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[54] **CONTINUOUSLY CONTROLLING THE BASIS WEIGHT OF PAPER BY A TIMED BASIS WEIGHT VALVE POSITION SIGNAL**
12 Claims, 2 Drawing Figs.

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[50] **Field of Search** 162/258, 253, 198, 252, 262, 263; 73/73; 235/151.33, 151.35

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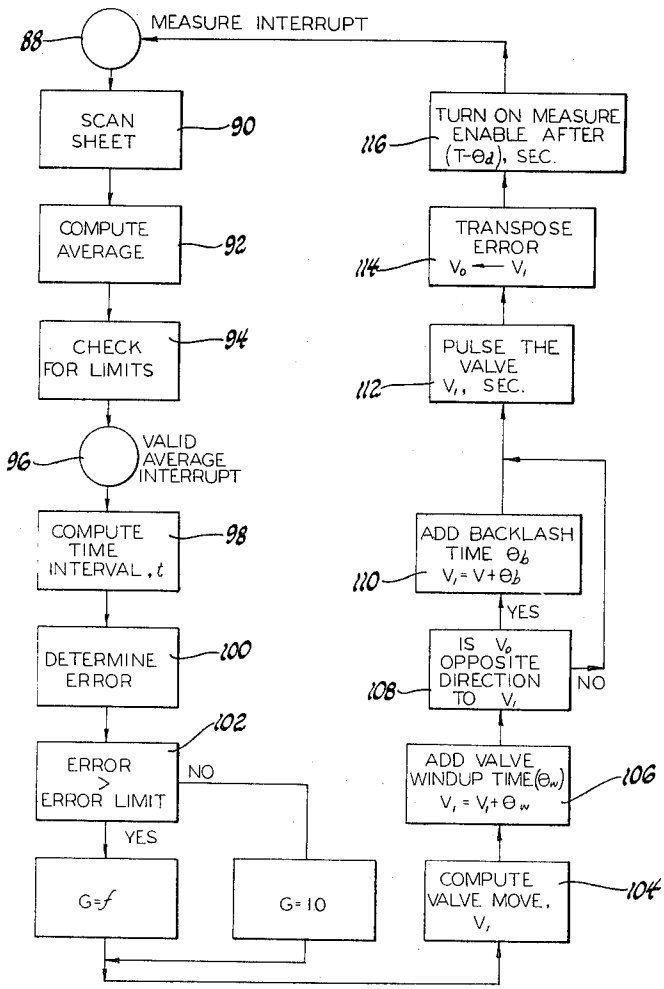
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ABSTRACT: Method and apparatus for controlling the basis weight of paper and the like whereby the basis weight of the paper from a papermaking machine is measured by scanning the paper with a gamma gauge. The gamma gauge develops corresponding analog outputs which are converted to digital equivalents. A digital computer from these digital equivalents determines the difference between the measured average basis weight and the desired basis weight, introduces various compensating factors, and then develops a timed valve position signal. This valve position signal through a valve operator adjusts the machines pulp slurry or papermaking stock control valve so that the actual basis weight will proximate the desired basis weight.



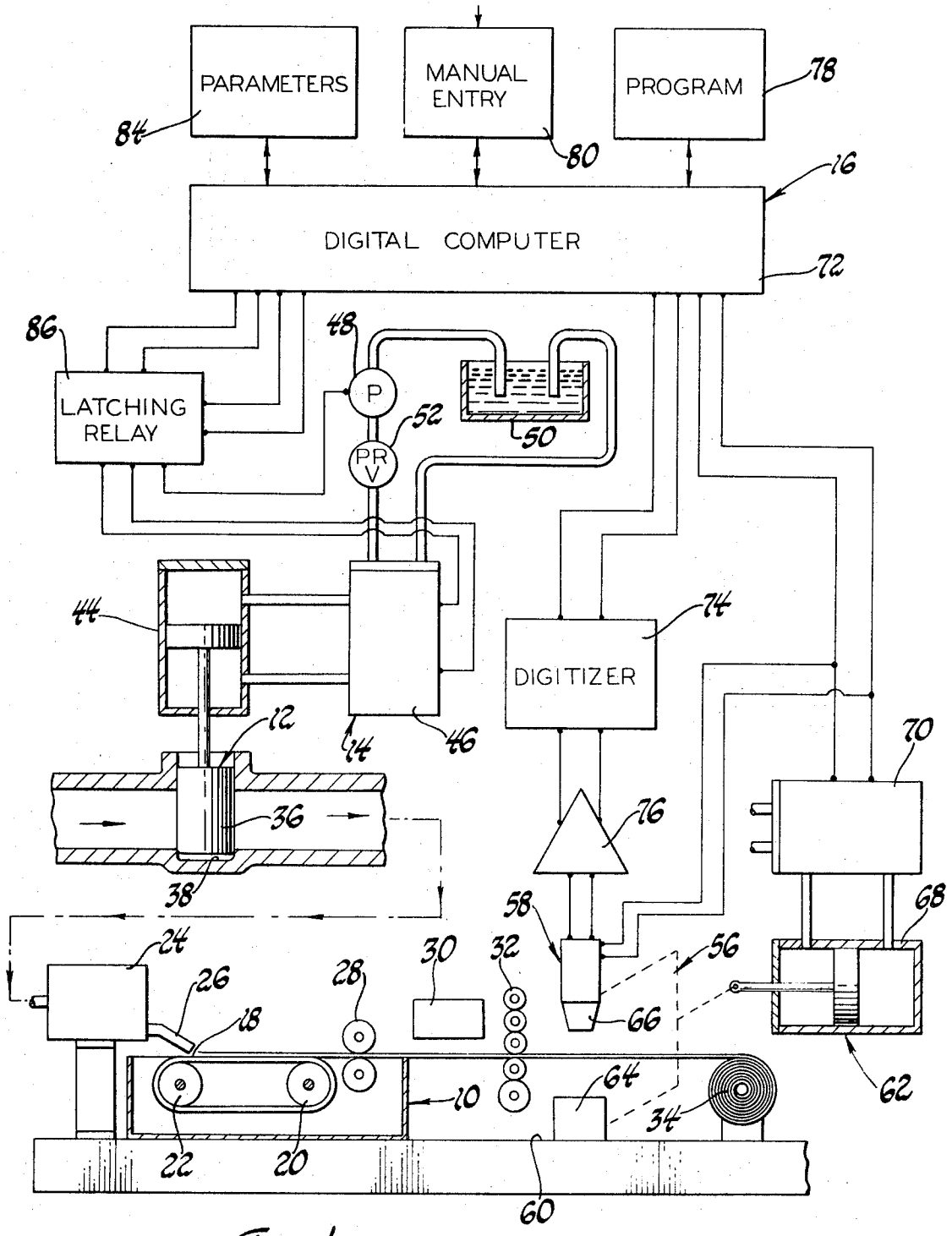


Fig. 1

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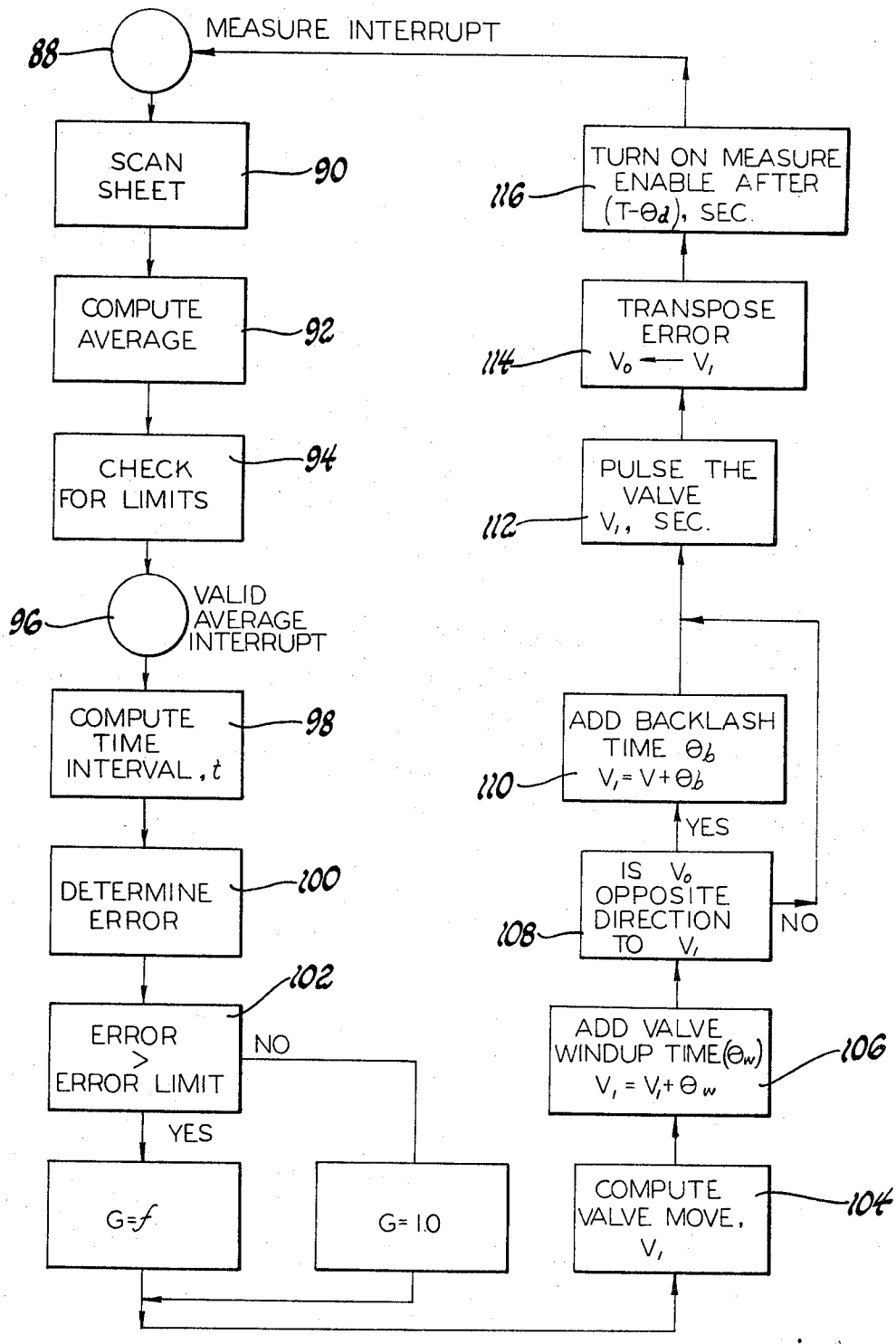


Fig. 2

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CONTINUOUSLY CONTROLLING THE BASIS WEIGHT OF PAPER BY A TIMED BASIS WEIGHT VALVE POSITION SIGNAL

This invention relates to improvements in method and apparatus for controlling the basis weight of paper and the like.

In the manufacture of paper, a pulp slurry, which is the papermaking stock, is supplied to a papermaking machine through a control valve and onto an endless-type belt, such as the well-known Fourdrinier wire screen. The wet paper formed in this way as a sheet passes through drying and pressing stages before being wound onto a reel. One of the concerns during paper manufacture is the basis weight of the paper, i.e., the weight per unit of area. For instance, if the paper grade is to be 26 pounds/1000 feet^2, the variation from this grade should be minimum. To do this the control valve must be adjusted as soon as variations are detected. Unless the adjustment is precisely done there may be an over or under correction, thus requiring further changes. Also, the lag of the system must be considered in any adjustment, i.e., the lapse in time before the correction takes effect.

With the foregoing in mind, novel method and apparatus are proposed that utilize direct digital controls for achieving more accurate paper basis weight control.

Also proposed are method and apparatus for controlling paper basis weight by a unique provision for system lag compensation during error correction.

Other objectives include the provision of method and apparatus for paper basis weight control whereby sheets are scanned to obtain both instantaneous and average measurements, and which are then converted to a digital form representing a required movement of a paper stock control valve to achieve a desired basis weight, and method and apparatus of this type that preserves the valve position of a previous scan and then subsequently uses this valve position to avoid over-correction and that develops and utilizes a simple noncomplex signal to achieve the correction.

The foregoing and other objects and advantages of the invention will become apparent from the following description and from the accompanying drawings, in which:

FIG. 1 is a schematic illustration of a paper basis weight control system incorporating the principles of the invention; and

FIG. 2 is a flow diagram of the sequential steps or cycle of events carried out by the FIG. 1 system.

Referring first to FIG. 1, the numeral 10 denotes a papermaking machine. The papermaking stock such as a pulp slurry is supplied from an appropriate source (not shown), by way of a control valve, designated generally at 12. Positioning of the control valve 12 is done by a valve operator, viewed generally at 14, as will be further explained. A control system, denoted by the numeral 16, monitors the basis weight of the paper sheets made by the machine 10 and through the valve operator 14 adjusts the settings of the control valve 12 so that the machine 10 will provide the selected or desired basis weight of paper.

The papermaking machine 10 may be of any well-Known type and therefore will not be described in detail. Briefly the machine 10 includes an appropriate endless belt 18, such as a Fourdrinier screen, which is supported and driven by a couch roll 20 and a breast roll 22. Adjacent the breast roll 22 is one or more head-boxes 24. These head-boxes 24 have an orifice 26 through which the pulp slurry jets onto the screen 18. The paper in sheet form passes through a series of press rollers 28 and then a drying stage where a series of dryers 30 employ suction and steam to aid in removing the moisture. The paper then goes through calendar stacks 32 and onto a reel shown at 34. The now dried paper in sheet form can be transported to a rewinder (not shown) for subsequent operations.

The control valve 12, for demonstration purposes, is shown including a control valve 36, which is engageable with a seat 38 formed in a valve chamber 40. This valve chamber 40 can either be an integral or a separate part of a supply pipe 42. The supply pipe 42 interconnects the head-box 24 with the pulp slurry source. The control valve 12 functions as a throttling valve to vary the pulp slurry supply in accordance with its setting or position and may be as depicted or of any other well-known type. For example, the control valve 12 may be of the kind made by Fisher-Governor Company, Marshall, Iowa and referred to as FG "Vee-Ball," type 469U.

It was mentioned that the adjustment or positioning of the control valve 12 is made by the valve operator 14. This valve operation 14 may be in various forms. That illustrated includes a fluid pressure actuated motor 44, which can be of the cylinder-piston type appropriately connected to the control valve 12, so as to maneuver it in accordance with the fluid pressure actuation of the motor 44. This fluid pressure control can be by a conventional force motor 46 and, as is well known, incorporates valving which is electrically operated to either supply or exhaust pressure fluid to or from one or the other of the ends of the motor 44. Also, the force motor 46 will provide a so called "hydraulic lock" by maintaining on each end of the motor 44 the appropriate pressures to hold it stationary and accordingly the control valve 12 in a selected setting. The pressure fluid can be supplied from a suitable pump 48 having its inlet connected to a sump 50 and its outlet to the force motor 46. A pressure-regulating valve 52 of known construction can be included, if wanted, to maintain some desired fluid pressure. The pressure fluid can be returned by the force motor 46 to the sump 50 by way of an exhaust line 54. The force motor 46, in response to electric signals, operates in the conventional way to direct pressure fluid to the motor 44 and cause the mentioned adjustments of the control valve 12. The motor 44 and the force motor 46 may be of the commercially available type made by Oil-Dyne Inc. of Minneapolis, Minnesota, and designated their Racine Miniature Hydraulics No. 5 Power Unit.

Considering now the control system 16 which provides the position signals to the force motor 46. The paper basis weight as it leaves the machine 10 is monitored by a sensor shown generally at 56. The sensor 56 is located between the calendar stacks 32 and the reel 34 but is not restricted to this location. The sensor 56 utilizes a gamma or beta ray gauge 58 to achieve the actual sensing and scans the sheet of paper during the sensing or measurement step by being maneuvered on a track 60 or the like by a scanner mechanism depicted at 62.

The gamma gauge 58 has positioned on one side of the paper a radioactive source 64, which may be a radioactive isotope, such as Krypton-85, and on the other side a radiation detector 66. The gauge 58 can be of any commercially available type, e.g., that manufactured by Industrial Nucleonics Corporation, Columbus, Ohio. The scanner mechanism 62 can employ any conventional type of motor to maneuver the gamma gauge 58 to achieve the scanning. By way of example, a fluid pressure actuated motor 68 of the same type as the cylinder-piston motor 44 can be employed and also a force motor 70 similar to the force motor 46. The same sump 50 and the pump 48 could also be used if wanted, so that when the force motor 70 is operated by the electric signals from the control system 16, the motor 68 will carry out the scanning operation.

The sensor 56, specifically, the radiation detector 66 develops analog information in the form of analog signals which represent the paper's basis weight as it is scanned. These analog signals are processed by a digital computer 72 which then develops position signals for actuating the valve operator 14 so as to make the necessary adjustments in the control valve 12.

To convert the analog signals to digital signals, a suitable digitizer 74 is employed. Also if the strength of the analog signal needs to be increased and/or impedance matching is required, an amplifier 76 can be connected to the output of the radiation detector 66.

The details of the digital computer 72 do not, per se, constitute a part of the invention; hence, a detailed explanation will not be made. Any commercially available digital computer capable of carrying out the following functions can be

employed. By way of example, an IBM 1800 Data Acquisition and Control System, incorporating an 1801 Processor-Controller to carry out the processing and controlling functions and IBM 1810 Disk Storages for memory purposes, can be used. Suitable provision is made for loading the digital computer **72** by way of a control program unit **78**, e.g., an IBM 1442 Card Read-Punch Unit, can be used to insert the program information into the computer's memory. The selected or desired basis weight can be written in by an appropriate manual entry unit denoted at **80** which can be a series of rotary decade switches or conventional card or tape write-in devices. Also, information relative to constants and other values used in determining errors in the sensed basis weight can be entered by a parameter printer shown at **84**. The printer **84** can be any of the mentioned type write-in devices or a Clary Printer made by Clary Corporation of San Gabriel, California. IBM 1443 and 1053 Printers can be used for readout purposes. The digital output from the computer **72** operates a latching relay **86**, which can be a flip-flop or other suitable bistable device capable of facilitating the application of timed position signals to the valve operator **14**.

The latching relay **86** can be operated in various ways as will occur to those versed in the art. One way for exemplary purposes is to have the computer **72** set the latching relay **86** in its latched setting when the control valve **12** is to be moved and its unlatched setting when the control valve **12** is not to be moved. Therefore, when the control valve **12** is to be moved, the computer **72** will first latch the latching relay **86**. Then the computer **72** will by the latching relay **86** cause the appropriate timed position signals to be furnished with the polarity determining whether the control valve **12** is to be opened or closed. Just before the timed position signal is furnished, a signal can also be applied to the pump **48**, so that it will commence operation.

Alternatively, the latching relay **86** can be operated so that in one of its two stable settings a valve open position signal is provided and in its other setting a valve closed position signal. The computer **72** will set the relay **86** accordingly and also the force motor **46** will in turn be connected to the relay **86** so as to properly respond to the signals. Subsequently, the computer **72** will turn off the position signal to provide the proper pulse timing. The time interval of the position signals is determined by the computer **72** as will become apparent.

The operation of the control system **16** can best be described by referring to the FIG. **2** flow chart which portrays the sequence of steps. Assuming that the digital computer **72** has been provided with the selected basis weight by way of the manual entry unit **80**, the computer **72** will check to insure that the selected basis weight is within the capability of the computer **72** program. A measure interrupt at **88** is initiated into the computer **72**, which will start the sensor **56**. The sensing mechanism **62** will commence to move the gamma gauge **58** across the paper to initiate the scan step **90**. The radiation detector **66** will develop a series of analog outputs that are converted to digital signals by the digitizer **74** during the scan. During this scan, the digital computer **72** will execute the compute average step **92** by integrating the basic weight digital signals and determining an average basis weight according to the equation:

$$\overline{W}=\frac{1}{m}\int_0^m W\,dm$$

where $\overline{w}$ represents the average basis weight, m is the time during the scan, and w is the instantaneous basis weight at time m.

The digital computer **72** will at this point pursue a check for limits step **94** to determine whether or not there is a false reading. For example, if the selected basis weight is for 42 pound grade paper and the values are for a 49 pound weight paper, the computer **72** will make the correction.

Next, a valid average interrupt **96** is initiated to the computer **72** so that the computer **72** will commence to execute the control program. Also, the scan will have been completed; hence, the detector **66** is turned off and the scan mechanism **62** returns it to the start position in preparation for the next scan.

The computer **72** will first compute the sample time interval t during a step **98**, which is the elapsed time from the commencement of one scan to the commencement of the next.

The computer **72** will then execute an error-determining step **100** and compare the average basis weight with the selected basis weight to determine the error E_1, which is the difference between the average basis weight W and the selected basis weight W_s.

This error E_1 is compared during a step **102** with a preset error limit E_{li} according to the relation

$$E_{li}=a+bW_s$$

where a and b are constants. This step **102** is to determine the gain factor, i.e., the gain for a fast response control system under specific operating conditions. If the error E_1 is equal to or greater than the error limit E_{li}, the factor G will be equivalent to the constant f. If the error E_1 is less than the error limit E_{li}, the constant G will be equal to **1**. The computer **72** will make the proper choice.

The computer **72** will now execute a step **104** and compute the valve movement V_1 in seconds required to correct for the error in accordance with the equation:

$$V_1=\frac{1}{GKp}\left[\frac{1-e^{-c(t-T)}}{1-e^{-A(t-T)}}\right]\left(E_1-C_1K_pV_oe^{-A(t-T)}-C_2K_pV_o\frac{(t'+T-t)}{(t')}(1-e^{-c(t-T)})\right)$$

where

V_1 = present valve move, sec.

G = Gain factor, a function of actual error.

K_p = Process Gain, $\frac{\Delta \text{ Basis weight (lb./1000 ft.}^2)}{\text{Second of valve move}}$

c = Turning coefficient, cycles/sec.

T = Process delay, sec.

A = Process pole (1/sec.)

t = Sample interval

E_1 = Present error, (setpoint-average basis weight), lb./1,000 ft.^{2}

C_1, C_2 = Constants to moderate anticipatory control terms.

V_0 = Previous valve move, secs.

t' = Basis weight gage scan time, sec.

e = Napierian logarithmic base.

The process parameters K_p, A and T and the constants C, C_1, C_2 are all predetermined by experiments. Because of system lag the computer **72** adds to V_1, a valve windup time constant θw at **106**. Then if valve movement V_1 is additionally determined at **108** to be opposite or backwards relative to previous valve movement V_o the computer will add a constant θ_b representing backlash time at **110**.

Now the computer **72** will carry out a pulse the valve step **112** and set the latching relay **86**. Assuming that the control valve **12** is to be opened further, a signal will be supplied to start the pump **48** and then a timed valve open position signal will be supplied to the force motor **46** and cause the motor **44** to open the valve **12** a corresponding extent which, of course, will be determined by the duration of the signal. In effect, the force motor **46** is pulsed for V_1 seconds so as to cause the control valves opening to be increased the necessary extent. Upon termination of the signal from the computer **72**, the hydraulic lock will cause the motor **44** to maintain its setting. Just the opposite occurs if it is necessary to reduce the opening of the control valve **12**.

The computer **72** utilizes this new information about the valve position V_1 for the next cycle and this is done as a transpose error step **114** so that V_1 becomes V_o for subsequent use in the V_1 equation.

Finally to insure that the adjustments, made by changing the position of the control valve **12**, have time to be carried out

and become effective, the computer **72** performs a time delay step **116**. This delay ($T-\theta_d$) is determined by experiments and will vary with the grade of paper being made. After this delay the computer **72** initiates a measure enable as a part of the step **116** to enable the sensor **56** to commence the scan step **90** after the measure interrupt **88** and the sequence of steps are repeated.

By way of example only, with a Fourdrinier wire screen of 240 inches width and 136 feet 3 inches long and with a pulp slurry of 0.25 –0.75 percent consistency, all grades of paper in the 26–90 pounds/1,000 ft.^{2} range have been made with the aforedescribed method and apparatus. The constants employed were

t'=90 sec.
f=0.85
θ_d=62 sec.
C_1=0.9
C_2=0.8
a=0.015
b=0.012

and the parameters for each grade used according to the following table

PARAMETERS FOR EACH GRADE

Basis Weight lb./1,000 ft.^{2}	T	K_μ	A	c
26	72	0.48	0.083	0.068
33	77	0.50	0.105	0.090
38	82	0.58	0.131	0.115
42	90	0.62	0.143	0.128
47	92	0.70	0.147	0.131
62	107	0.85	0.189	0.174
69	122	0.92	0.200	0.185
90	142	1.30	0.222	0.215

From the foregoing, it will be appreciated that the method and apparatus provides both continuous monitoring of the paper's basis weight and continuous correction by a closed loop control. The correction takes into consideration system lag so that there is adequate opportunity for the correction to be accomplished before the next scan and the new basis weight can be measured. This avoids over or under correcting Also, the new valve position is stored by the computer **72** for use during the next scan. Additionally by computing the control valve's movement in time, pressure fluid is applied to the motor **44** for this computed time interval to achieve proportional control valve movement. Therefore, a complex position signal is not required nor the complicated circuitry to provide it. Then too, pressure fluid can be used to obtain improved response.

What is claimed is:

1. The method of continuously controlling the basis weight of paper sheets or the like made by a machine of the character incorporating valve means for controlling the supply of papermaking stock to the machine comprising the steps of scanning a sheet of paper formed by the machine so as to measure the basis weight thereof and develop a corresponding analog signal, converting the analog signal to an equivalent digital signal, determining the elapsed time between scans, comparing the digital signal with a reference representing the desired basis weight to develop a difference error, comparing the difference error with a predetermined error limit to determine a system gain factor, computing a timed position signal of a certain time duration from the system gain factor, the elapsed time, the difference error and a predetermined system delay corresponding to the extent and direction of movement required of the valve means to alter the supply of stock to the machine, maneuvering the valve means in accordance with the position signal for the certain time duration so as to alter the supply of stock to the machine and thereby cause the paper to be of about the desired basis weight, and after the certain time duration immediately repeating the foregoing steps.

2. The method of continuously controlling the basis weight of paper sheets or the like made by a machine of the character incorporating valve means for controlling the supply of papermaking stock to the machine comprising the steps of scanning a sheet of paper formed by the machine with a measuring device to develop an analog signal corresponding to the basis weight, converting the analog signal to an equivalent digital signal, comparing the digital signal with a reference representing the desired basis weight to determine a difference error, comparing the difference error with a certain error limit to establish a system gain factor, computing from the difference error, the system gain factor, and a predetermined system lag factor a timed position signal of a certain time duration and corresponding to the extent of movement and direction required of the valve means to alter the supply of stock to the machine, maneuvering the valve means in accordance with the position signal for the certain time duration to thereby cause the paper to be about the desired basis weight at the measuring device and repeating the cycle of steps immediately after the certain time duration.

3. The method as described in claim **2** wherein the computing step introduces an additional time delay factor determined by the grade of paper being made for accordingly altering the certain time duration.

4. The method as described in claim **2** wherein the step of comparing the digital signal with a reference includes determining the average of a plurality of measurements of the basis weight obtained during the scanning step.

5. The method as described in claim **2** wherein the step of comparing the digital signal includes determining the average of the measurements of the basis weight for the time of the scanning and determining the difference between the average of the basis weight measurements and the desired basis weight to establish the difference error, and wherein the method comprises the further step of comparing the difference error with a predetermined error limit to determine a system gain factor for incorporating in the timed position signal.

6. The method as described in claim **2** wherein the computing step includes determining the required valve means movement and direction of movement from the previous valve means movement and direction and the predetermined system lag factor includes a certain valve means windup factor and also a certain backlash valve means factor determined by the direction of movement of the valve means relative to previous valve means movement.

7. The method as described in claim **5** wherein the computing step includes determining the required valve means movement and the direction of movement from the previous valve means movement and direction and the predetermined system lag factor includes a certain valve means windup factor and also a backlash valve means factor when the direction of the movement of the valve means is opposite that of the previous valve means movement.

8. The method as described in claim **2** further including the step of storing the position signal for use during the next cycle of control.

9. The method of cyclically controlling the basis weight of paper sheets or the like made by a machine of the character incorporating valve means for controlling the supply of papermaking stock to the machine comprising the steps of measuring the basis weight of a sheet of paper formed by the machine by scanning the sheet and developing a series of analog signals corresponding to the instantaneous measured basis weight, converting the analog signals to equivalent digital signals, determining the difference between the average of the digital signals and a desired basis weight to establish a difference error, comparing the difference error with a certain error limit to establish a system gain factor, computing from the difference error, the previous position signal, a predetermined system lag factor and the gain factor a new timed position

signal, of a certain time duration corresponding to the extent and direction of movement required of the valve means to alter the supply of stock to the machine, maneuvering the valve means in accordance with the position signal for the certain time duration so as to alter the supply of stock to the machine and thereby cause the paper to be about the desired basis weight, storing the new timed position for use in the next measuring cycle, and repeating the cycle immediately after the certain time duration.

10. In a control system for a papermaking machine, the combination of valve means controlling the supply of paper stock to the machine, means operating the valve means so as to vary the supply of paper stock in accordance with a position signal of a certain time duration, control means for developing position signals for application to the operating means so as to pulse the valve means for the certain time duration to vary the supply of paper stock, the control means including means sensing the actual basis weight of the paper and developing a corresponding analog signal, analog to digital converter means developing from the analog signal an equivalent digital signal, and computer means determining from the digital signal the difference between the actual basis weight and the desired basis weight comparing the difference between the actual basis weight and the desired basis weight with a predetermined error limit to establish a system gain factor, and developing for application to the valve operating means a position signal of the certain time duration and corresponding to the extent and direction of the valve means movement required to cause the actual basis weight to proximate the desired basis weight from the difference and system gain factor.

11. The control system as described in claim **10** wherein the sensing means includes a gamma gauge and scanner means moving the gamma gauge along the paper.

12. A control system as described in claim **10** wherein the computer means determines valve means windup and backlash factors determined by the direction of required movement to the valve means for determining the position signal.

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