is then ramped at 110. Sample and hold device 112 converts the output of ramper 110 to a target command signal for steam value controller 114. Because of the problems mentioned earlier in connection with moving set points in a grade change, steam pressure and speed will not end up at precisely the right point. However, they will be very close, and the feedback mechanisms of the dryer limited system will quickly adjust speed to the right value.

While the invention has been described with reference to a particular embodiment, it will be understood

that the invention is limited only by the appended claims.

I claim:

1. In a method of controlling a paper machine having a pulp stream flow feeding into a headbox and controlled by a pulp stream valve to thereby control total head, T_H , said headbox being provided with rectifier rollers and a slice that permits pulp to jet onto a moving wire to form a paper sheet and from which the water passing through is collected, mixed with stock from a stock flow line controlled by a stock flow valve and supplied to the pulp stream, said sheet then being passed at a characteristic master speed through a drier section to which steam is supplied in a dryer limited mode, the steps comprising: scanning said sheet after the dryer section and determining a value related to the moisture of said sheet, comparing said measured value with a target value for said moisture content, and utilizing the moisture error signal therefrom to manipulate at substantially every scan said master speed so that said moisture content is maintained within specifications; determining a value related to conditioned weight of said sheet, comparing said measured value with a target value for said conditioned weight, and utilizing the error signal therefrom to manipulate said stock flow valve so that conditioned weight remains

within specifications; cross-coupling conditioned weight error signals to master speed and to said moisture error signal so that changes in conditioned weight error signals will not upset moisture, crosscoupling said moisture error signal to said stock flow so that changes in moisture error signal will not upset conditioned weight; coupling said moisture error signal modified by said crosscoupled weight error signals to a control loop wherein the total headbox head, T_H , is controlled by manipulating said pulp stream valve, said coupling being such that the jet-to-wire ratio remains constant; coupling said headbox head control loop with said headbox slice such that said slice will be adjusted in response to jet velocity changes to keep the pulp fiber concentration for the sheet constant; detecting the rotational velocity of said rectifier rollers; supplying said detected velocity to a rectifier roller compensation signal generator; generating a rectifier roller compensating signal based on the detected roller velocity such that said compensating signal eliminates pressure differentials at the slice caused by the rotational velocity of said rollers when said compensating signal is supplied to said headbox head control loop; and supplying said rectifier roller compensating signal to said headbox head control loop.

* * * * *

30

35

40

45

50

55

60

65