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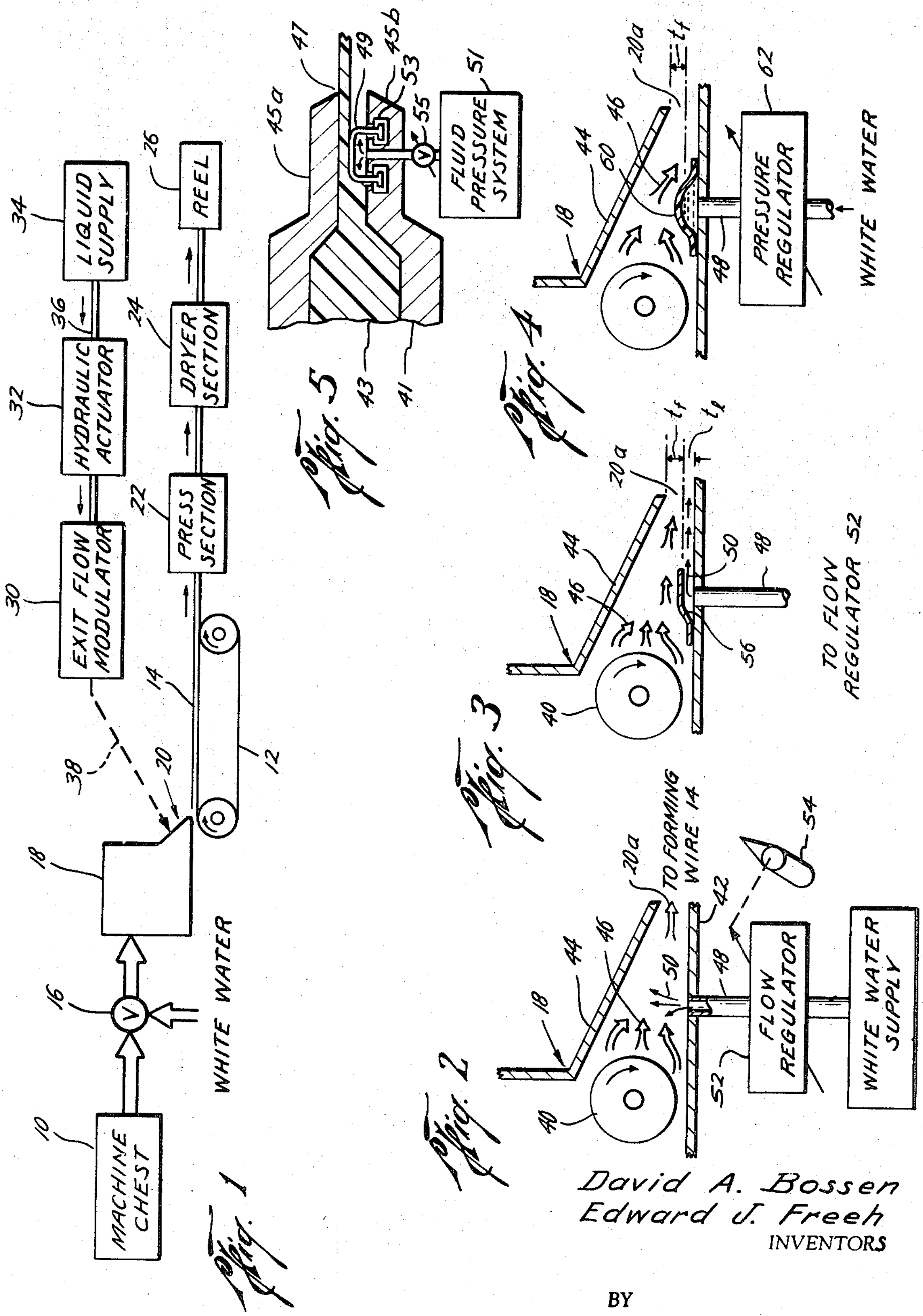
MEANS AND METHOD FOR MODULATING FIBER STOCK FLOW IN PAPERMAKING HEADBOX IN RESPONSE TO PAPER SHEET PRODUCT PARAMETERS

Filed April 29, 1966 2 Sheets-Sheet 1



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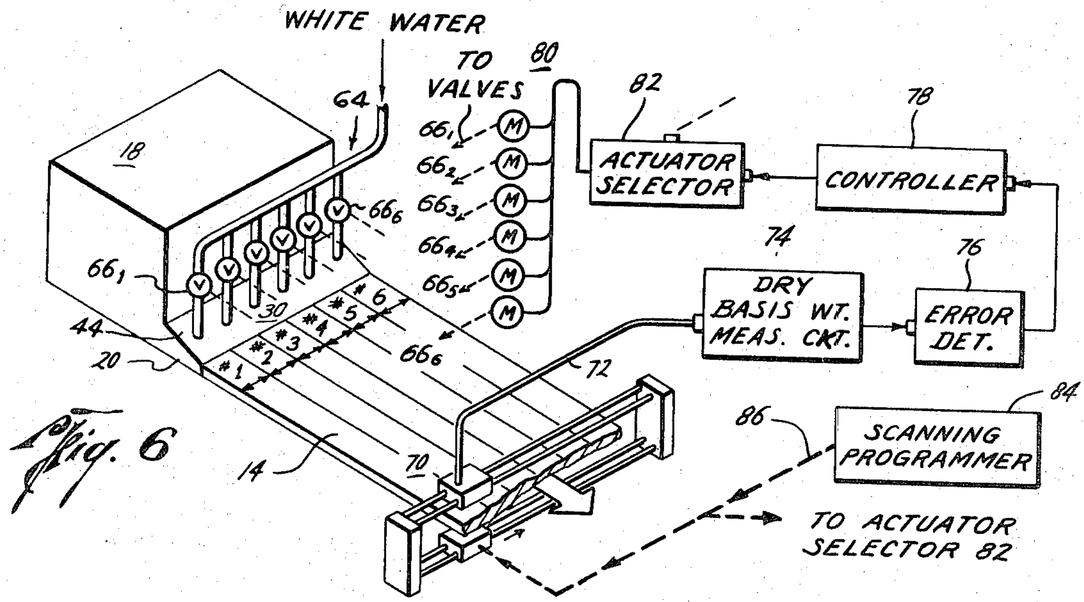


Fig. 6

Fig. 7

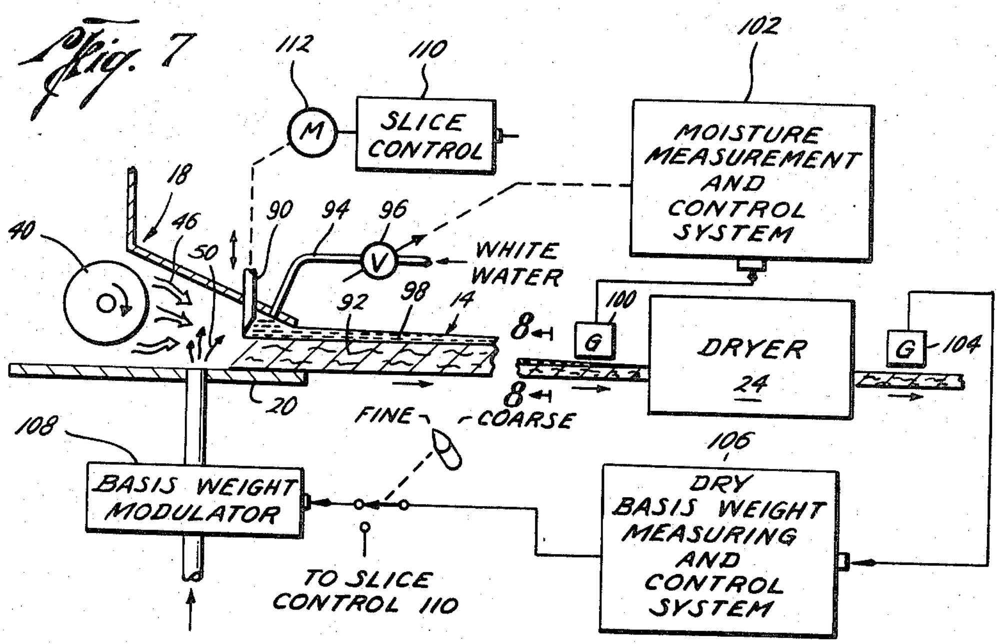
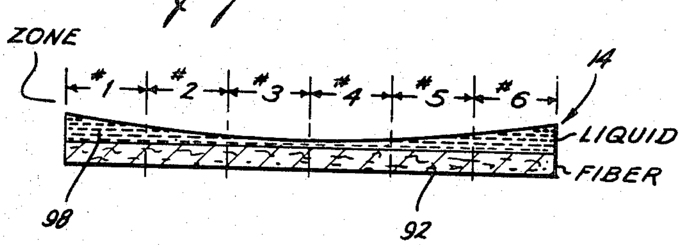


Fig. 8



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MEANS AND METHOD FOR MODULATING FIBER STOCK FLOW IN PAPERMAKING HEADBOX IN RESPONSE TO PAPER SHEET PRODUCT PARAMETERS

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U.S. Cl. 162—198 33 Claims

ABSTRACT OF THE DISCLOSURE

A paper sheet forming apparatus and method wherein the fiber stock flowing to the slice orifice of the headbox is modulated upstream of the orifice. The flow may be suppressed by employing a flexible diaphragm which constricts the stock flowing to the orifice or by contacting the lower surface of the stock with a layer of liquid such as white water. These modulations ultimately affect the basis weight of the formed paper sheet. Further, the upper surface of the stock may be contacted with a layer of dilute liquid which then effects the moisture content of the formed paper sheet. The flow consistency may be modulated by regulating the addition of either dilute liquid or fiber stock to the flowing stock prior to exiting the orifice which ultimately affects the basis weight of the formed paper sheet. The flow modulation is controlled in response to controller means which include scanning moisture gauges and scanning basis weight gauges.

This invention relates generally to product manufacturing apparatus, and more particularly, to a method and apparatus for controlling the general uniformity of product formed by adjustable members.

BACKGROUND FOR DESCRIPTION

Quality control of industrial products have always been difficult. Examples may be found in the manufacture of sheet products such as provided by a paper machine or a plastic extruder wherein weight uniformity, for example, of the sheet product is desired.

Some insight into the quality control problem can be gained by first examining the apparatus commonly employed by paper manufacturers. While several different methods are used, one of the most common is the Fourdrinier method by which an aqueous suspension of wood pulp fibers is laid over a traveling fine wire mat to form the paper sheet or web. The fiber stock flows from a machine chest into a headbox from which it exits over a lip or through a slice opening or aperture extending across the lateral extent of the wire mat. The size of the opening may be adjustable by slice screws to control the thickness dimension of the formed sheet. Water is removed from the sheet as it is carried along the wire mat. The sheet passes through press and dryer roll stands before being wound up on a reel in substantially dry form.

BACKGROUND

Many techniques have been employed to insure the manufacture of sheet of uniform weight per unit area or a basis weight. For example, individual automatic control of slice screw settings in accordance with the measurements of a scanning radiation gauge is disclosed in U.S. Pat. 3,000,438 issued Sept. 19, 1961 to F. M. Alexander, and assigned to the same assignee as the present invention.

Both thickness and moisture content are simultaneously controlled by a dryer temperature gauge as disclosed in U.S. Patent 1,936,225, issued Nov. 21, 1933 to A. E. Broughton. Thickness is controlled by altering the flow

of stock before it enters the headbox with an adjustable flow of white water (diluted stock). A common conduit carries the white water stock mixture to the paper machine where it is subsequently delivered to the forming wire or cylinder. Uniform moisture content is provided by changing the amount of heat supplied to the dryer. With this type of control, there is an excessively long time lag between the point the stock flow is altered and the point it is deposited on the wire.

Other disclosures such as U.S. Patent 2,951,007, issued Aug. 30, 1960 to P. Lippke are concerned only with moisture control. This patent discloses the use of a scanning moisture gauge to control simultaneously the spraying of water laterally on a partially dried sheet and the slice opening. The water spray may damage the sheet and may be ineffective for moisture control. The speed of slice adjustment is limited due to the inertia of the gearing system required to reduce the speed of the actuating motor making the control of basis weight or thickness difficult and unstable.

BRIEF DESCRIPTION OF THE INVENTION

The present invention provides generally a method and means for quickly effecting a change in the weight per unit area of fibers deposited on the forming wire or cylinder. We modify or modulate the flow of fiber stock with a fluid before it exits the slice opening. In a preferred form, the flow modification is hydrodynamic in nature and can be accomplished either by altering the consistency of the stock just before it leaves the headbox or by suppressing or throttling the flow thereof at this point in the process. Moreover, fluid modulation of flow can be provided at a plurality of points across the width of the machine to obtain uniform fiber weight per unit area of the formed sheet in the cross-sheet direction, hereinafter referred to as profile, as well as in the machine direction.

A liquid such as water, diluted fiber stock or white water, may be used to provide the desired mixing or suppression. Usually, a source of white water is readily available and a conduit can supply a manifold communicating with the interior of the headbox upstream from the slice.

In the flow consistency embodiment, the manifold exits are open to the stock flow and individual valves are installed to change the rate of flow of white water into the headbox. The local consistency of fiber content of the stock is altered by the mixing of the two flows occurring at each manifold exit. The modified stream then flows out through the slice opening and onto the wire.

In the flow suppression embodiment, at least two different methods may be employed. The mechanical slice member is fixed and defines with the floor of the headbox an aperture providing for a given cross-sectional area of flow normally occupied by the fibrous slurry. By employing flow deflectors over the manifold exits, the liquid may be forced to flow generally in a layer adjacent to the stock and occupy a portion of the available headbox aperture cross-section. The layer flow thus provided serves to regulate the weight per unit area of the formed sheet.

The layer flow of liquid may be injected either at the top or at the bottom of the fiber slurry flow. Control exerted in the region of the upper flow permits regulation of the moisture content of the sheet since the liquid must drain through the sheet. Thickness control of the lower flow permits regulation of the final sheet bone dry basis weight. The layer flow technique is distinguished from the stock mixing technique described above in the relative degree of flow turbulence resulting from injection. The moisture profile control system enables more moisture to be provided at the edges of the sheet than at the center to insure a uniform cross-sheet moisture content after it is dried in a dryer having a nonlinear drying rate.

In addition, rather than force the liquid into direct contact with the stock, it may be more advisable to confine the liquid flow in a closed hydraulic system wherein a force can be quickly transmitted by a liquid column against a deformable elastic membrane positioned in the path of the slurry. The surface of the membrane cooperates with the edge of the slice member to establish a flow area of adjustable dimension. In this manner, there is no commingling of the flows, but the fast response of hydraulic actuation is provided nevertheless. By making the deformable elastic membrane permeable, some of the actuating liquid passes through the membrane and mixes with the stock producing a combined suppression and dilution action. This suppressed flow control technique can be advantageously applied to other product forming devices such as a plastics extruder die. In this embodiment, a deformable membrane restricts the flow of plastic directed out through the lips of the die. The thickness of the formed plastic sheet varies inversely with the extension of the membrane into the plastic flow.

In certain applications, our novel flow modulation techniques can be used in conjunction with a basis weight gauge positioned downstream from the headbox to measure and automatically control the weight per unit area of the formed sheet. More specifically, a scanning gauge may be used for measuring the weight per unit area of various cross-sheet zones, the basis weight or, in the alternative fiber content, of each zone being determined by one of the several cross-machine flow modulators. The appropriate modulator is actuated to bring the basis weight of the sheet in its zone of control to the desired value. The modulator control signal may be developed after each zone is scanned. Alternatively, the gauge signal may be stored for purposes of a later correction in order to eliminate any short term transient effects that might result from immediate zone-by-zone control.

It should be noted that the basis weight of the sheet is equal to the product of the thickness and the density of the sheet. Therefore, the terms basis weight and thickness may be used interchangeably when the density is relatively constant. This assumption may not be true for some paper-making processes. Since the modulators of the present invention primarily affect the fiber weight of the formed sheet, it may be preferred to measure the dry weight per unit area of the sheet and base control action of this quantity.

OBJECTS OF THE INVENTION

Accordingly, it is a primary object of the present invention to provide a product manufacturing machine having a faster speed of response than other devices of a similar nature.

It is another object of the present invention to provide an improved basis weight control system for a paper-making machine.

It is also an object of the present invention to provide a more stable paper-making operation than heretofore possible.

It is yet another object of the present invention to provide an improved method and apparatus for leveling both the moisture and the fiber weight profiles of a paper sheet product.

DESCRIPTION OF FIGURES

FIG. 1 is a diagrammatic view of a paper-making machine comprising one preferred embodiment of the present invention;

FIG. 2 is a partial sectional view showing the construction of one type of flow modulator for use in the machine shown in FIG. 1;

FIG. 3 is a partial sectional view of an alternative construction for a flow modulator;

FIG. 4 is a partial sectional view of another type of flow modulator;

FIG. 5 is a partial sectional view of an improved modulator for a plastic extruder;

FIG. 6 is a perspective view of a basis weight control system constructed in accordance with the present invention;

FIG. 7 is a partial sectional view, partially schematic, of a combined basis weight and moisture control system; and

FIG. 8 is a sectional view taken on the line **8—8** of FIG. 7.

DESCRIPTION OF THE INVENTION

With reference now to the drawings, and particularly to FIG. 1, the present invention is described in connection with a paper-making process but other types of product manufacturing processes may be regulated in a similar manner. A typical paper-making line includes a machine chest **10** for storing the water-fiber slurry or stock that is deposited onto a traveling forming wire **12** to form the paper sheet **14**. The stock is frequently mixed by means of a valve **16** with a flow of white water prior to the headbox **18**. The mixture is pumped into the headbox **18** which has an exit slice lip **20** extending across the width of the forming wire **12**. Excess water drains from the wire **12** and is later removed from the sheet **14** by rolls in a press section **22** and a dryer section **24**. A reel **26** winds up the dried paper sheet.

It is desirable to produce a sheet having a uniform weight per unit area or basis weight. To this end, mechanical slice members have heretofore been employed across the lip **20** of the headbox and adjusted manually or automatically up or down, depending on whether the sheet was running lighter or heavier than desired. Motion was provided by a screw connected to the slice member. A motor was coupled to the screw by means of a reduction gearing arrangement. In general, this type of actuator has left much to be desired because of its sluggish operation. Backlash and inertia effects have made control of the slice member very difficult. Further, the amount of mechanical warpage is limited and excessive corrective action can cause slice failure.

In an effort to increase the speed of response we have provided a hydraulic system which modulates the stock flow in the region of the lip **20**. Not only is the speed of response increased but the system also requires fewer moving components. The hydraulic system includes an exit flow modulator **30** coupled to a hydraulic actuator **32**. A liquid supply unit **34** may include pumping equipment to maintain in the conduit **36** either a fixed volumetric flow rate or a given head or pressure. The flow modulator's coupling to the stock flow is illustrated by the dotted line **38** extending toward the lip **20** of the headbox.

Generally speaking, the modulator **30** affects the distribution of the fibers being deposited on the wire **12** thereby altering the weight per unit area of the formed sheet **14**. The modulator **30** may affect the flow equally at all points across the face of the lip **20**. Alternatively, it may be desired to produce a sheet heavier in some cross-sheet areas than in others, or to otherwise increase the flexibility of the system, in which case, a plurality of individual modulators are provided, each affecting the flow across and through a small local region of the lip. The stock flow in the headbox **18** is modulated upstream from the lip **20** at a point where the flow is relatively streamlined with little lateral mixing. The location of this point depends on the construction of the headbox. Since the flow streamline improves the nearer one approaches the lip **20**, we have found it preferable to modulate in this region. A constant mass flow of fiber through each region produces a constant basis weight zone extending downstream in the machine direction toward the press and dryer sections **22** and **24**. Several of these zones, side-by-size, occupy the width of the sheet **12** and determine the profile or variations in the value of a physical variable of the sheet such as basis weight or moisture with distance across the sheet **14**. A discussion of profile measurement and control will be taken up hereinafter; but, first it is instructive to describe several types of preferred flow modulators. For simplicity, these descriptions are confined to a single modulator operative to vary the sheet weight of only one zone.

FLOW CONSISTENCY MODULATOR

One type of modulator is shown in FIG. 2. An enlarged view taken at a cross-section of the lip **20** reveals a holey roll **40** positioned between the floor **42** and the upper sloping face **44** of the lip **20** of the headbox **18**. The holey roll **40** breaks up the fiber slurry before it moves out through the lip opening **20***a* and thereby prevents flocculation. The local fiber stock flow is indicated by the large arrows **46**. Several pairs of holey rolls may be located at different positions within the headbox **18** between the stock entrance and the lip opening **20***a*. Other rotatable or non-rotatable members may be used to provide the function of the holey roll.

The purpose of this embodiment is to alter the consistency of the stock stream **46** before it exits the lip opening **20***a* and is deposited onto the form wire **12**. This may be accomplished by altering the flow in other streamline flow regions further upstream in the headbox **18**. A change in consistency means, of course, that the mass flow of fiber through the opening **20***a* will be altered. This alteration of fiber mass flow is reflected by a corresponding change in the basis weight of the sheet being formed. Although many ways may be available to vary the stock consistency, one of the most convenient is to mix liquid with the slurry to dilute the same. This procedure assumes that, with no liquid being added, the stock is sufficiently dense to provide the heaviest sheet weight desired. Liquid dilution of the stock decreases the sheet weight. It is, of course, within the scope of this invention to add fiber to local flow if the foregoing assumption cannot be made.

Water or other liquid may be added to change the flow consistency. The ready availability of white water makes this liquid most convenient. White water may be pumped through a conduit **48** that terminates in the interior of the headbox **18** preferably between the holey roll **40** and the lip opening **20***a*. The flow of white water, indicated by the single curvilinear arrows **50**, commingles with the local stock flow **46**. An adjustable liquid flow regulator **52** may be provided in the conduit **48** to vary the amount of white water flowing per unit time into the headbox lip **20**. The flow regulator **52** may be manually adjustable by means of a knob **54** to vary the consistency of stock delivered to the forming wire **12**. For example, an increase in white water flow, lowers the stock consistency and decreases the weight of the sheet **14**. Conversely, throttling of the white water flow increases the basis weight of the sheet. Automatic control of the white water flow will be described hereinafter.

FLOW SUPPRESSION MODULATOR EMBODIMENTS

Another embodiment of modulator alters the mass flow of stock from the lip **20** by suppressing the flow hydrodynamically. FIGS. 3 and 4 illustrate only two of several forms of suppression. In either case, the total exit area of flow available to the local fiber stock flow **46** is throttled by movable diaphragm members actuated by white water or other fluid. This stock flow exit area is proportional to the height of the opening indicated by the thickness dimension t_f of fiber slurry laid on the wire.

In FIG. 3, a valve such as a flexible stainless steel cover **56** is positioned over the open end of the conduit **48**. The rear of the cover **56** is fastened to the floor **42** of the headbox **18** away from the lip opening **20***a*. White water **50**, flowing into the headbox, strikes the steel valve **56** deflecting it upwardly in accordance with the pressure in the conduit **48**. A laminar flow of white water **50** deflected by the valve **56** is provided beneath the local stock flow **46** and occupies a portion of the total lip opening **20***a* proportional to the thickness t_1 of the white water layer.

There is little, if any, change in the consistency of the slurry **46** in this embodiment. The weight of the sheet **14** is increased by reducing the mass flow of white water flowing into the headbox. The valve **56** lowers and permits an increase in the flow of fiber out through the lip opening **20***a*. The underlying layer of white water quickly drains through the wire **12** and is collected and recirculated. The remaining fibrous sheet travels on to be dried more completely.

Another flow suppression embodiment is shown in FIG. 4. Here a deformable elastic membrane **60** completely encloses the end of conduit **48**. No white water is permitted to flow but a force is conveyed by the enclosed liquid column and directed against the membrane **60** to project more or less of its outer surface into the path of the fiber stock **46** flowing toward the lip opening **20***a*. A pressure regulator **62** is made adjustable to vary the "head" or pressure of the liquid column provided in the closed system.

This technique of flow control may also be applied to a plastic extruder. FIG. 5 shows a portion of an extruder housing **41** containing a supply of plastic material **43**. Normally, the plastic material **43** is forced out of the extruder housing **41** through a pair of die members **45***a* and **45***b*. The die may be either linear to provide a flat sheet of plastic or circular as commonly employed on blown film lines. In either case, the die is normally adjustable at sections along its length by means of mechanical screws (not shown) capable of altering the gap thickness at the lip **47** of the die. This affects the thickness of the extruded product. A better description may be found in an article by H. E. Sponaugle entitled "Automatic Profile Gauge Control" reported at vol. 19, No. 6, June 1963 of the Society of Plastics Engineers Journal.

We have found it preferable to employ a movable diaphragm **49** between the lip **47** and the main body **41** of the extruder to change the thickness of the extruded plastic product. A fluid pressure system **51** may be used to provide a flow of fluid against the underside of the diaphragm **49** to force it upwardly against the flow of plastic. The diaphragm **49** may be carried in a pair of slots **53** provided in one of the die members **45***b*. A valve **55** controls the fluid pressure and thus the thickness of the extruded product.

A plurality of diaphragms can be provided along the length of the die to control the profile of the extruded sheet product. In this case, a valve **55** is connected between the fluid pressure system **51** and each diaphragm and adjusted in accordance with the zone control techniques described hereinabove.

Other diaphragm constructions may be employed to provide the desired result. In certain types of extruders it may be more desirable to eliminate the diaphragm member and direct a flow of readily vaporizable fluid against the flow of plastic to restrict the same in a manner similar to that described above in reference to the papermaking apparatus.

In the operation of this embodiment, to decrease the basis weight of the formed sheet, an increase in white water pressure extends the membrane **60** upwardly, thereby constricting the stock flow from the lip opening **20***a*. The fiber thickness t_f decreases causing a reduction in the weight per unit area of the sheet **14**. A basic weight increase can be accomplished by a reduction of the pressure in the conduit **48**. It will be apparent to those skilled in the art that many alternatives of this embodiment are possible. For example, membranes of various materials, sizes and mounting position may be tried, depending on the weight and character of sheet being produced. For example, semi-porous membranes may be used, permitting a combination of both the stock consistency and the stock suppression techniques of the invention. In addition, other variations of the hydraulic actuating system may be made to improve the operation of the system.

Regardless of which type of modulator is selected, it is apparent that a fast mode of weight control is available due to the employment of a hydraulic actuating system. Any of the modulators described above can be advantageously combined with sheet weight gauging apparatus to provide an improved automatic control system. Such a system is described in the following section.

IMPROVED FIBER WIEGHT CONTROL SYSTEM

With reference now to FIG. 6, several modulators can be positioned side-by-side across the width of the headbox **18** to produce a sheet **14** having a predetermined fiber weight profile; frequently fiber weight per unit area is termed bone dry basis weight. Six modulators are shown for purposes of illustration. Each modulator controls the fiber weight per unit area, i.e., bone dry basis weight, in one of the six zones #1–#6 defined by the dotted lines extending in the machine direction down the sheet **14.** Hereinafter apparatus associated with a particular zone will be identified with a subscript numeral indicative of that zone. A manifold piping arrangement **64** may be employed to convey the white water to the several local cross-sheet regions of the lip **20.** The flow modulators are shown communicating with the upper surface **44** of the lip **20** for convenience of illustration. A separate valve 66_1–66_6 serves to regulate the mass flow of white water into each local lip region. Other flow regulating devices may also be suitable for this purpose.

In order to derive control signals suitable for actuating the valves 66_1–66_6, a traversing gauge **70** is employed to scan the sheet **14** laterally and provide on line **72** a signal proportional to the fiber weight per unit area of the portion of the sheet being scanned. A measuring circuit **74** amplifies this signal and transmits it to an error signal detector **76.** Detector **76** develops a signal whenever the measured weight and the desired weight differ. Controller **78** causes actuation of an appropriate one of a bank of motors **80** each coupled to one of the valves **66** by means of an actuator selector unit **82.** A scanning programmer **84** causes the gauge **70** to scan across the sheet **14** and demands from the actuator selector **82** that the controller **78** be coupled to the appropriate motor in the bank **80** to insure that weight control is exerted on the zone being measured. The cooperation between the programmer **84** and the guage **70** and the actuator selector **82** is indicated by the heavy dotted line **86.** A more detailed description of the construction of some of the units briefly described above may be found in the aforementioned patent to Alexander. Alternatively, the modulators can be controlled simultaneously by changing the programming and selection functions of units **84** and **82** respectively.

The gauge **70** may include any of the known sensors sensitive to basis weight such as those operating on the radiation absorption principle. U.S. Pat. 2,790,945, issued to H. R. Chope and assigned to total the same assignee as the present invention describes a gauge of this type. Since the sheet **14** is eventually dried to a very low moisture content, it is usually desirable to maintain uniformity of the bone dry weight of the sheet. A total sheet weight measurement may have to be compensated for moisture (if it varies significantly) to compute the dry weight and permit more accurate control of the fiber content by our improved modulators. It is appreciated that the total sheet basis weight is proportional to the dry basis weight thereof only when the moisture content of the sheet remains invariant. Gauge **70** would include preferably both a moisture sensor and a basis weight sensor and instrumentation providing for the moisture compensation of a total basis weight signal would be provided in measuring circuit **74.** Circuit **74** would deliver an amplified signal proportional to the dry weight per unit area or dry basis weight of the sheet region being scanned.

The mounting location of the gauge **70** is not critical; however, it is preferred to position the gauge as near as possible to the headbox **18** to shorten the time lag between the point of control and the point of measurement. Measurement of the sheet **14** as soon as possible after it leaves the forming wire **12** would provide a time lag of only a few seconds at the most. Of course, measurement after the dryer section **24** would eliminate the need for moisture compensation but the excessively long transport time may nullify the advantages afforded by the modulator's quick response.

Since the gauge will measure an area of sheet substantially smaller than the width of the cross sheet zones, provision may be made to average the weight of the sheet across each zone. Electrical integrators similar to those described in the Alexander patent, supra, may be employed for this purpose.

This system operates in the following manner. The gauge **70** scans across zone #1 and the dry weight of this area of the sheet **14** is computed. The gauge signal may be stored while the entire sheet is scanned. The stored signal may be drawn from storage and used to provide the desired zone-by-zone profile control. Alternatively, control for a given zone may be effected immediately after that area of the sheet is measured. If the computed dry weight is larger than it should be, controller **78** energizes motor **80,** for a period of time proportional to the weight error. Valve 66_1 is actuated to increase the flow of white water into the left-hand edge of the slice lip **20.** Accordingly, a reduction in sheet weight in any zone will be accompanied by an increase in the flow of white water into the region of the lip associated with the zone. Successive measurement and control of sheet zone weight enables the fiber weight profile of the sheet to be leveled. It also permits contouring of the profile if it is desired to have a sheet lighter or heavier in the center than near the edges.

COMBINED MOISTURE AND FIBER WEIGHT CONTROL SYSTEM

The present invention provides not only for fiber profile weight control but also for moisture profile control of the sheet **14.** This is of great benefit in view of the nonlinear drying characteristics of most dryer sections. Dryers characteristically remove more water from the edges of the sheet than near the center. This means that the dried sheet will not have a uniform cross-sheet moisture content. Moreover, the sheet may be damaged by overdrying the edges in attempting to eliminate the wet center. An attempt has been made to correct this without success by skewing the press rolls.

We precondition the sheet by supplying white water to the upper surface of the fiber stock flowing out through the slice opening **20***a.* A greater flow of white water is provided at the edges of the slice opening than at the center of the sheet. The added white water eventually drains through the sheet, but the center is left with a lower moisture content than the edges. After passing through the dryer **24,** the sheet emerges with a level moisture profile.

FIGS. 7 and 8 illustrate this novel method of sheet moisture control. The headbox construction is similar to that described above with the exception that a vertically adjustable slice member **90** is shown defining the exit flow area with the floor of the headbox **18** from which the fiber stock flows in a sheet layer **92.** The flow of white water through a conduit **94** communicating with the roof of the headbox lip **20** is controlled by an adjustable valve **96.** The water is deposited on top of the fiber stock in a layer **98,** the thickness of which decreases with distance from the headbox because of drainage through the fiber stock layer 92.

A moisture gauge 100 measures the moisture content of the sheet before it enters the dryer section 24. The type of moisture gauge used is not critical. A moisture measurement and control unit 102 may be used to actuate the valve 96.

Several valves may be provided across the width of the headbox lip 20 to provide the desired moisture profile illustrated in FIG. 8. The desired moisture profile of the sheet 14 prior to entering the dryer 24 is indicated by the crowned liquid layer 98. The illustration is diagrammatic and is not necessarily the distribution of white water and fiber actually occurring in the sheet 14 at this point in the process. To obtain the nonlinear moisture profile shown in FIG. 8, the control unit 102 works against a different desired or target moisture content for each zone #1–#6. For example, the target moisture for zone #2 may be several percent lower than that for zone #1 and yet several percent higher than that set for zone #3 near the center of the sheet 14. In most cases, the profile will be symmetrical about the center of the sheet and the targets for zones #4, #5 and #6 may be substantially the same values set for zones #3, #2, and #1, respectively.

To accommodate this profile control, the moisture gauge 100 must be scanned across the sheet unless the moisture variations are proportional at all points across the machine, in which case, a single point measurement will be representative. Valve control is coordinated with the scanning of the moisture gauge 100 in a manner similar to that described above in connection with FIG. 6 to insure that moisture control is exerted on the zone being measured. Of course, simultaneous valve operation is an alternative mode of operation as in the case of bone dry basis weight control.

Concomitant bone dry basis weight control may be employed by positioning a fiber content measuring gauge 104 after the dryer 24. Little, if any, moisture compensation of the gauge 104 is required when it is located adjacent to the dried sheet. A bone dry basis weight modulator 108 utilizes the output signal from the gauge 104 and control system 106 to vary the stock consistency of the flow exiting the lip 20. Of course, the suppression methods of weight modulation described hereinabove also may be employed with substantially equal utility.

A coarse adjustment of bone dry basis weight may be provided by slice control unit 110 energizing a motor 112 mechanically coupled to the slice member 90 (see the Alexander patent, supra). This alternative is desirable should a correction be called for that may be beyond the capability of the hydraulic modulator 108. It may be apparent that any adjustment of either the slice member 90 or the flow consistency may alter the moisture content of the sheet 14 as well as the dry fiber weight per unit area. Therefore, the cooperation of the two variable control systems, viz. bone dry basis weight and moisture, is evident and both are required for the most economical return derivable from profile leveling.

Our system for measuring and controlling the dry weight and moisture simultaneously may be provided for other processes and by equipment other than that disclosed hereinabove. For example, dry weight may be controlled by a slice adjustment alone or by regulation of a stock dilution valve located upstream from the headbox. Product moisture content may be controlled by spraying water directly on the product in varying amounts or by regulating the humidity of the environment in which the product is produced.

SUMMARY

The present invention provides a new method of papermaking whereby the bone dry basis weight and moisture of the sheet product are automatically regulated to reduce significantly the amount of undesirable footage product and to permit control within narrow limits. This results from the use of fast-acting hydraulic actuators modulating the flow of fiber stock as it is deposited onto the forming member, whether it be a wire, cylinder or other type. In addition, the present invention also provides a moisture profile control system to correct for the non-linear drying rates prevailing in different lateral regions of the dryer section. Simultaneous measurement and control of both the moisture and the fiber weight is another important feature of our invention.

Although certain specific embodiments of the invention have been shown and described herein, many modifications may be made thereto without departing from the true spirit and scope of the invention as set forth in the appended claims.

I claim:

1. A method of controlling the formation of a fibrous sheet product derived in response to a fibrous slurry emerging from a headbox outlet and being fed to a drying wire, said slurry having a bottom, horizontal surface as it emerges from the outlet, said headbox having a floor, comprising feeding a liquid dilute relative to the slurry along the floor into substantial contact with the bottom surface of the slurry so that the slurry as it emerges from the outlet and while it is on at least a portion of the wire is bounded on said surface by the dilute liquid, measuring a parameter of the product affected by the dilute liquid, deriving an error indication for the parameter in response to the measured value and a target value, and controlling flow of the dilute liquid in response to the error indication.

2. The method of claim 1 further including the steps of measuring the moisture content of the formed sheet product and controlling the flow of the dilute liquid to the upper surface of the slurry in response to the measured moisture content to maintain a substantially predetermined moisture content in the formed sheet product.

3. The method of claim 1 further including the steps of measuring the fiber content of the formed sheet product, and controlling the flow of the dilute liquid to the lower surface of the slurry in response to the fiber content measurement to maintain the fiber content substantially at a predetermined value.

4. The method of claim 1 wherein the slurry has an upper surface as it emerges from the outlet and further including the steps of measuring the moisture and fiber content of the formed sheet product, and controlling the flow of the dilute liquid to the upper and lower surfaces of the slurry in response to the moisture and fiber content measurements, respectively, so that the formed sheet product has a predetermined moisture and fiber content.

5. A method of controlling the formation of a fibrous sheet product derived in response to a fibrous slurry emerging from a headbox outlet, the headbox having a floor and including a deflocculating roller for slurry flowing to the outlet, comprising modulating the flow of local slurry to said outlet by feeding a liquid dilute relative to the slurry along the headbox floor into contact with the slurry at a location immediately upstream of the outlet and downstream of the roller to control the amount of fiber passing through the outlet, said flow being modulated by bringing said dilute liquid into substantial contact with only the bottom surface of the slurry, directing said dilute liquid toward the slice to control the mass flow rate of the slurry through said outlet, measuring a parameter of the product affected by the dilute liquid, deriving an error indication for the parameter in response to the measured value and a target value, and controlling flow modulation in response to the error indication.

6. A method of controlling th formation of a fibrous sheet product derived in response to a fibrous slurry emerging from a headbox slice opening, the headbox having a deflocculating roller feeding slurry to the opening,

comprising modulating the flow of local slurry to said slice opening by feeding a liquid dilute relative to the slurry into contact with the slurry at a location immediately upstream of the opening and downstream of the roller to control the amount of fiber per unit volume of liquid passing through the slice opening, measuring the dry weight of the sheet product, deriving an error indication between a target value for dry weight and measured dry weight, and controlling the flow of the dilute liquid in response to the dry weight error indication to achieve a desired sheet fiber content.

7. The method of claim **6** wherein said slurry has a lower, horizontal boundry layer and said flow is modulated by varying the mass flow rate of slurry passing through the slice by bringing said dilute liquid into substantial contact with only said boundry layer of the slurry and directing said dilute liquid towards the slice.

8. The method of claim **6** wherein said slurry has a lower horizontal boundry layer and said flow is modulated by varying the mass flow rate of slurry passing through the slice by bringing said dilute liquid into substantial contact with only a surface of the slurry and directing said dilute liquid towards the slice, said measuring step including deriving a measurement of the dry weight in each of a plurality of zones across the width of the sheet, said error deriving step including deriving an error indication between a target value and measured dry weight in each of the zones, and said modulating step including responding to the error indication in each of the zones to control an actuator for the dilute liquid in each of a plurality of cross-sheet regions corresponding with the cross-sheet zones to achieve a desired sheet dry weight in each of the regions.

9. The method of claim **6** wherein the modulating step includes varying the consistency of the slurry passing through the slice by commingling the dilute liquid with the slurry.

10. The method of claim **6** wherein the modulating step includes varying the consistency of the slurry passing through the slice by commingling the dilute liquid with the slurry, said measuring step including deriving a measurement of the dry weight in each of a plurality of zones across the width of the sheet, said error deriving step including deriving an error indication between a target value and measured dry weight in each of the zones, and said modulating step including responding to the error indication in each of the zones to control an actuator for the dilute liquid in each of a plurality of cross-sheet regions corresponding with the cross-sheet zones to achieve the target dry weight in each of the zones.

11. The method of claim **6** wherein said measuring step includes deriving a measurement of the dry weight in each of a plurality of zones across the width of the sheet, said error deriving step including deriving an error indication between a target value and measured dry weight in each of the zones, and said modulating step includes responding to the error indication in each of the zones to control an actuator for the dilute liquid in each of a plurality of cross-sheet regons corresponding with the cross-sheet zones to achieve the target dry weight in each of the zones.

12. The method of controlling the moisture content of a paper sheet formed by depositing a slurry of fiber stock flowing through an aperture of a headbox onto a moving forming member, said headbox including a deflocculating roller comprising the steps of: measuring the moisture content of said formed sheet, responding to the measured moisture content and a moisture target value to derive a moisture error indication, and injecting a flow of a liquid dilute relative to the slurry between the roller and aperture into contact with the upper surface of said slurry while the slurry is within the headbox, and controlling the flow rate of the dilute liquid in response to the moisture error indication to maintain the measured moisture content of said sheet at the target value.

13. The method of claim **12** which further includes the step of selectively controlling said liquid flow at each of several regions across said aperture to provide a sheet having a predetermined moisture profile characteristic.

14. The method of controlling the uniformity of a paper sheet formed by depositing fiber stock flowing through an aperture onto a moving forming member, said stock flowing through the aperture having an upper surface, comprising the steps of:

measuring the moisture content of the sheet, responding to measure moisture content and a moisture target value to derive a moisture error indication, controlling the injection flow of a dilute liquid adjacent the upper surface of said fiber stock flow prior to the formation of the sheet in response to the moisture error indication to maintain the moisture content of said sheet at the moisture target value,

measuring the bone dry basis weight of the sheet, responding to measured bone dry basis weight and a bone dry basis weight target value to derive a bone dry basis weight error indication, and controlling the mixing of a liquid with said stock flow in response to the bone dry basis weight error indication to maintain the consistency of said deposited fiber stock at the bone dry basis weight target.

15. Control apparatus for a papermaking machine, comprising:

a headbox for storing fiber stock and including a slice lip opening for delivering a local flow of said stock onto a moving sheet-forming wire and a roll rotatably mounted in the path of said stock flowing toward said lip opening to prevent flocculation of said fiber stock,

a dryer section having a non-linear cross-sheet drying characteristic whereby certain cross-sheet zones of said sheet are dried to a greater extent than others, and

a plurality of means positioned across said lip opening and between said lip opening and said rotatable roll for modulating the moisture content of said stock exiting said lip opening in each of said zones, comprising:

separate means for each of said zones feeding a source of dilute stock of controllable amounts on to different cross-sheet zones of the upper surface of said stock flow to change the moisture content of said sheet in each of said zones, and

means for controlling each of said modulating means to provide a sheet having a moisture profile characteristic inversely related to the cross-sheet drying characteristic of said dryer section to provide a dried sheet having a uniform moisture profile.

16. Control apparatus as set forth in claim **15** which further includes means for simultaneously hydrodynamically controlling the local flow of said fiber stock to provide a sheet having a uniform bone dry basis weight.

17. Control apparatus as set forth in claim **15** which further includes gauge means for measuring the moisture content of said sheet to generate a control signal for said controlling means.

18. Control apparatus for a papermaking machine including a headbox for storing a slurry of fiber stock and including aperture means for delivering a local flow of said slurry onto a moving sheet-forming wire and a roll rotatably mounted in the path of said slurry flowing toward said aperture means to prevent flocculation of said fiber stock, said slurry having an upper surface while in the headbox, a dryer section having a nonlinear cross-sheet drying characteristic whereby certain cross-sheet zones of said sheet are dried to a greater extent than others, the improvement comprising:

means positioned between said roll and aperture means for feeding a liquid dilute relative to the slurry onto the upper surface of the slurry to control the moisture content across said sheet to provide said sheet entering said dryer section with a moisture profile characteristic inversely related to said cross-sheet drying characteristic of said dryer section, said liquid feeding means including different actuators for the different cross-sheet zones, and

means controlling said actuators to enable the inverse moisture profile to be attained.

19. Control apparatus for a papermaking machine, comprising:

a headbox for storing fibrous stock including a slice lip opening for delivering a local flow of said stock onto a moving sheet-forming wire at least as wide as said slice lip opening and a rotatable member positioned in the path of said stock flowing to said slice lip opening to prevent flocculation of said slurry fibers,

a plurality of stock flow modulating means positioned between said slice lip opening and said rotatable member and spaced across the width of said opening to vary the consistency of said stock flow at each of several local regions, said modulating means including:

a source of diluted stock and

means for mixing a controllable proportion of said diluted stock with said local flow of fibrous stock.

gauge means scanning across said sheet formed by said wire to provide a control signal indicative of the variations in the dry weight of said sheet in each cross-sheet zone corresponding to one of said local stock flow regions, and

control means responsive to said control signal for actuating each of said valve means to vary the fiber content per unit area of said scanned cross-sheet zone.

20. In an apparatus for controlling the formation of a fibrous sheet product, a headbox feeding a slurry of fibrous material to a slice opening, said headbox having a floor and including a deflocculating roller for slurry flowing to the outlet, means within the headbox immediately upstream of the outlet and downstream of the roller for modulating the flow of local slurry to said slice opening to control the consistency of fiber in liquid passing through the slice opening, and a wire downstream of the outlet for receiving the slurry emerging from the outlet for enabling liquid to be removed from the emerging slurry, the slurry emerging from the outlet and received by the wire having a bottom surface, said modulating means including means for feeding a liquid dilute relative to the slurry along the floor into substantial contact with the bottom surface of the slurry emerging from the outlet so that the slurry fed to the wire is bounded on said surface by said dilute liquid, means for measuring a parameter of the formed sheet product affected by the dilute liquid, means responsive to said measuring means to a target value for the parameter for deriving an error signal and means responsive to the error signal for controlling the flow of the dilute liquid onto said surface to control the sheet parameter.

21. The apparatus of claim 20 further including means for measuring the moisture content of the formed sheet product and means responsive to said measuring means for controlling the flow of the dilute liquid to the upper surface of the slurry.

22. The apparatus of claim 21 wherein a dryer is positioned downstream of said wire, and said measuring means is positioned upstream of the dryer.

23. The apparatus of claim 20 further including means for measuring the moisture and fiber content of the formed sheet product, and means responsive to the measured moisture and fiber content for controlling the flow of the dilute liquid to the upper and lower surfaces, respectively, of the slurry.

24. In an apparatus for controlling the formation of a fibrous sheet product, a headbox feeding a slurry of fibrous material to a slice opening, said headbox having a deflocculating roller, means within the headbox immediately upstream of the slice and downstream of the roller for modulating the flow of local slurry to said slice opening to control the amount of fiber per unit volume of slurry passing through the opening, said modulating means including means for feeding a liquid dilute relative to the slurry into contact with the slurry, means for measuring the bone dry basis weight of the sheet product, means responsive to the bone dry basis weight measuring means and to a target value for bone dry basis weight of the sheet product for deriving a bone dry basis weight error signal, and actuator means responsive to the bone dry basis weight for controlling the flow of the dilute liquid to the modulating means.

25. The apparatus of claim 24 wherein said slurry has a bottom surface and said modulating means includes means for varying the mass flow rate of slurry passing through the slice by bringing said dilute liquid into substantial contact with only the bottom surface of the slurry and for directing said dilute liquid towards the slice opening.

26. The apparatus of claim 24 wherein said modulating means includes means for varying the mass flow rate of slurry passing through the slice by bringing said dilute liquid into substantial contact with only a surface of the slurry and for directing said dilute liquid towards the slice opening, said measuring means including means for deriving a measurement of the bone dry basis weight in each of a plurality of zones across the width of the sheet, and said modulating means being responsive to an error signal for each of the zones derived in response to the measurement in each of the zones and a target value to vary the bone dry basis weight in each of a plurality of cross-sheet regions corresponding with the cross-sheet zones.

27. The apparatus of claim 24 wherein said modulating means includes means for commingling the dilute liquid with the slurry to control the fiber consistency of the slurry passing through the slice.

28. The apparatus of claim 24 wherein said modulating means includes means for varying the mass flow rate of slurry passing through the slice by bringing said dilute liquid into substantial contact with only a surface of the slurry and for directing said dilute liquid towards the slice opening, said measuring means including means for deriving a measurement of the bone dry basis weight in each of a plurality of zones across the width of the sheet, and said modulating means being responsive to an error signal for each of the zones derived in response to the measurement in each of the zones and a target value to vary the bone dry basis weight in each of a plurality of cross-sheet regions corresponding with the cross-sheet zones.

29. The apparatus of claim 24 wherein said measuring means includes means for deriving a measurement of the bone dry basis weight in each of a plurality of zones across the width of the sheet, and said modulating means being responsive to an error signal for each of the zones derived in response to the measurement in each of the zones to vary the bone dry basis weight in each of a plurality of cross-sheet regions corresponding with the cross-sheet zones.

30. In an apparatus for controlling the formation of a fibrous sheet product, a headbox having a deflocculating roller feeding a slurry of fibrous material to an outlet of the headbox, said headbox having a floor, said slurry having a bottom surface, and means within the headbox immediately upstream of the outlet and downstream of the roller for modulating the flow of local slurry to said outlet to control the amount of fiber passing through the outlet, said modulating means including conduit means having an orifice for feeding a liquid dilute relative to the

slurry along the headbox floor into contact with the slurry, said modulating means further including means for bringing said dilute liquid into substantial contact with only the bottom surface of the slurry and for directing said dilute liquid towards the outlet to control the mass flow rate of the slurry passing through the outlet, gauge means for sensing the dry weight of the sheet, means responsive to said gauge means and a target value for dry weight for deriving a dry weight error signal, and means controlling said modulating means in response to the error signal.

31. Control apparatus for a fibrous product manufacturing machine including a headbox for storing fibrous stock and having flow aperture means providing for a flow of said fibrous stock onto a product forming wire, said stock flowing through the aperture having an upper surface, said apparatus comprising:

gauge means positioned adjacent and responsive to the moisture content and basis weight of said formed product to provide a first signal indicative of the moisture content of said formed product and a second signal indicative of the bone dry weight of said formed product, means responsive to said first signal and a target value for moisture content for deriving a moisture error signal,

means responsive to said second signal and a target value for bone dry weight for deriving a bone dry basis weight error signal,

means responsive to said moisture error signal for injecting water onto the upper surface of said fibrous stock flowing to said wire to control the moisture content of said formed product so that it is substantially equal to the moisture target value, and

means responsive to said bone dry basis weight error signal for modulating the local flow of said fiber stock in the region of said aperture to control the bone dry basis weight of said formed product so that it is substantially equal to the bone dry basis weight target value.

32. Control apparatus for papermaking machine including a headbox for storing fibrous stock and having an aperture from which said stock flows onto a moving wire to form a sheet, said apparatus comprising:

first gauge means positioned adjacent said formed sheet to provide a measurement signal proportional to the moisture content of said formed sheet,

second gauge means positioned adjacent to said formed sheet to provide a measurement signal proportional to the dry weight per unit area of said formed sheet, first controller means responsive to said moisture measurement signal and a target value for sheet moisture for deriving a moisture error signal, first actuator means responsive to said moisture error signal for depositing a layer of dilute stock of controllable thickness on the upper surface of said stock flow in the region of said aperture to control the moisture content of said sheet approximately to the moisture target value,

second controller means responsive to said dry weight per unit area measurement signal and a target value for sheet dry weight per unit area for deriving a dry weight error signal, and second actuator means responsive to said dry weight error signal for varying the consistency of said stock in the region of said aperture to control the fiber content of said formed sheet so that the sheet has approximately the bone dry basis weight target value.

33. Control apparatus for a fibrous product manufacturing machine including a headbox for storing fibrous stock and having an aperture from which said stock flows onto a moving wire to form a sheet, said apparatus comprising:

gauge means positioned adjacent said formed sheet to provide a measurement signal indicative of the dry weight per unit area thereof,

means responsive to said gauge means and a target value for dry weight per unit area of the sheet to derive a dry weight error signal,

actuator means responsive to said dry weight error signal for modulating the local flow of said fiber stock to said aperture to provide a sheet of uniform dry weight per unit area equal approximately to the target value,

means for scanning said gauge laterally across said sheet to measure the dry weight per unit area thereof in each of several discrete zones across the width of said web whereby a bone dry basis weight error signal for each of the zones is derived,

said modulating actuator means including:

a plurality of means spaced across the width of said sheet for varying the consistency of said stock delivered to said aperture at each of a plurality of cross-sheet regions corresponding to one of said discrete cross-sheet zones, and

means responsive to the error signal for each zone for actuating each of said stock consistency varying means according to the measured dry weight of said scanned zone and a target value for each zone to provide a sheet having a uniform dry weight per unit area.

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