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(54) **Apparatus and method for the on-line control of the filler content of a paper product.**

(57) Apparatus and method for controlling on-line the weight percent of filler in the paper product of a papermaking system, the method comprising :

providing a stock slurry to the system, the stock slurry comprising a mixture of water and pulp fibers ;

introducing the recyclable solution to the system, the recyclable solution comprising a mixture of water, pulp fibers, and filler ;

mixing the stock slurry and the recyclable solution, thereby forming the system slurry ;

introducing the system slurry to the headbox (19) and distributing the system slurry therefrom to the means for draining (22) ;

draining solution from the system slurry to thereby form the recyclable solution, and to thereby also form the concentrated system product for processing to form the paper product ;

computing the concentration of total solids in the system slurry at the headbox ;

measuring the concentration of total solids in the system slurry at the headbox ;

computing the weight percent of filler in the system slurry as a function of the computed concentration of total solids in the system slurry and the measurement of concentration of total solids in the system slurry ;

measuring the total solids concentration of the recyclable solution ;

computing first pass filler retention as a function of the measurement of concentration of total solids in the system slurry and the measurement of the total solids concentration of the recyclable solution,

computing the weight percent of filler in the paper product as a function of the weight percent of filler in the system slurry and the first pass filler retention ;

comparing the computed weight percent of filler in the paper product to a desired such value of weight percent of filler in the paper product and computing the amount and flow rate of additional filler to add to the system slurry ; and

adjusting and controlling the amount and flow rate of the additional filler to the system slurry, thereby controlling the weight percent of filler in the paper product of the system.

EP 0 541 457 A1

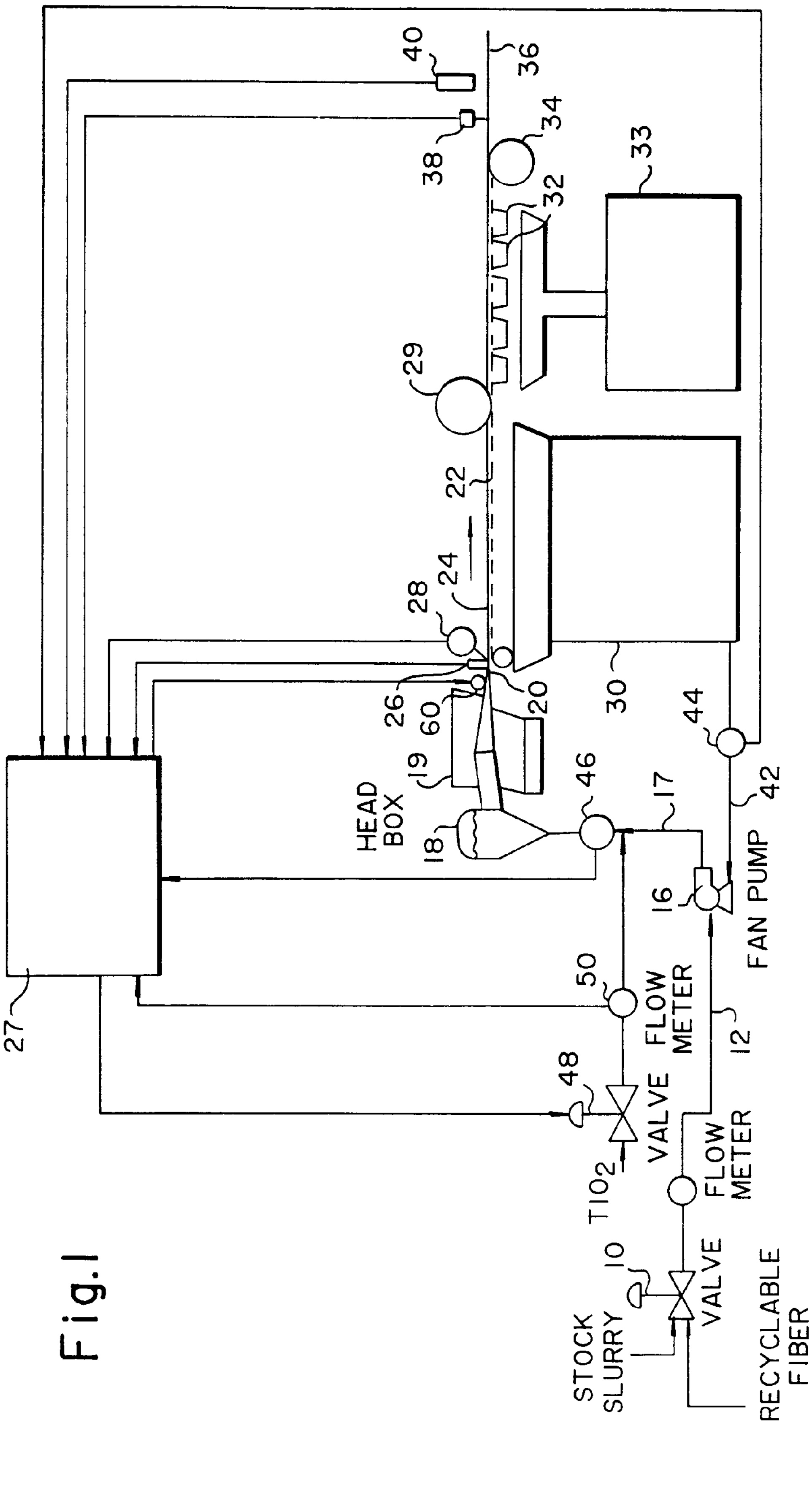
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Fig.1

Field of the Invention

The present invention is directed to an apparatus and method for controlling on-line the weight percent of filler in a paper product. In particular, the invention relates to controlling the filler content of a paper support for use in photographic applications.

Background of the Invention

In the preparation of paper products such as paper supports for use in photographic applications, fillers are added to paper stock slurrys as low cost pulp substitutes or to provide enhanced optical properties. Examples of fillers include clay, titanium dioxide, and calcium carbonate, to name a few. It is desirable to provide good control of the filler content in the paper product. Paper so produced demonstrates good consistency in optical properties, which is desirable for paper employed in such applications as reflective photographic supports.

Headbox consistency and first pass filler retention are important process variables in papermaking. Headbox consistency is defined as the concentration of total solids, including filler, in the slurry at the headbox, and directly affects paper product qualities such as formation, surface and strength that are further defined below. Headbox consistency also is a major factor influencing the drainage and drying processes. First pass filler retention is the weight proportion of filler in the paper, after drainage, to filler in the headbox, expressed in percent. First pass filler retention affects the basis weight uniformity and optical uniformity of the paper. In the past these variables were measured off-line in the laboratory, resulting in a poor response time for adjusting system settings and in a nonuniform paper product.

More recent approaches to solving the problem of nonuniform paper quality have suggested the use of on-line sensors for measuring concentration of total solids in a papermaking system slurry. Adjusting concentration of total solids in the slurry based on the measured total solids content in the slurry, however, does not provide adequate or real-time control of filler content in the paper product, since filler content is also affected by factors such as first pass filler retention as discussed herein.

One prior art approach discusses the use of an optical sensor to determine fiber and filler retention in a papermaking system. In this method, filler concentration and total solids concentration in a slurry are calculated based on measurement of light attenuation and depolarization. The method, however, may not provide the inherent level of accuracy desirable for many papermaking applications, such as the manufacture of photographic support paper. It also does not provide a means for trueing on-line a slice opening to obtain a substantially correct slurry flow, the lack of which introduces further nonuniformity into the paper product.

Assesment of the Art

An object of the invention is to provide a method and means for on-line, real-time control,of the filler content in a paper product.

Disclosure of the Invention

There is provided, in accordance with this invention, an apparatus and method for controlling on-line the weight percent of filler in the paper product of a papermaking system, the method comprising the steps of providing a stock slurry to the system, the stock slurry comprising a mixture of water and pulp fibers; introducing the recyclable solution to the system, the recyclable solution comprising a mixture of water, pulp fibers, and filler; mixing the stock slurry and the recyclable solution, thereby forming the system slurry; introducing the system slurry to the headbox and distributing the system slurry therefrom to the means for draining; draining solution from the system slurry to thereby form the recyclable solution, and to thereby also form the concentrated system product for processing to form the paper product; computing the concentration of total solids in the system slurry at the headbox; measuring the concentration of total solids in the system slurry at the headbox; computing the weight percent of filler in the system slurry as a function of the computed concentration of total solids in the system slurry and the measurement of concentration of total solids in the system slurry; measuring the total solids concentration of the recyclable solution; computing first pass filler retention as a function of the measurement of concentration of total solids in the system slurry and the measurement of the total solids concentration of the recyclable solution; computing the weight percent of filler in the paper product as a function of the weight percent of filler in the system slurry and the first pass filler retention; comparing the computed weight percent of filler in the paper product to a desired such value of weight percent of filler in the paper product and computing the amount and flow rate of additional filler to add to the system slurry; and adjusting and controlling the amount and flow rate of the additional filler to the system slurry, thereby controlling the weight percent of filler in the paper product of the system.

The invention also provides a method of on-line trueing of the slice opening measurement and slice opening for improved control of system slurry flow rate, comprising the steps of measuring the slice opening, measuring the pressure head of the system slurry, computing slice flow, computing trued slice opening value, computing δslice opening, and adjusting on-line the slice opening in accordance with the δ slice opening value to thereby obtain substantially accurate system slurry flow.

Advantageous Effects of the Invention

The apparatus and method of the invention provide the advantage of on-line control of the filler content of a paper product that is responsive not just to the total solids content in the system slurry but also to other process variables such as first pass filler retention. System parameters including concentration of total system slurry solids, first pass filler retention, concentration of filler in the headbox, and percent filler retained can be measured in the practice of the invention. The invention also allows the on-line trueing of slice opening and calculates a constant that indicates when changes in the draining process occur. The invention produces a paper product that has uniform paper properties desirable for applications requiring high quality paper, such as photographic support paper.

Brief Description of the Figures

Figure 1 is a partial schematic representation of a papermaking system comprising an on-line filler control system of the invention.

Figure 2 is a schematic elevation view of a headbox useful in the invention, partially in section, showing details of slice 20.

Figure 3 is a functional flow diagram of a processing technique of the invention.

Figure 4 is a functional flow diagram of a method of the invention for trueing slice opening measurement and slice opening on-line.

Figure 5 is a chart, showing the deviation of Computed Total Solids compared to measured Total Solids in a system employing the invention, useful for trueing the measured value of slice opening.

Figure 6 is a chart, showing the deviation of computed First Pass Filler Retention ("FPFR") compared to measured FPFR, useful for trueing the constant G in the FPFR system equation.

Detailed Description of the Invention

As used herein, the following terms will have the meanings set forth:

Basis weight is the weight of a specific amount of paper product, e.g. the weight of 1000 square feet of paper.

Dry weight is the same as basis weight but with the weight of the water content of the paper subtracted out.

Calender speed is the speed at which paper is produced, in units of length of paper produced per unit time, e.g. feet per minute.

Couch is the paper product, also termed fiber mat, after it leaves the draining sections of the system but before it enters the pressing section.

Headbox consistency is the concentration of total solids in the slurry at the headbox, and directly affects paper product qualities such as formation, surface and strength.

First pass filler retention is the weight proportion of filler in the paper after drainage to filler in the headbox, expressed as a percentage.

Formation is a measure of the uniformity of light transmissivity across the surface of a paper product.

Headbox is a paper making device that transforms the flow of stock slurry from the shape of the piping carrying the stock to the headbox to a wide, thin, rectangular jet of stock slurry. The headbox delivers the stock slurry to a moving drainage screen to begin the water removal process.

The term stock slurry as used herein is a mixture of water and pulp fibers. More generally, a stock slurry can also comprise one or more fillers such as clay, Titanium Dioxide, Calcium Carbonate, along with pertinent paper making chemicals. Generally, a slurry is comprised of 90% or more of water.

Silo is a large chest where white water from the 1st step of the drainage process resides before it is recycled into the paper making process.

Size is a solution, such as a starch solution, that is applied to the surface of the paper after the paper has been dried to about 1% to 5 % moisture for imparting strength or other desirable propertios to the paper.

Surface is a measure of the surface streaking and texture of the surface of a paper product when illuminated by reflected low incident angle light.

White water is an aqueous solution containing solids that comprises the drainage from the system slurry obtained from the drainage process.

FIG. 1 illustrates a representative paper making system, including an associated control hardware configuration, of the invention. Stock slurry is supplied to the system via stock valve 10 and line 12 to fan pump 16. Recyclable fiber may also be provided as shown to mix with the stock slurry for introduction to the system. Sources of such recyclable fiber can include solution from a Broughton tank, other waste products and solutions from the system, and other recyclable sources capable of providing useable such product as are well known in the industry. A recyclable slurry from silo 30 is also supplied to the system through pump 16. The stock slurry and recyclable slurry mix in pump 16 and line 17 to form a system slurry which is supplied through pulse elimination tank 18 to headbox 19. Referring also to FIG.2, system slurry jets from headbox 19 under slice 20 to exit headbox 19 through slice opening 21 above and substantially parallel to wire 22 to form wet web 24. Slice 20 is associated with sensor 26 that measures slice opening 21. In one embodiment, sensor 26 can comprise a linear voltage displacement transmitter. Other types of sensors well known in the art can also be employed, such as a physical displacement sensor. Sensor 26 also provides an output signal representative of slice opening to process controller 27. Positioned in the slice just upstream of the slice opening is differential pressure gauge 28 for measuring the pressure head of the system slurry. Gauge 28 provides an output signal representative of system slurry head pressure to process controller 27.

Solution from web 24 drains through wire 22 into silo 30 as web 24 is conveyed by wire 22 and moves transversely over silo 30 as shown by the direction arrow. Dandy 29 contacts web 24 to place on the surface of web 24 a physical impression such as a watermark. Web 24 then moves transversely over vacuum boxes 32 into which further solution drains from web 24 and then into Broughton tank 33. Web 24 then leaves wire 22 at couch 34 where it is subsequently pressed, sized, and dried to the finished paper product 36.

On-line tachometer 38 measures the speed of the paper as it is being wound into finished rolls ("calendar speed") and provides a representative output signal to process controller 27. Infrared absorption gauge 40 measures the ratio of the dry weight of the paper to the area of the surface of the paper for a representative section of paper, and provides a representative output signal to process controller 27.

Solution collected by silo 30 is recycled into the system via line 42 as described above for recyclable solution. On-line optical sensor 44 is means for measuring the concentration of total solids of the recyclable solution from silo 30 and provides a representative output signal to process controller 27. On-line optical sensor 46 is means for measuring the concentration of total solids of the system slurry at headbox 18 and provides a representative output signal to process controller 40. Flow control valve 48 controls the flow of aqueous solution containing filler (labeled "titanium dioxide") into the system. A typically range of concentration in solution of a filler such as titanium dioxide can be selected from about 10% to 70 %, depending on factors such as piping size, pump size, filler storage facilities capacity and the like. Flow meter 52 measures the flow rate of titanium dioxide solution into the system and provides a representative output signal to process controller 27.

FIG. 2 illustrates headbox 19 showing details of slice 20. Slice 20 comprises a metal rod 51 mounted on plate 52. Plate 52 is slidably and pivotally mounted in the convential manner in headbox 19 under top front wall 54 such that rod 51 remains substantially flush with the plane of slice opening 21 along its range of movement. Slice 20 extends from sidewall 56 to sidewall 58 of headbox 19. The width of plate 52 is just less than the width between sidewalls 56 and 58 to seave plate 52 free to move within headbox 19 while forming a seal therebetween to substantially prevent leakage of slurry past plate 52. Means for moving slice 20 comprises motor 60 attached by linkage 62 to plate 52. Motor 60 in response to a control signal from process controller 27 moves slice 20 to a desired position, thereby adjusting slice opening 21. Motor 60 can comprise a stepper motor such as is well known in the art. System slurry jets as described above under slice 20 through slice opening 21 as shown by the direction arrow.

The system operating equations and derivations, as well as assumptions made in their derivations, are as follows.

The terms necessary for the derivation of Equation I are defined:

DW = dry weight of the paper, e.g. (lb/1000 sq.ft.)

CS = calendar speed, e.g. (ft/min)

SF = Volumetric flow rate for system slurry through the slice, e.g. (gal/min)

CTS = Concentration on a wet basis ,that is, Concentration of total solids in the system slurry (lbs of total solids in systems slurry/total lbs in system slurry)

The Concentration Of Total Solids In The System Slurry ("CTS") at the headbox is calculated from the equation:

$$CTS = A[(DW)(CS)/(SF)] + B \quad (I)$$

The parameters employed in Equation I are further defined as follows:

Dry weight and calendar speed are system operating parameters that are measured continuously on-line. Dry weight is the weight of the paper product expressed as a function of area (of one side) of the paper surface, e.g. in units of dry lbs. per 1000 sq. ft. of paper (KSF). Such area of paper produced by the system is determined by the width of the paper and also the speed of manufacture. Typical values of Dry Weight in the practice of the invention can range from 10 to 50 lb/KSF. Calender speed is the speed at which paper is produced, in units of length of paper produced per unit time, e.g. feet per minute.

Slice flow (SF) of Equation I is the volumetric flow rate of the system slurry at the slice opening of the headbox, e.g. in gallons per minute. Slice Flow is calculated according to the equation

$$SF = (JS)(SW)(SO)K_1 \quad (II)$$

where:

JS = Jet speed, e.g. (ft/min)
SO = Slice opening, e.g. (mils)
SW = Slice width, e.g. (inches)
K_1 = unit conversion constant, e.g. (gal/(ft. in mils))

Slice width is the width of the headbox. Slice opening is the adjustable height of the rectangular opening on the headbox through which the jet passes and is measured by sensor 26. FIG. 6 illustrates a representative slice opening of a typical headbox. The slice opening is adjustable to provide the desired slurry flow. K_1 is a dimensionless constant the value of which depends on the units selected. When JS is feet per minute, SW is in inches, and SO is in mils (thousandths of an inch), K_1=0.0000519. K_1 can be readily recalculated for other such units selected.

JS, or Jet Speed, is the speed of the jet of headbox slurry flowing through the headbox slice opening, e.g. in units of feet per minute. It has been found experimentally that a value for JS may be calculated within an accuracy af about plus or minus 0.5 % according to the equation

$$JS = [K_2 * PHSS/K_3]^{0.5} \quad (III)$$

where:

PHSS = Pressurehead of system slurry, e.g. (inches of water)

PHSS is referenced to atmospheric pressure and is measured by gauge 28. To calculate JS in feet per minute, with PHSS in inches of water, K_2 is experimentally determined to equal 19380. K_2 can be readily recalculated should other units be employed.

Inserting Equation III for Jet Speed into Equation II results in the equation

$$SF = [K_2 * PHSS/K_3]^{0.5}(SW)(SO)K_1 \quad (II')$$

showing that slice flow (SF) can be controlled by adjusting the slice opening (SO) as necessary to obtain a desired system slurry flow rate.

Turning again to Equation 1, A and B are constants determined by a linear regression solution of equations I-III performed on at least two system slurry samples drawn from the system while the system is operating, wherein the linear regression solution employs operating values of system operating parameters of the equations I-III measured contemporaneously with the drawing of the samples.

Equations I-III provide a substantially accurate value of CTS under the following conditions: the rate of sizer added at the size press is maintained substantially constant; the shrinkage of paper from the headbox to the reel is substantially constant; the concentration of pulp fiber in the stock slurry is substantially constant; and the fiber and fines retention is substantially constant. Minor variations, for example about plus or minus 1-5 %, can be acceptable, depending on the acceptable range of variation of uniformity in the paper product, which can be readily determined by the operator in a given application.

The percentage of filler in the system slurry is calculated according to the equation where:

CFS = Weight percent on a dry basis Computed weight percent filler in system slurry
CTS = Concentration on a wet basis -- Concentration of total solids in the system slurry (lbs of total solids in systems slurry/total lbs in system slurry)
MCTSS = Measured concentration total solids in system slurry Headbox opticon signal

$$C(CFS)(CTS) + D = MCTSS \quad (IV)$$

C and D are constants determined by linear regression solution of Equation IV on at least two system slurry samples. The linear regression solution of Equation IV, for example, can comprise a statistical least squares analysis such as described in Engineering in Training Review Manual, pp.1-14 to 1-15, 6th Ed., Professional Publications, San Carlos, CA, incorporated herein by reference.

First pass filler retention (FPFR) is calculated according to the equation:

$$FPFR = \{1 - G[((MCTSR - X_1)/X_2)/((MCTSS - Y_1)/Y_2)]\}100\% \quad (V)$$

where MCTSR = Measured concentration total solids in recyclable solution Silo opticon signal MCTSS is as defined above; Y_1 and Y_2 are equal to D and C, respectively; and X_1 and X_2 are derived by linear regression analysis as described above. The constant G is determined experimentally as is shown in the derivation of FPFR in Example 1 below.

The percent of filler retained is calculated using Equation VI.

EQ. VI. is $$FPP = FPFR * CFS$$

where:

FPP is the weight percent on a dry basis of filler in the paper (lbs of filler/lbs solids).

CFS = weight percent on a dry basis , that is, computed weight percent filler in system slurry.

The δ percent of filler retained is calculated with Equation VI′.

EQ. VI′ is: $$\delta\ FPP = FPP\ \text{set point} - FPP\ \text{from EQ. VI.}$$

The invention could also be used in a similar manner to provide component information for a slurry stream with two fillers. In this case a second optical sensor such as a Kajaani LC-100 would need to be used. Equations of the form:

Kajaani Output =A+B(% total solids)+C(%filler 1)+D(%filler 2)

Opticon Output =E+F(% total solids)+G(%filler 1)+H(%filler 2)

could be solved simultaneously since % total solids or headbox consistency could be calculated, as it is for the invention, leaving a determinant set of equations.

Means for carrying out the computation steps and for receiving and providing control signals as described herein comprises process controller 27. Process controller 27 is configured and/or programmed to independently receive and process each representative signal indicated above, to solve Equations I-VI′ above and Equations VII-IX in the below Examples, compute the indicated values, and provide the output control signals discussed below. Also within the scope of the invention is employing a plurality of process controllers, or substituting another device or devices, capable of performing the described functions. For example, a pneumatic controller can be used, such as the Model 40 manufactured by Foxboro Control Corp.. Examples of useful electronic controllers include the Taylor Model 30 series, manufactured by Asea-Brown Boveri ("ABB"), and a distributed control system such as Taylor Mod 300 manufactured by ABB.

Means for carrying out the computation steps and for receiving and providing control signals can also comprise an operator, who upon receiving the measurements described herein computes the indicated values and provides and/or inputs some ar all of the control signals of the invention. For example, any of the computing means provided in the apparatus of the invention, e.g. means for computing the new filler flow control valve set point, can be performed manually as well as by a computer or other process controller. Similarly, any such computing steps in the method of the invention can be performed manually as well as by a computer or other process controller.

Each sensor 44 and 46 can comprise a sensor operating under a light transmission principle for measuring the concentration of total solids of a slurry or other turbid solution, as is well known in the art. For example, such means for measuring total solids can comprise a transmission turbidity meter using a specific value or range of wavelength of light to which the solids being measured are sensitive. Such sensors are readily available, as for example those manufactured by Opticon. Another the of optical sensor useful in the invention is a transmission sensor employing polarized light, such as the LC-100 manufactured by Kajaani. Means for measuring total solids can also have non-optical operating principles such as with magnetic sensors. Any such sensor can be useful in the invention, the selection of which is made based on the filler or fillers employed so that the device selected is sensitive to measuring the concentration of the filler used.

FIG. 2 is a representative flow diagram of a processing technique of the invention. Upon startup of a processing cycle, a filler such as titanium dioxide is provided to the system and a digital signal representative of the initial filler flow control valve set point 100 is provided to and stored in process controller 27 (FIG. 1). Process controller 27 obtains on-line measurements of MCTSS, Pressure Head of the System Slurry, Slice Opening, Calendar Speed, Paper Dry Weight to Surface Area Ratio, and MCTSR, 102 "Obtain Digital Values Representative Of MCTSS, PHSS, SO, CS, DW, and MCTSR". These new values are stored in process controller 27, which stores additional new values as follows, and old values are discarded. CTS is computed according to Equations I-III and the value is stored, 104 "Compute CTS Using Equations I-III". CFS is then computed according to Equation IV and the value is stored, 106 "Compute CFS Using Equation IV". FPFR is computed according to Equation V and the value is stored, 108 "Compute FPFR Using Equation V". FPP is computed according to Equation VI and the value is stored, 110 "Compute FPP Using Equation VI". δFPP is computed according to Equation VI′ the value is stored, 112 "Compute δFPP using Equation VI′". The new filler flow control valve set point is computed by adding δFPP to the filler flow control set point, 114 "Compute New Filler Flow Control Valve Set Point", and the new set point value is stored and the old value discarded, 116. Process controller 27 then provides a control signal representative of the new set point to filler flow control valve 48 whereby valve 48 is set according to the new value.

The system can also comprise a plurality of means for the controlled independent addition of each of a plurality of additional fillers, and wherein the method further comprises:

repeating the computing and measuring steps for each such additional filler; and

adjustably and independently controlling the amount and flow rate of each additional filler to the system slurry, thereby independently controlling the weight percent of each filler in the paper product of the system.

Also, the method can include providing a plurality of means for measuring the concentration of total solids in the system slurry and for measuring the total solids concentration of the recyclable solution.

In one embodiment, the number of additional fillers is one so that the total number of fillers added to the system slurry is two.

Certain operating procedures and adjustments can be made to the system described herein to ensure its proper operation. The system settings, after the system has been operating for a time, can become out of adjustment and the above system equations provide less precise control of the filler content of the paper product. Factors such as maintenance work on and around the slice opening and headbox cleaning can affect the representative value.

This invention therefore further provides the ability to adjust slice opening 21 on-line by trueing the slice opening value. The calibration of sensor 26 can drift with time or shift after maintenance is done in the area of the slice, causing the measured slice opening value to be inaccurate. Static calibration of the slice opening with no slurry flowing through may not be repeatable or compensate for the effects that pressure and stock temperature have on the measured slice opening value. Accordingly, system slurry flow rate can be incorrect and affect critical papermaking parameters such as jet to wire ratio, stock flow rate, and impingement point of the jet on the wire, resulting in process and/or product instabilities and difficulties.

Accordingly, there is also provided a method of trueing the slice opening measurement to obtain improved control of system slurry flow rate. This is done without shutting down the system, enabling the system to stay operational in the process and in effect "true" the representative slice opening value as follows, employing lab-measured and on-line calculated values of CTS and comparison-charting such values as shown in FIG. 5. The operator can determine that the slice opening value requires trueing by charting deviations as in FIG. 5,and noting when there is a trend of deviation between the computed and measured values of total solids in the system slurry (as circled in FIG. 5) over a representative system operating interval. The slice opening value can then be trued without shutting down the system as follows.

The on-line calibrations of the apparatus for measuring PHSS (Pressure Head of System Slurry), DW (Dry Weight), and CS (Calendar Speed) are verified by standard procedures well known in the art for such apparatus such as that described herein. CTS is calculated using Equations I-III as described above and as further shown in the Examples to calculate the respective actual value or actual average value of SO (slice opening). The difference between the measured slice opening and the calculated value of slice opening is δSO, which is the offset added to the measured value of SO for trueing SO without shutting down the system for maintenance and recalibration.

FIG. 3 is a representative flow diagram of a process of the invention employing some of the same on-line measurements discussed above to calibrate and true the slice opening measurement. A digital signal representative of the initial slice opening measurement 200 is provided by sensor 26 and stored in process controller 27. Process controller 27 obtains an on-line measurement of PHSS as described above, 202 "Obtain Digital Value Representative Of PHSS". SF is computed according to Equation VII and the value is stored, 204 "Compute SF Using Equation VII". Trued slice opening is computed according to Equation VIII′, 206 " Compute Trued Slice opening Using Equation VIII". The δ slice opening value is computed from the initial slice opening measurement and the trued slice opening value, 208 "Compute δ Slice Opening Value", and the new value is stored, 210, and old value discarded. The slice opening is then adjusted on-line according to the trued value, thereby controlling the system slurry flow rate with more precision through slice opening 21.

Similarly, FPFR (First Pass Filler Retention) can be charted and deviation corrected for by trueing the constant G in Equation V. FIG. 5 is identical to the chart of FIG. 4 except that it graphically depicts a fractional deviation between measured and calculated values of FPFR over a representative system operating interval. The operator can determine that constant G requires trueing by employing such a chart and noting when there is a trend of deviation between the computed and measured values of total solids in the system slurry as circled in FIG. 5. The slice opening value can then be trued without shutting down the system as follows.

FPFR is calculated using Equations V. FPFR is then measured on a system sample and a trued value of G is calculated. The previous value of G is then replaced by the trued constant G in Equation V for subsequent calculations of FPFR.

The materials and methods used in the manufacture of paper products, and in particular photographic supports, of the invention are widely known in the industry. Examples of such, such as pulps, preparation of pulps, sizing agents, fillers, size press formulation, paper surface treatment, a papermaking system process, and preparation of a photographic print material from a photographic support may be found in U.S. Patents 2,062,679, 3,096,231, 3,592,731, 4,042,398, 4,794,071, and 4,994,147, incorporated herein be reference. Further details of the components of a photographic reflection print material, the way they are prepared, and how they are processed to obtain a viewable image are provided in Research Disclosure, November 1979, Item No. 18716, published by Kenneth Mason Publications, Ltd., The Hold Harbouraster's, 8 North Street, Emsworth, Hampshire P010 7DD, England and from Atwell U.S. Patent No. 4,269,927, issued May 26, 1981.

The following examples are intended to further illustrate this invention.

EXAMPLE 1

Equation V can be derived as follows. Terms defined above and further terms and abbreviations defined as follows are used in the derivation:

FP = Mass flow rate of filler in paper, e.g. (lb/min)
FHB = Mass flow rate of filler in headbox, e.g. (lb/min)
FSi = Mass flow rate of filler in Silo, e.g. (lb/min)
FBT = Mass flow rate of filler in Broughton Tank, e.g. (lb/min)
DP = mass flow of dry solids after 2nd drainage step, e.g. (lb/min)
Sr = Slurry density, assumed to equal the density of water for consistencies less than 6% = 8.34 (lb/gal)
SF = Volumetric flow rate for the slice, e.g. (gal/min)
SiF = Volumetric flow rate for the slio, e.g. (gal/min)
BTF = Volumetric flow rate for the Broughton Tank, e.g. (gal/min)
PF = Volumetric flow rate of paper after 2nd drainage step, e.g. (gal/min)
bta = Weight percent on a dry basis -- Broughton tank ash = dry lbs of filler/dry lbs of solids * 100% in the BTF
btc = Concentration on a wet basis -- Broughton tank consistency = dry lbs of solids/(lbs of solids + lbs of water) * 100%
CFS = Weight percent on a dry basis Computed weight percent filler in system slurry
CM = moisture content of the paper after 2nd drainage step = (lb of water)/(total lbs) * 100%
CTS = Concentration on a wet basis -- Concentration of total solids in the system slurry (lbs of total solids in systems slurry/total lbs in system slurry)
sa = Weight percent on a dry basis -- Silo ash = dry lbs of filler/dry lbs of solids * 100%
sc = Concentration on a wet basis -- Silo consistency = dry lb of solids/(lbs of solids and lbs of water) *100%
OR = Overall retention = lbs of dry solids after 2nd drainage step/lbs of dry solids in the headbox * 100%
FPFR = First pass filler retention (filler after 2nd drainage step)/filler in headbox *100%
MCTSR = Measured concentration total solids in recyclable solution Silo opticon signal
MCTSS = Measured concentration total solids in system slurry Headbox opticon signal
DW = dry weight of the paper, e.g. (lb/1000 sq.ft.)
CS = calendar speed, e.g. (ft/min)
SO = Slice opening, e.g. (mils)
SW = Slice width, e.g. (inches)
PHSS = Pressurehead of system slurry, e.g. (inches of water)
K_1 = unit conversion constant, e.g. (gal/(ft. in mils))
K_2 = unit conversion, e.g. $ft^2/(min^2$ inches of water)
K_3 = concentration coefficient (unitless)
G = G-factor, unitless indicates drainage performance

The following conditions are assumed to be substantially constant:
Slurry density (Sr) = 8.34 lb/gal
Ratio of (bta*btc)/(sa*sc) is constant
OR = 95%
BTF/SiF is constant
CM is constant at 78%
The equation:

a. FPFR = FP/FHB

can be derived from a mass balance for the filler, e.g. TiO2.

It follows that

b. FP = FHB - FSi - FBT

Mass flows for each of the terms are as follows:

c. $FHB = SF * Sr * CTS * CFS$

d. $FSi = SiF * Sr * sc * sa$

e. $FBT = BTF * Sr * btc * bta$

Equations **a** and **b** can be combined:

f. $FPFR = (FHB - FSi - FBT)/FHB$

or written another way

g. $FPFR = 1 - FSi/FHB - FBT/FHB$

The problem then becomes one of actually calculating the mass flows of filler. For the silo, slurry density is assumed to be constant at 8.34 lb/gal and the Silo ash*Silo consistency term is provided by sensor 44. Therefore, filler in the silo can be calculated combining Equations **d** and **IV.**

h. $FSi = SiF(8.34)\ ((MCTSR - 2.335)/19.638)$

For the headbox, slurry density is also assumed to be constant at 8.34 (lb/gal) and headbox ash * headbox consistency is provided by sensor 46. Slice flow is a calculated term based on PHSS and SO. Filler can be calculated as follows combining Equations **c** and **IV**:

i. $FHB = SF\ (8.34)\ ((MCTSS - 17.742)/5.616)$

In order to calculate a measure of retention without the knowledge of Broughton Tank flow, ash or consistency and without the knowledge of Silo flow, the following assumptions are made:

1. Experimentally, the ratio of Broughton Tank Ash*Broughton Tank Consistency to Silo Ash * Silo Consistency is constant.
2. The overall fiber and filler retention is constant at about 95 %.
3. The ratio of Broughton Tank Flow to Silo Flow is constant.
4. Couch moisture is constant at about 78%.

It is possible to calculate overall paper flow according to the equation:

j. $DP = OR * SF * 8.34 * CTS$

j. $DP = 0.95 * SF * 8.34 * CTS$

k. $PF = DP/(1 - CM)/8.34$

k. $PF = DP/(1 - 78\%)/(8.34)$

Assuming that the relationship between Silo Flow and Broughton flow remains fairly constant, the following expressions for Silo flow and Broughton flow can be written, wherein Broughton Tank Flow + Silo Flow = Slice Flow - Paper Flow:

l. $SiF = 80\% * (SF - PF)$

m. $BTF = 20\% * (SF - PF)$

The substantially constant relationship between Silo Ash*Silo Consistency and BT Ash*BT Consistency leads to the equation:

n. $bta * btc = 0.29(sa)(sc)$

With these assumptions and relationships an online measure of retention can be written:

g. $FPFR = 1 - FSi/FHB - FBT/FHB$

Silo flow can be calculated from the following equations:

h. $FSi = SiF * 8.34 * ((MCTSR - 2.335)/19.638)$

l. $SiF = 80\% * (SF - PF)$

j. $DP = 95\% * SF * 8.34 * CTS$

k. $PF = DP/(1 - 78\%)/8.34$

Combining these 4 equations yields:

o. $FSi = 0.8 * SF * (1 - CTS * 0.95/(1 - 0.78)) * 8.34 * ((MCTSR - 2.335)/19.638))$

o. $FSi = 0.8 * SF * [1 - CTS * 4.318] * 8.34 * ((MCTSR - 2.335)/19.638)$

Since Filler in the HB can be written:

i. $FHB = SF * 8.34 * ((MCTSS - 17.742)/5.616)$

The term FSi/FHB

p. becomes $\dfrac{0.8 * [1 - \text{HB Cons.} * 4.318] * ((MCTSR - 2.335)/19.638)}{((MCTSS - 17.742)/5.616)}$

To calculate the Broughton Tank Flow, 5 equations are needed:

e. $FBT = BTF * 8.34 * btc * bta$

n. $bta * btc = 0.29 * sa * sc$

m. $BTF = 20\% * (SF - PF)$

j. $DP = 95\%(SF * 8.34 * CTS)$

k. $PF = DP/(1 - 78\%)/8.34$

Combining these 5 equations yields:

q. $FBT = 0.2 * SF * (1 - CTS * 4.318) * 8.34 * 0.29 * ((MCTSR - 2.335)/19.638)$

The term FBT/FHB

r. becomes $\frac{0.058 * [1 - CTS * 4.318] * ((MCTSR - 2.335)/19.638)}{((MCTSS - 17.742)/5.616)}$

Therefore retention can be written:

s. $FPFR = 1 - \frac{0.858 * [1 - CTS * 4.318] * ((MCTSR - 2.335)/19.638)}{((MCTSS - 17.742)/5.616)}$

The retention derived above is the ratio of lb/min filler in the paper to lb/min filler in the headbox. Lab retention however is the ratio of %filler in the paper to % filler in the headbox. The difference between the two measures depends upon the overall fines and fiber first pass retention. It is assumed that overall first pass retention is about 95%. It is necessary to divide the derived first pass retention by 0.95 to equate the lab and online first pass retentions.

If one assumes that the term (I - CTS*4.318) is constant over the range of consistencies tested and that it can be approximated to be 0.95 then the above expression can be written

EQ. V. $FPFR = 1 - \frac{G * ((MCTSR - 2.335)/19.638)}{((MCTSS - 17.742)/5.616)}$

wherein G is a constant indicating long-term changes in drainage characteristics.

EXAMPLE 2

The filler content of a paper product is determined from a set of representational system operating values as follows.

Equations I-III are solved as follows for PHSS=57.0 In of H_2O, SO=735 mils, DW=32.9 lb/ksf, MCTSR = 18, MCTSS = 35, SW = 109.7 inches, CS = 1100 fpm, K_1 = 0.0000519, K_2 = 19320, K_3 = 0.96:

EQ. III $JS = (K_2 * PHSS/K_3)^{0.5}$

EQ. II $SF = (K_1)(SO)(JS)(SW)$

EQ. I CTS = (DW) (CS/(4480) (0.131) + 0.034 = 1.09%

EQ. IV CFS = (MCTSS - 17.742)/5.616/1.09% = 2.81% Ash

EQ. V FPFR = (1 - G((MCTSR - 2.335)/19.638)/((MCTSS - 17.742)/5.616)) (100%) = 80.5%

EQ. VI FPP = (80.5%) (2.81%) = 2.26%

The G-factor used in the FPFR calculation is 0.75

The value of filler content obtained (FPP) of 2.26 % is compared to a desired such value, and as described above, the operator or process controller computes δFPP using Equation VI′. The filler flow control valve is adjusted in accordance with the new set point, thereby controlling the flow rate of filler into the system in accordance with the desired filler content of the paper product. The results show the invention is useful in controlling the filler content and thus the uniformity of a paper product.

EXAMPLE 3

The slice opening is recalibrated to a trued slice opening value as follows. FIG. 5 is a Consistency Control Chart charting the deviation of laboratory-measured values of CTS in comparison with values of CTS calculated according to Equation I. In this case the deviation between the lab average of three and the calculated consistency does not substantially deviate until the last 6 points of the control chart where it appears that the lab average has consistently been about 0.05 units higher than the calculation.

Inspection of the calculations shows how to back calculate for the true slice opening based on a deviation in consistency.

EQ. III $JS = (K_2 * PHSS/K_3)^{0.5}$

EQ. II $SF = K_1 * SO * SW * JS$

EQ. I CTS = ((DW * CS)/SF) * 0.131 + 0.034 = 1.09%

The first step is to verify that the on-line calibrations of the total head (PHSS), dry weight (DW), and calender speed (CS) are correct. When this is verified take the actual average consistency and substitute it in the headbox consistency calculation. In this case the value is 1.14%.

EQ. VII from EQ. I 1/((1.14 - 0.034)/(0.131)/(CS)/(DW)) = 4287 gpm instead of 4480 gpm.

Then the corrected slice flow must be substituted into EQ. II to solve for the new slice opening.

EQ. VIII from EQ. II $4287\ gpm/K_1/SW/JS = SO'$

The solution is that SO′=703 mils.

Since 703 mils is the true value of SO instead of 735 mils, a -32 mil offset is introduced to TAYLOR MOD 300 distributed control system for computation to on-line true the measured value of SO to provide the actual value of SO.

EXAMPLE 4

The constant G in Equation V for calculating FPFR is trued as follows. FIG. 6 is a Consistency Control Chart charting the deviation of laboratory-measured values of FPFR in comparison with values of FPFR calculated according to Equation V.

Differences in lab retention and calculated retention are used to find the G-factor in a manner similar to the method of calibrating the slice opening. Inspection of the equation indicates how this is possible.

EQ. V. FPFR = (1 - G ((MCTSR - 2.335)/19.638)/((MCTSS - 17.742)/5.616))(100%) = 80.5%

If as the control chart indicates, there has been a shift in deviation of the lab and calculated retention of 5% units, then to calculate the new G-factor a simple substitution is required.

EQ. IX [(85.5%)/(100%) - 1]/[((MCTSR - 2.335)/19.638] ∗ [((MCTSS - 17.742)/5.616] ∗ (- 1) = G - factor' = 0.559

Due to a shift in the drainage process the G-factor changed from 0.75 to 0.559. 0.559 is then simply input to the control computer and the retention is calibrated.

In the past these changes in the G constant have been linked to changes in foil arrangement, changes in machine speed, drastic changes in the grade being manufactured, and drastic changes in the kinds and amounts of paper making chemicals being added.

The invention has shown outstanding agreement between lab tested results and calculated results.

The invention has been described in detail with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be affected within the spirit and scope of the invention.

Claims

1. A method for controlling on-line the weight percent of filler in a paper product of a paper-making system, said paper making system comprising a headbox (19), means for draining a slurry and introducing a recyclable solution to said system (22,24,30,42), means for the controlled addition of additional filler to a system slurry (48), and means for processing a concentrated system product to produce a paper product (32,34,36), said method including the steps of providing a stock slurry to said system, said stock slurry comprising a mixture of water, pulp fibers, and a filler; introducing said recyclable solution to said system, said recyclable solution comprising a mixture of water, said pulp fibers, and said filler; allowing said stock slurry and said recyclable solution to mix, thereby forming said system slurry; introducing said system slurry to said headbox (19)and distributing said system slurry therefrom to said means for draining (22,24); draining solution from said system slurry to thereby form additional said recyclable solution, and to thereby also form said concentrated system product for processing by said means for processing to form said paper product; characterized by:

   computing the concentration of total solids in said system slurry at said headbox;

   measuring the concentration of total solids in said system slurry at said headbox;

   computing the weight percent of filler in said system slurry as a function of said computed concentration of total solids in said system slurry and said measurement of concentration of total solids in said system slurry;

   measuring the total solids concentration of said recyclable solution;

   computing first pass filler retention as a function of said measurement of concentration of total solids in said system slurry and said measurement of said total solids concentration of said recyclable solution;

   computing the weight percent of filler in said paper product as a function of said weight percent of filler in said system slurry and said first pass filler retention;

   comparing said computed weight percent of filler in said paper product to a desired such value of weight percent of filler in said paper product and computing the amount and flow rate of additional filler to add to said system slurry; and

   adjusting and controlling said amount and flow rate of said additional filler to said system slurry, thereby controlling the weight percent of filler in the paper product of said system.

2. The method of Claim 1, wherein said filler is titanium dioxide.

3. The method of Claim 1, wherein each said measuring step is performed according to a light transmissivity principle employed by an optical sensor device (44,46).

4. The method of Claim 1, wherein said computing step computing concentration of total solids in system slurry at said headbox comprises the computation:

$$CTS = A[(DW)(CS)/(SF)] + B \quad (I)$$

wherein CTS is said Computed Concentration Of Total Solids In The System Slurry at said headbox;

$$SF = (JS)(SW)(SO) K_1 \quad (II)$$

$$JS = [K_2 * PHSS/K_3]^{0.5} \quad (III)$$

and

A and B are constants determined by a linear regression solution of equations I-III performed on at least two system slurry samples drawn from said system while said system is operating, wherein said linear regression solution employs operating values of system operating parameters of said equations I-III measured contemporaneously with said drawing of said samples.

5. The method of Claim 1, wherein said computing step computing weight percent filler in said system slurry as a function of said computed concentration of total solids in system slurry comprises the computation:

$$C(CFS)(CTS) + D = MCTSS \quad (IV),$$

where

CFS= Computed Weight Percent Filler In System Slurry;

CTSS= Computed Concentration Total Solids In System Slurry, measured at the headbox;

MCTSS= Measured Concentration Of Total Solids In System Slurry, measured at the headbox; and

C and D are constants determined by linear regression solution of Equation IV on a system slurry sample.

6. The method of Claim 1, wherein said system further comprises a plurality of means for the controlled independent addition of each of a plurality of additional fillers (48), and wherein said method further comprises:

repeating each measuring and computing step for each such additional filler; and

adjustably and independently controlling the amount and flow rate of each said additional filler to said system slurry, thereby independently controlling the weight percent of each filler in the paper product of said system.

7. The method of Claim 6, wherein the number of additional said fillers is one so that the total number of fillers added to said system slurry is two.

8. The method of Claim 1, further comprising trueing on-line the slice opening (20) of the headbox for improved control of system slurry flow rate in a papermaking system by the steps of:

measuring said slice opening (20);

measuring the pressure head of said system slurry;

computing slice flow through said slice opening (20);

computing a trued slice opening value;

computing a δ slice opening value; and

adjusting on-line said slice opening (20) in accordance with said δ slice opening value to thereby obtain substantially accurate system slurry flow.

9. Apparatus for controlling on-line the weight percent of filler in a paper product of a paper making system, said system comprising a headbox (19), means for draining a slurry and introducing a recyclable solution to said system (22,24,30,42), means for adding a filler to a system slurry (48), and means for processing a concentrated system product to produce a paper product (32,34,36), said apparatus comprising means for providing a stock slurry to said system (10,12,16,17), said stock slurry comprising a mixture of water, pulp fibers, and a filler; means for introducing said recyclable solution to said system (30,42,44), said recyclable solution comprising a mixture of water, said pulp fibers, and said filler;

means for allowing said stock slurry and said recyclable solution to mix (16,17), thereby forming said system slurry; means for introducing said system slurry to said headbox (17,18) and distributing said system slurry therefrom onto said means for draining (19,20), thereby forming additional said recyclable solution, and thereby also forming said concentrated system product that is thereafter processed by said means for processing to produce said paper product; characterized in that the system further comprises:

means for computing the concentration of total solids in said system slurry at said headbox (27);

means for measuring the concentration of total solids in said system slurry at said headbox (46);

means for computing the weight percent of filler in said system slurry as a function of computed concentration of total solids in said system slurry and measurement of concentration of total solids in said system slurry;

means for measuring the total solids concentration of said recyclable solution (44);

means for computing first pass filler retention as a function of measurement of concentration of total solids in said system slurry and measurement of said total solids concentration of said recyclable solution (27); and

means for computing the weight percent of filler in said paper product as a function of computed weight percent of filler in said system slurry and computed first pass filler retention, comparing said computed weight percent of filler in said paper product to a desired such value of weight percent of filler in said paper product, and computing the amount and flow rate of additional filler to add to said system slurry (27); and

means for adjusting and controlling said amount and flow rate of said additional filler to said system slurry, thereby controlling the weight percent of filler in the paper product of said system (27).

10. The apparatus of Claim 9, further comprising a plurality of means for the controlled independent addition of each of a plurality of additional fillers (48).

11. The apparatus of Claim 10, further comprising a plurality of means for measuring said concentration of total solids in said system slurry (46) and for measuring said total solids concentration of said recyclable solution (44).

12. A method of trueing on-line a slice opening (20) of a headbox for improved control of system slurry flow rate in a papermaking system, said method comprising the steps of:

measuring said slice opening (20);

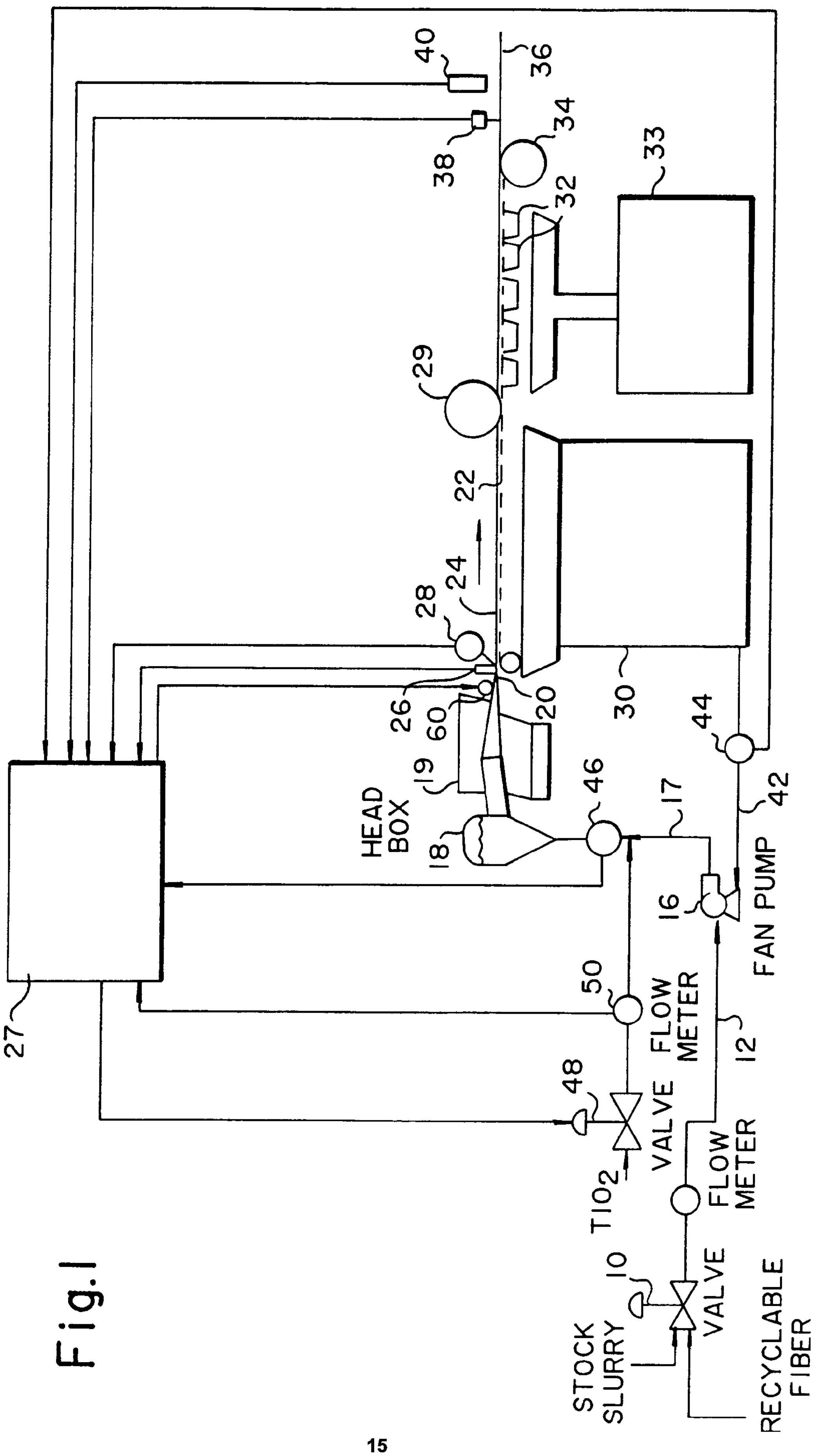
measuring the pressure head of said system slurry;

computing slice flow through said slice opening (20);

computing a trued slice opening value;

computing a δ slice opening value; and

adjusting on-line said slice opening (20) in accordance with said δ slice opening value to thereby obtain substantially accurate system slurry flow.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36
38
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32
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22
24
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HEAD
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46
17
42
16
FAN PUMP
27
50
FLOW
METER
12
48
VALVE
TiO_2
FLOW
METER
10
VALVE
STOCK
SLURRY
RECYCLABLE
FIBER

Fig.1

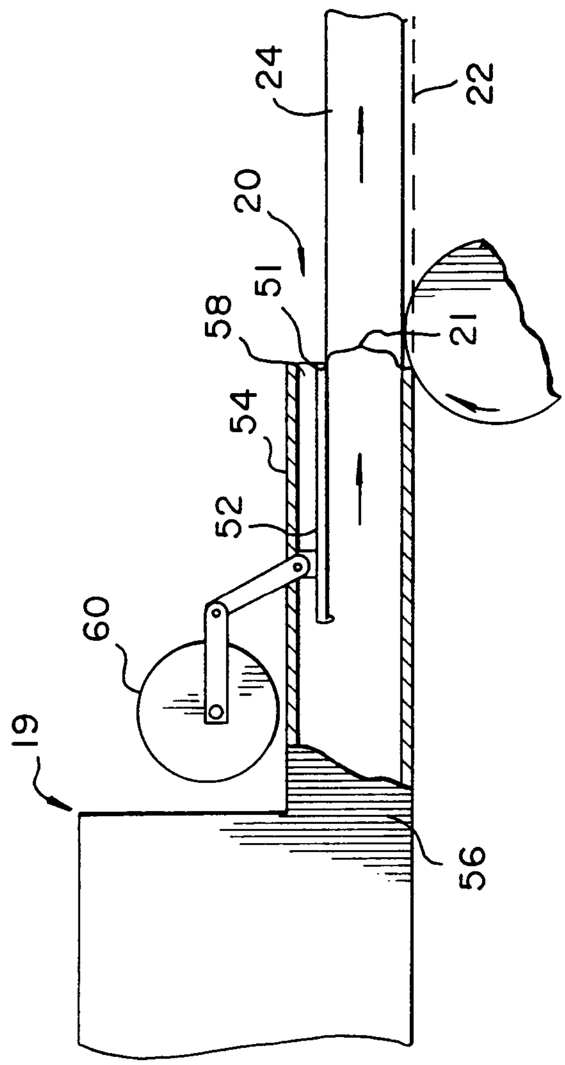


FIG.2

Fig.3

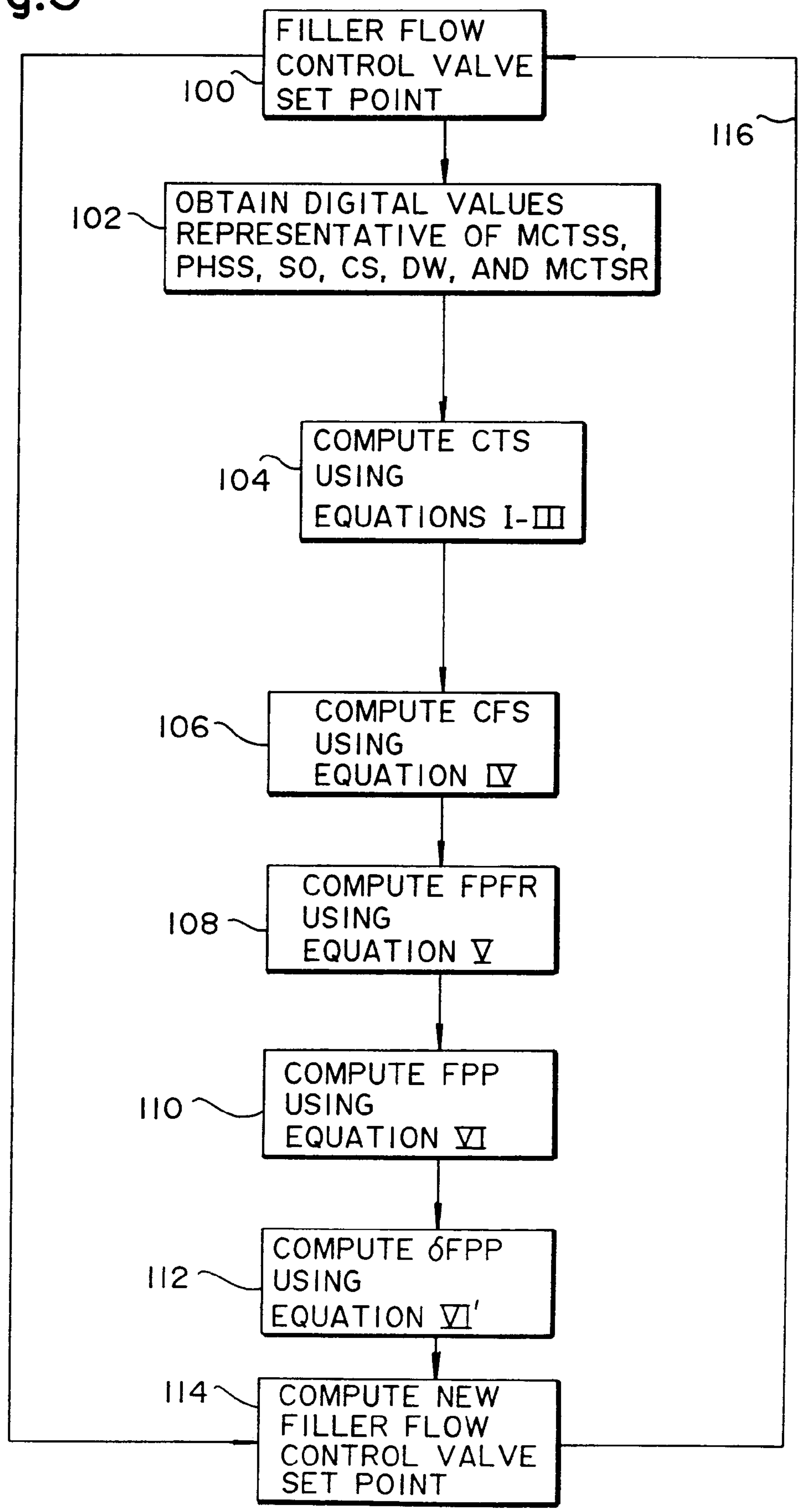
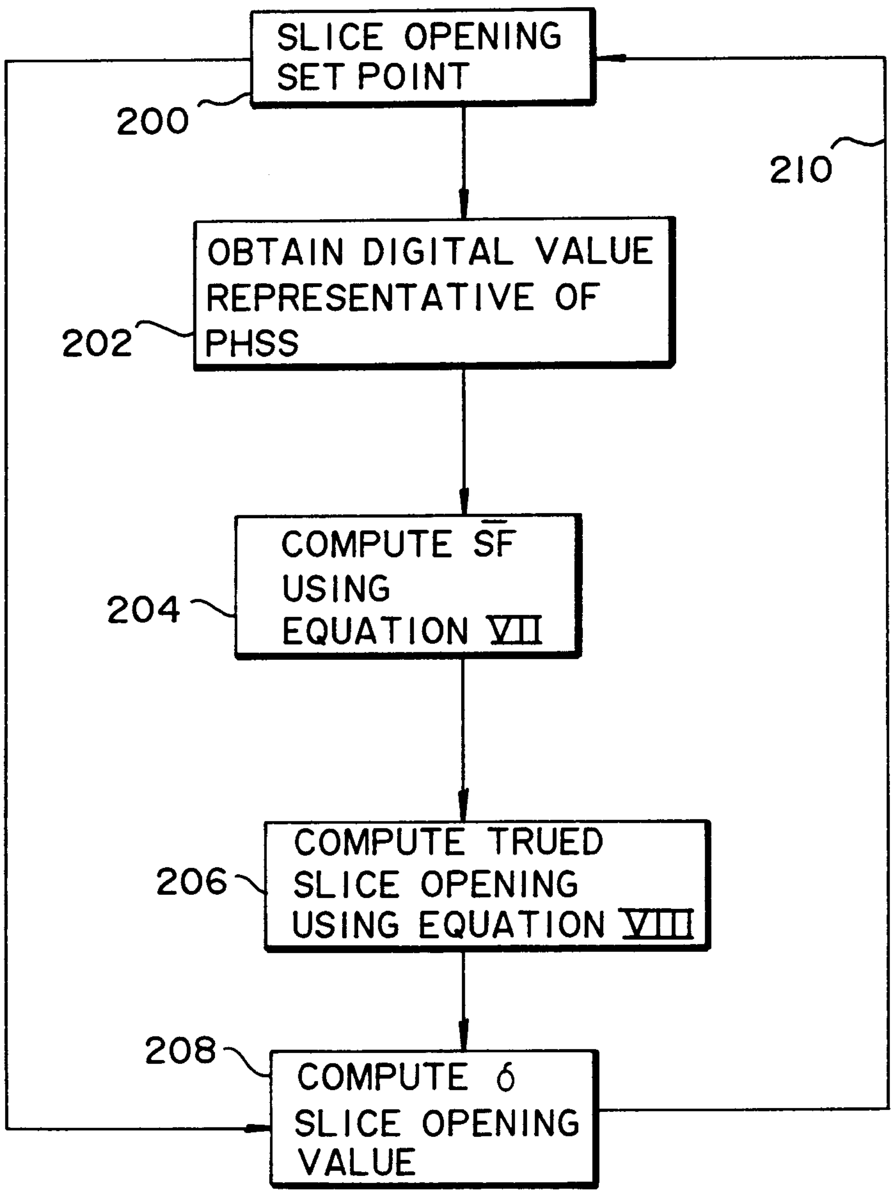

FILLER FLOW CONTROL VALVE SET POINT
100
116
OBTAIN DIGITAL VALUES REPRESENTATIVE OF MCTSS, PHSS, SO, CS, DW, AND MCTSR
102
COMPUTE CTS USING EQUATIONS I-III
104
COMPUTE CFS USING EQUATION IV
106
COMPUTE FPFR USING EQUATION V
108
COMPUTE FPP USING EQUATION VI
110
COMPUTE δFPP USING EQUATION VI'
112
COMPUTE NEW FILLER FLOW CONTROL VALVE SET POINT
114

Fig.4


SLICE OPENING
SET POINT
200
210
OBTAIN DIGITAL VALUE
REPRESENTATIVE OF
PHSS
202
COMPUTE $\overline{SF}$
USING
EQUATION VII
204
COMPUTE TRUED
SLICE OPENING
USING EQUATION VIII
206
208
COMPUTE δ
SLICE OPENING
VALUE

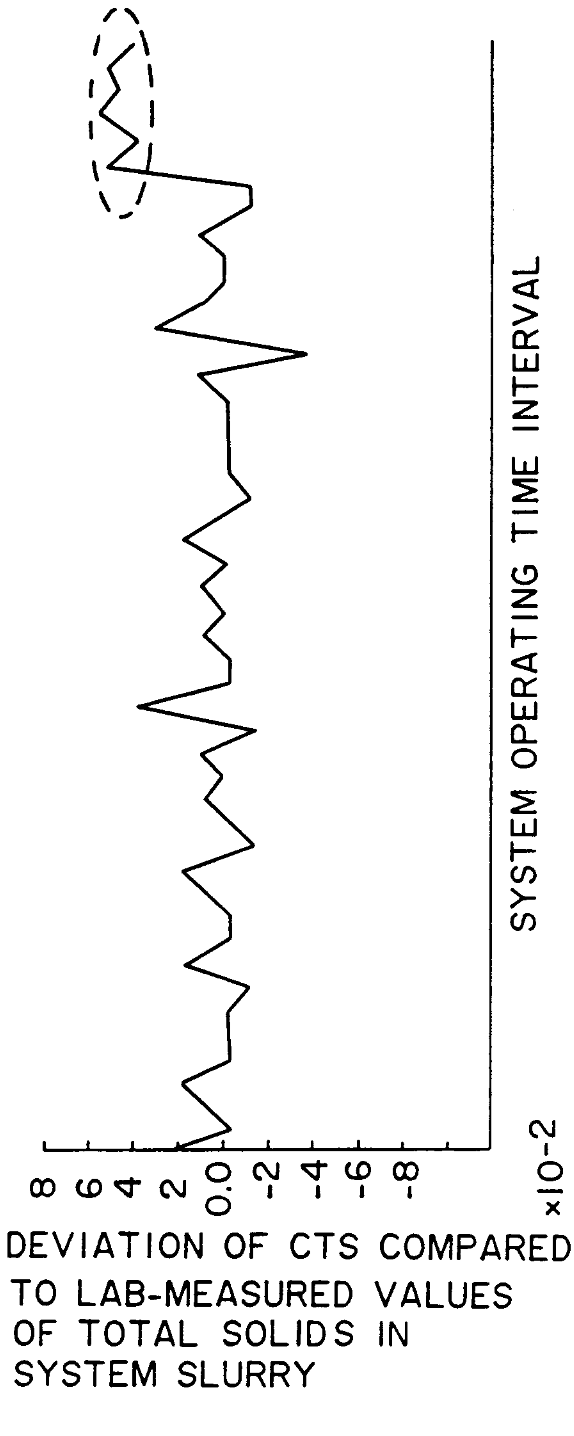

SYSTEM OPERATING TIME INTERVAL
8
6
4
2
0.0
-2
-4
-6
-8
×10-2
DEVIATION OF CTS COMPARED TO LAB-MEASURED VALUES OF TOTAL SOLIDS IN SYSTEM SLURRY

Fig.5

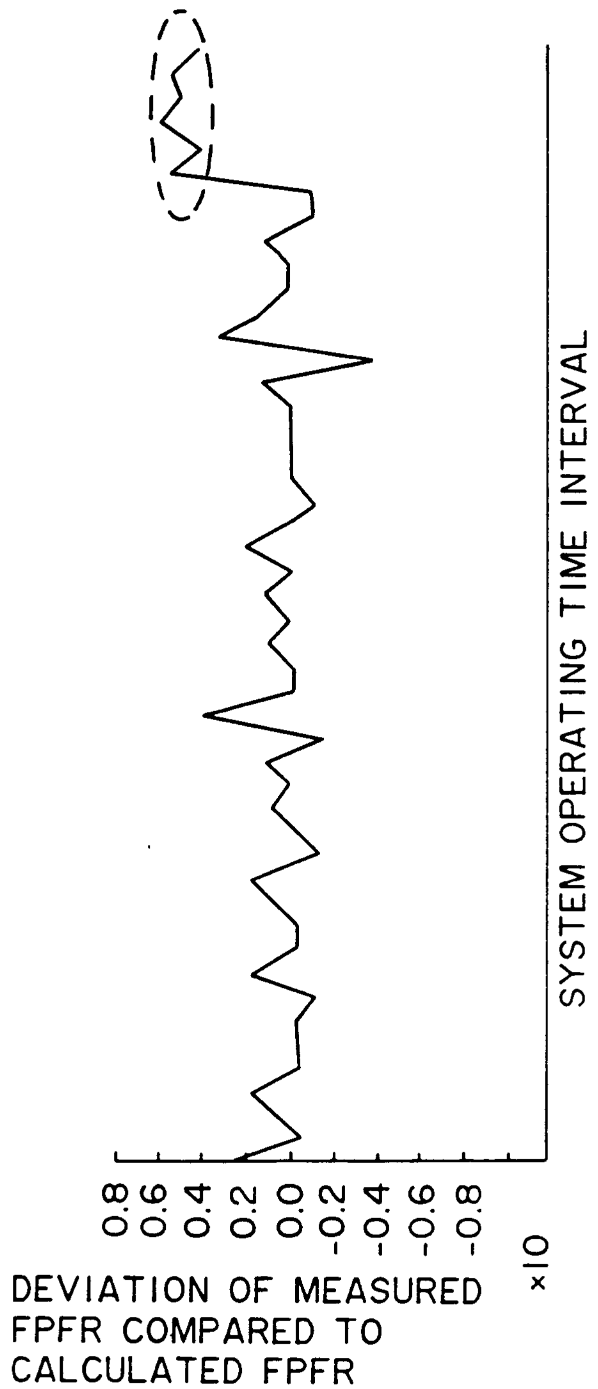

SYSTEM OPERATING TIME INTERVAL
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
×10
DEVIATION OF MEASURED FPFR COMPARED TO CALCULATED FPFR

Fig.6

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 42 0382

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	TAPPI JOURNAL vol. 72, no. 8, August 1989, NORCROSS, GA., US pages 113 - 119 , XP000069041 KORTELAINEN, NOKELAINEN, HUTTUNEN, LEHMIKANGAS 'mill application of a new system that simultaneously monitors fiber retention and filler retention' * the whole document * ---	1,9	D21G9/00 D21F1/66
A	PROC. IEE vol. 116, no. 10, October 1969, NEW YORK pages 1755 - 1758 SIDEBOTTOM 'computer control of paper-making plant' * the whole document * ---	1,9	
A	US-A-4 098 641 (CASEY ET AL) * the whole document * ---	1,2,9	
A	US-A-3 035 967 (SACKSEN ET AL) * the whole document * ---	1,9	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
A	MEASUREMENT AND CONTROL vol. 1, no. 8, August 1968, pages 287 - 291 JONES, WHIGHT 'the digital control of a fourdrinier paper machine' -----		D21G D21F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	26 FEBRUARY 1993	DE RIJCK F.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document