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(54) PROCEDURE AND SYSTEM FOR CONTROL OF A REFINER TO IMPROVE ENERGY EFFICIENCY AND PULP QUALITY

VERFAHREN UND SYSTEM ZUR STEUERUNG EINES REFINERS IN RICHTUNG VERBESSERTER ENERGIEEFFIZIENZ UND STOFFQUALITÄT

PROCÉDURE ET SYSTÈME DE COMMANDE D'UN RAFFINEUR AFIN D'AMÉLIORER LE RENDEMENT EN ÉNERGIE ET LA QUALITÉ DE PÂTE

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Description

TECHNICAL FIELD.

[0001] The invention relates to an improved method for controlling one or more refiners in a process section for thermo-mechanical pulp (TMP) refining. The present invention is applicable in all technical areas where refiners are used, such as pulp and paper industry as well as related industries.

TECHNICAL BACKGROUND

[0002] Refiners of one sort or another play a central role in the production of high yield pulp for the pulp and paper industry and related industries through grinding, for example, thermo-mechanical pulp (TMP) or chemical thermo-mechanical pulp (CTMP) starting from lignin-cellulose material such as wood chips. Two types of refiners are important to mention here; low consistency (LC) refining where the pulp is refined at about 4 per cent consistency (dry content), and high consistency (HC) refining where the consistency is commonly about 40 per cent. LC refining is done in a two-phase system chips/pulp and water, while HC refining has three phases; chips/pulp, water and steam. Refiners are also used in other industrial applications, such as for example manufacturing of wood fiber board.

[0003] Most refiners consist of two circular plates, in between which the material to be treated passes from the inner part to the periphery of the plates. Usually there is one static refiner plate and one rotating refiner plate, rotating at a very high speed.

[0004] A more complete schematic illustration of a known refiner 1 is given in Figure 4. The raw material which may consist of wood chips 5 or already treated pulp for a previous stage enters at the center C of the refiner. In a first stage refiner as the one illustrated in the figure, the material is transported via one or more screw feeders 7. Before entering the actual refiner the raw material is normally mixed with dilution water 2 whose flow is usually measured and controlled.

Alternatively water may be added directly in the refiner. The material is then treated on its way to the periphery of the refiner plates. The static refiner plate 3, or stator, is usually pushed towards the rotating one 4, or rotor, either electro-mechanically or hydraulically. The rotating disc or discs are driven by one or two motors 10. The grinding zone or as it is often called the refining zone may also have a variable gap along the radius dependent on the design of the plates. The figure also shows the outlet position 6 where the pressure P_{outlet} is measured, and the point where production inlet pressure P_{inlet} 8 may be measured.

[0005] The diameter of the refiner plates differ dependent on size (production capacity) of the refiner and brand. Originally the plates (also called segments) were cast in one piece, but nowadays they usually consist of a number of modules that are mounted together on the stator or rotor. These segments have grinding patterns, see Figure 5, with bars 15, 15' and troughs 16 that differ dependent on supplier. The bars act as knives that defibrillate chips or further refine the already produced pulp. In an HC refiner, fibers, water and steam is also transported in the troughs between the bars. The amount of steam is spatially dependent, why both water and steam may exist together with chips/pulp in the refining zone. In an HC refiner water will normally be bound to the fibres. Dependent on the segment design different flow patterns will occur in the refiner. In an LC refiner no steam is generated.

[0006] There are also other types of refiners such as double disc, where both plates rotate counter to each other, or conic refiners. Yet another type are called twin refiners, where there are four refiner plates. A centrally placed rotor has two refiner plates mounted one on either side, and then there are two static refiner plates that are pushed against each other using, for example, hydraulic cylinders thus creating two refining zones.

[0007] When refining wood chips or previously refined pulp the refiner plates are typically pushed against each other to obtain a plate gap of approximately 0.2-0.7 mm dependent on what type of refiner is used.

[0008] In traditional control concepts for refiner control the controlled variables consist of the specific energy (i.e. the ratio between the refiner motor load and the pulp production), alternatively just the motor load, the pulp consistency out of the refiner, and best case also at least one variable describing the quality of the pulp (e.g. Canadian Standard Freeness, CSF). To control these process variables there are typically manipulated variables such as hydraulic pressure, dilution water flow, and wood chips or pulp production. Moreover, a typical refiner line consists of two refiners in series; a primary refiner (PR) and a secondary refiner (SR). Often there is also a processing step called reject refining.

[0009] Therefore control of a complete refiner line often becomes quite complex. Examples of commercially available control concepts may be found in the Licentiate thesis by Lidén [1] and in the patent application US-A-2005/263259 (WO-A-2005/106114) [2]. These control concepts based on Model Predictive Control (MPC) using the controlled variables described above, are used for large complex systems consisting of multiple refiner lines but also single lines or single refiners.

[0010] An alternative control variable central in, for example, [2] is the plate gap, which is then controlled by manipulating the hydraulic pressure P_{hydr} . Today there are plate gap sensors on the market which are applied directly in the refiner plates. Usually only one gap sensor is used per refining zone, primarily to avoid the plates clashing together, and thus

not to control the gap since they are not reliable enough.

[0011] There are also other systems on the market where the temperature and/or pressure are measured along the refining zone for the purpose of visualizing a temperature profile, and/or a pressure profile. When circumstances in the refiner are varied, for example gap, production or dilution water the temperature changes and can thus be controlled. Usually several temperature and/or pressure sensors are used placed directly in the plate or may be encapsulated in a measurement strip, also called sensor array, along the active radius of the refiner, see EP0788407[3].

[0012] In US6024309[4] a control concept is described for refining zone control where the temperature profile is used for controlling the process. Similar subsequent patents, for example US6314381 [5], which treats the same concept is also using the temperature profile to control refiners.

[0013] The design of the refiners segments have proven very important for the shape of the temperature profile along the radius, and it is crucial to take this into account when placing the temperature and/or pressure sensors in the sensor array.

[0014] There are no other measurement devices that have been applied in the refining zone, other than the ones mentioned above. There are, however, instruments which may be placed in the blowline of the refiner, where the consistency of the flowing pulp can be calculated using algorithms coupled to NIR (near infra red) measurements, which are assumed available in, for example, US 7,381,303 [2].

[0015] In US 7,381,303 entitled "System and Method for Controlling a Thermo-Mechanical Wood Pulp Refiner", assigned to Honeywell Inc, a system is described where separate controllers are used for the fast dynamics (motor load and blow line consistency) and the slow dynamics (pulp quality) respectively, with an optimizing coordinating control on top. It is described that a stabilizing controller preferably regulates the refiner motor loads and the blow-line consistencies, and that a Quality controller preferably controls the slow dynamics associated with pulp quality variable. It is also described that by operating the refiner lines at the maximum allowable motor loads the production is automatically maximized for a given pulp window.

[0016] However, it has become clear to the inventors that controlling the refining process based on measurements of specific energy as represented by motor load does not provide reliable control over pulp quality parameters because different pulp qualities can be produced at the same specific energy or motor load.

SUMMARY OF THE INVENTION

[0017] The aim of the present invention is to remedy one or more of the above mentioned problems. In a first aspect of the invention, this and other aims are obtained by a method according to claim 1.

[0018] In the first aspect of the invention a method is described for controlling a process section for thermo-mechanical pulp (TMP) refining, which comprises the features of claim 1.

[0019] According to an embodiment of the invention a method is described for controlling a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner for the process section and measuring, alternatively estimating, one or more values representing one or more internal states inside said at least one first refiner, and the possibility to manipulate one or more variables by means of a mathematical process model, and wherein a change is calculated for said at least one manipulated variable for said at least one refiner using a mathematical process model which is described by a set of nonlinear differential equations or difference equations with a vector valued non linear function.

[0020] According to another embodiment of the invention a method is described for controlling a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner for the process section and measuring, alternatively estimating, one or more values representing one or more internal states inside said at least one first refiner, and the possibility to manipulate one or more variables using a mathematical process model, wherein the mathematical process model is described by a set of linear differential equations or difference equations.

[0021] According to another embodiment of the invention a method is described for controlling a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner for the process section and measuring, alternatively estimating, one or more values representing one or more internal states inside said at least one first refiner, and the possibility to manipulate one or more variables using a mathematical process model, wherein the mathematical process model is described by Laplace transforms and transfer functions.

[0022] According to another embodiment of the invention a method is described for controlling a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors

arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner for the process section and measuring, alternatively estimating, one or more values representing one or more internal states inside said at least one first refiner, and the possibility to manipulate one or more variables using a mathematical process model, by calculating a process change using a measurement in which said internal state is temperature which is calculated using an array of temperature measurements along the radius of a disc inside said at least one refiner.

[0023] According to another embodiment of the invention a method is described for controlling a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner for the process section and measuring, alternatively estimating, one or more values representing one or more internal states inside said at least one first refiner, and the possibility to manipulate one or more variables using a mathematical process model, by calculating a process change and changing at least one manipulated variable to affect a change in a measure or estimate of pulp quality.

[0024] According to another embodiment of the invention a method is described for controlling a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner for the process section and measuring, alternatively estimating, one or more values representing one or more internal states inside said at least one first refiner, and the possibility to manipulate one or more variables using a mathematical process model, by using the mathematical process model to minimize the deviation between reference values and measured values, or functions, of internal and/or external states.

[0025] According to another embodiment of the invention a method is described for controlling a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner for the process section and measuring, alternatively estimating, one or more values representing one or more internal states inside said at least one first refiner, and the possibility to manipulate one or more variables using a mathematical process model, by using the mathematical process model to minimize the deviation between reference values and estimated values of internal and/or external states.

[0026] According to another embodiment of the invention a method is described for controlling a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner for the process section and measuring, alternatively estimating, one or more values representing one or more internal states inside said at least one first refiner, and the possibility to manipulate one or more variables using a mathematical process model, and by feeding the output from said at least one first refiner into a second refiner such that said process section comprises a two stage refiner.

[0027] According to another embodiment of the invention a method is described for controlling a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner for the process section and measuring, alternatively estimating, one or more values representing one or more internal states inside said at least one first refiner, and the possibility to manipulate one or more variables using a mathematical process model, by calculating a process change for at least one manipulated variable for the second refiner using said measurement of an internal state of the second refiner and a measurement of said one or more external states for said process section by means of a mathematical model.

[0028] According to another embodiment of the invention a method is described for controlling a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner for the process section and measuring, alternatively estimating, one or more values representing one or more internal states inside said at least one first refiner, and the possibility to manipulate one or more variables using a mathematical process model, by calculating a process change for at least one manipulated variable of a process section comprising two or more refiners using said at least one measurement of an internal state for each refiner and a measurement of an external state for each refiner and at least a quality measurement after the second refiner.

[0029] According to another embodiment of the invention a method is described for controlling a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors

arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner for the process section and measuring, alternatively estimating, one or more values representing one or more internal states inside said at least one first refiner, and the possibility to manipulate one or more variables using a mathematical process model, by calculating a process change for at least one manipulated variable of a process section comprising two or more refiners using said measurement of an internal state for each refiner and a measurement of an external state for each refiner and a quality measurement of the second refiner in order to optimize energy input to said process section.

[0030] According to another embodiment of the invention a method is described for controlling a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner for the process section and measuring, alternatively estimating, one or more values representing one or more internal states inside said at least one first refiner, and the possibility to manipulate one or more variables using a mathematical process model, by calculating a process change using a measurement in which said internal state is pressure (P_1) which is calculated using an array of measurements along the radius of a disc inside said at least one refiner.

[0031] In another aspect of the present invention, a **system** is described including a process section for thermo-mechanical pulp (TMP) refining, which comprises the features of claim 16.

[0032] According to another embodiment of the invention, a system is described including a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring one or more process variables for said process section and measuring one or more internal states in said at least one first refiner wherein the system further comprises apparatus for applying a process change calculated on at least one manipulated variable for said at least one refiner using said measurement or estimate of an internal state of said at least one refiner and a measurement of said one or more process variables for said process section by means of a mathematical model to control said at least one first refiner wherein one or more of said plurality of sensors are arranged on an active radius of a beating disc of a refiner in said process section.

[0033] According to another embodiment of the invention, a system is described including a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring one or more process variables for said process section and measuring one or more internal states in said at least one first refiner wherein the system further comprises apparatus for applying a process change calculated on at least one manipulated variable for said at least one refiner using said measurement or estimate of an internal state of said at least one refiner and a measurement of said one or more process variables for said process section by means of a mathematical model to control said at least one first refiner wherein said process section comprises two or more refiners which are arranged connected in series, alternatively in parallel.

[0034] According to another embodiment of the invention, a system is described including a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring one or more process variables for said process section and measuring one or more internal states in said at least one first refiner wherein the system further comprises apparatus for applying a process change calculated on at least one manipulated variable for said at least one refiner using said measurement or estimate of an internal state of said at least one refiner and a measurement of said one or more process variables for said process section by means of a mathematical model to control said at least one first refiner wherein the system further comprises one or more control units arranged as a control optimiser.

[0035] According to another embodiment of the invention, a system is described including a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring one or more process variables for said process section and measuring one or more internal states in said at least one first refiner wherein the system further comprises apparatus for applying a process change calculated on at least one manipulated variable for said at least one refiner using said measurement or estimate of an internal state of said at least one refiner and a measurement of said one or more process variables for said process section by means of a mathematical model to control said at least one first refiner wherein the system further comprises one or more control units arranged as a state estimator.

[0036] According to another embodiment of the invention, a system is described including a process section for thermo-mechanical pulp refining, the process section comprising at least one first refiner having a plurality of sensors arranged in a predetermined position on a refiner plate of said at least one first refiner, the method comprising measuring one or more process variables for said process section and measuring one or more internal states in said at least one first refiner wherein the system further comprises apparatus for applying a process change calculated on at least one ma-

nipulated variable for said at least one refiner using said measurement or estimate of an internal state of said at least one refiner and a measurement of said one or more process variables for said process section by means of a mathematical model to control said at least one first refiner wherein the system further comprises a memory storage device in which are stored one or more computer programs according to claim 15.

[0037] The aim with all refiner control systems is to secure the pulp quality at a specified energy input to the refiners. The problem, however, is that existing control systems on the market are slow which results in difficulties to guarantee a specific pulp quality to a minimum energy input demand.

[0038] Traditionally, process control systems for refiners have no information from the true refining process, i.e. the process which occurs in the refining zone and the process descriptions are normally based on outputs to be controlled such as, specific energy E or the motor load M and if available also the measured consistency C in the blowline. These outputs are normally manipulated by changing e.g. the plate gap (controlled by the applied hydraulic pressure P_{hydr} which results in a force on the plates or e.g. a electro-mechanically based force on the plates) and the dilution water flow F_D to the refiners as described by

$$Y = \begin{bmatrix} E \\ C \end{bmatrix} = GU = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \begin{bmatrix} P_{hydr} \\ F_D \end{bmatrix}$$

where Y represents the vector to be controlled and G a transfer function matrix which describes the process dynamics by the elements g_{ij} . The vector U describes an input vector with variables possible to manipulate.

[0039] The drawback with traditional control systems, such as US 7,381,303 [2] which is based on the above type of system description, is that the specific energy or the motor load are affected by a number of process variables besides the two mentioned above which makes it difficult to pre-specify an optimal operating window where to run the refiners.

[0040] Another problem with this structure is that the specific energy or the motor load will always be related to the integral of the force distribution along the radius in the refining zone and it will not give any information about the spatial energy consumption. It is clear, from this aspect alone, that the specific energy or motor load provides limited information about how the local process conditions affect the final pulp quality which is essential to get a good control performance.

[0041] Additional problems exist but one to be mentioned here is that traditional control systems do not handle natural non-linearities caused by e.g. plate wear, fluctuations in fiber pad distribution, different operating points et cetera which also reduce the control performance. As a consequence, the controllability in traditional control concepts as described above is possible to improve from a pulp quality perspective as different qualities can be produced at the same specific energy or motor load.

THE SOLUTION

[0042] In this invention the internal states, ζ , i.e. information (estimated or measured) directly from the refining zone plays a vital role to describe how to find improved strategies for process control. To distinguish the internal states from other states we introduce the external states, η , as states obtained from measurement devices outside the refiners or estimated from mathematical models. These states are normally possible to sample relatively fast but still at a slower sampling rate compared with the internal states. Other external states, Q , typically representing measured pulp quality that may only be sampled at a much slower sampling rate, will be important to follow as well. All states which can be controlled are elements in the state vector x , i.e.

$$x = \begin{bmatrix} \zeta \\ \eta \\ Q \end{bmatrix}$$

and with this terminology a clear distinction between traditional control concepts and this invention, with a new process optimization approach, can be described. Notice, that each component of the state vector x may in turn be a vector.

[0043] The relationship between the input vector u_i and the state vector x_i may be described by a set of nonlinear differential equations characterized by a vector valued nonlinear function f_i :

$$\dot{x}_i(t) = f_i(x_i(t), u_i(t))$$

where i represents the refiner to be described.

[0044] Normally, the input vector can vary in size dependent on the type of refiner studied but could typically be represented by chip or pulp production flow, dilution water flow, and plate gap (or means to influence the plate gap such as hydraulic pressure or alternatively an electromechanic force). For some refiners also the inlet pressure in the pulp feeding system is possible to manipulate.

[0045] To describe this more concretely, typical internal states to be used in this invention can be described as e.g. temperature in the refining zone, pressure or force measurements in the refining zone or states estimated from physical or empirical models by using different software solvers. Examples of that is the predicted forces along the radius in the refining zone, estimated consistency in the zone, mean fiber residence time in different regions of the zone, plate gap, pulp quality from the refining zone et cetera. Pulp quality estimations can be valuable when comparing them with the measured pulp quality from the downstream analyzers. Hence, the variables can refer to a set of soft sensors (or estimates from the models) describing the hidden process variables in the refining zone. In this model e.g. temperature measurements can be used to get proper estimates of the energy balance which indirectly together with zone specific data give information normally difficult to measure directly, like the residence time, defibration/fibrillation work et cetera. The variables can also be referred to as estimates obtained from an algorithm which uses spatial refining zone measurements to find some optimum, like the position for the maximum temperature in the refining zone which can be controlled by e.g. P_{inlet} as described by Sikter [6].

[0046] Typical examples of external states, which may be measured relatively fast outside the refining zone but slower than the internal states, will be the blow-line consistency, pressure, motor load et cetera. Such external states can also be estimated by a mathematical model. Other typical external states, which are only possible to sample much more slowly are placed in the vector Q . Such states are naturally the pulp quality variables CSF, the mean fiber length and shives et cetera which are measured downstream the refiners. If pulp quality variables are estimated from ordinary system identification procedures, e.g. using ARMAX models, to be used as input to the feedback control, such estimated variables will be placed in the vector η as the sampling rate will be fast enough.

[0047] Note, external states like the motor load or combinations to get the specific energy (load/production) are not considered to be a part of the concept described by this invention which differs from traditional control concepts. The measured motor load in the optimization routines may be used as a constraint to the optimization.

[0048] Moreover, it is worth to mention that the vector u can be truncated to a smaller vector if necessary and/or extended if e.g. the plate gap can be measured accurately (as the hydraulic pressure P_{hydr} could be replaced) which of course affects the size of the matrix. In the matrix i , i.e. the number of refiners $i=\{1,2\}$ included, is not specified and provides many possible combinations and a selection of each structure will be refiner specific.

[0049] By distinguishing the internal and external states from each other the fast dynamics in the refining zone can be handled and controlled faster compared with traditional control concepts and the reason why internal states such as the refining zone temperature measurements give a good contribution to the optimization procedure as well as the pulp quality estimations is that local non-linearities, i.e. spatially dependent information not captured by the specific energy (or the motor load), can be handled. An example of such non-linearities is the different process conditions encountered before and after the temperature maximum in the refining zone. Earlier work has shown that the residence time of pulp material in these two parts of the refining zone will be dependent on a complex set of phenomena. In other words the internal states, such as the temperature measurements provide information indirectly of how the defibration/fibrillation is carried out in the refiner since it relates to the difficulties for the steam to evacuate from the refining zone.

[0050] Hence, from a mathematical point of view, the main variables to be controlled are obtained from the refining zone, i.e. not from the traditional concepts based on motor load or specific energy control. The essence will be that compared with the traditional concept soft sensors and measurements from the refining zone provide information which can be used almost momentarily. Of course, the consistency measured in the blow line can be used, if available, but the spatial consistency, which is available from the models, is to be preferred.

[0051] If a refiner line comprising two refiners is controlled a model for the whole line can be constructed by combining the individual refiner models. For example, neglecting the mixing effect of the blow-line and only taking the time-delay D_1 into account (which is typically in the order of 5-10 s) we have

$$\dot{x}_2(t) = f_2(x_1(t - D_1), x_2(t), u_2(t))$$

[0052] What is actually measured of course varies from installation to installation.

[0053] Normally we would in our application expect these measurements to just be a subset of the process states, but more generally a model equation describing the relationship between measurements and states may include a nonlinear function, i.e.

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$$y(t) = h(x(t), u(t))$$

[0054] In each iteration of the control, i.e. any time a new measurement is collected, two optimization problems have to be solved; one to estimate the state vector x and one to optimize the future control variables u . Then applying a receding control approach the control variables for the first time instant are sent to the process, and when at the next measurement instant optimizations are repeated.

[0055] The present invention describes a way, using among other things temperature and/or pressure measurements directly in the refining zone, to control and optimize process conditions in refiners to improve energy efficiency and pulp quality. The procedure means that the internal states, represented by temperature and/or pressure measurements, are primarily used to minimize the variations in pulp quality or energy consumption. Thanks to the availability of the internal states for use in the feedback system, the number of interaction elements can be minimized in the model based control.

[0056] The present invention presents the solution to the problems described, and concerns use of robust temperature and/or pressure measurements in combination with available measurement signals from the process together with a mathematical model to control both pulp quality and energy input to refiners much faster than what is the case today.

[0057] The principle advantage of the present invention is that thanks to measuring internal states such as temperature and/or pressure directly in the refining zone a faster control response may be produced of variables that better correlate to the final pulp quality than in traditional refiner control concepts. The present invention also provides a significant improvement over the prior art by introducing model based optimization involving internal states of the refiner. In an aspect of the invention the method:

a) involves the temperature (and possibly force) measurements in the refiner, but not necessarily the motor load. More importantly

b) it treats the whole two-stage refiner line as one (multi-rate) optimal control problem, which is described in more detail below.

[0058] A computer program, and a computer program recorded on a computer-readable medium is disclosed in another aspect of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0059] A more complete understanding of the method and system of the present invention may be had by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

Figure 1 shows a schematic block diagram of a method and system for controlling a TMP pulp refining process comprising a first refiner, according to an embodiment of the invention;

Figure 2 shows the invention according to Figure 1 in which the diagram also shows a process comprising two refiners, according to an embodiment of the invention;

Figure 3 shows a schematic flowchart of the invention according to Figure 1 or Figure 2 and in particular steps for carrying out a method according to an embodiment of the invention.

Prior Art

[0060] Figure 4 shows a schematic diagram for a known primary refiner, Figure 5 shows a known refiner grinding plate arranged with temperature or pressure sensors, and Figure 6 shows a known array of temperature sensors (or pressure sensors) arranged on a refiner plate.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0061] Figure 1 shows a schematic diagram for a method of controlling a TMP pulp refiner. The diagram shows a

process with a single refiner 33, and a first control unit 32. One or more setpoints 30 are input to the first control unit or control optimiser 32, or similar device with the same function. The first control unit, the control optimiser, is arranged to manipulate external process variables such as the hydraulic pressure P_{hydr} pressing together the refiner plates, flow of wood chips 5_{flow} , indicated as F_p and dilution water 2' indicated as F_D , as inputs to the process 33. Refined pulp is produced from the process 33. External variables 37 representing pulp consistency 37 from the process and quality Q from sampling unit 35 are input to a second control unit, a state estimator 39. Internal values 36 representing a temperature profile or a pressure profile from inside the refiner using a sensors as shown 21 in Fig 6, are fed to the state estimator 39. The state estimator calculates and sends 40 a state estimation $\hat{x}$ to the first control unit, the control optimiser 32. In the control optimiser the estimated state is used as a starting point to calculate the future trajectories of all state variables based on the process model. The setpoints are then compared with the model outputs to obtain a control error. This control error is minimised with the future changes of the manipulated variables as free variables in the optimisation.

[0062] For the primary refiner the manipulated input variables are summarized below in the vector u_1 ,

$$u_1 = \begin{bmatrix} F_p \\ F_D \\ P_{hydr} \end{bmatrix}$$

where F_p denotes the chip production flow, F_D the dilution water flow and P_{hydr} the hydraulic pressure applied on the refiner plates. Notice that there are other potential means to manipulate the force pressing the plates together, such as using electromechanic devices. When plate gap is measured a cascaded control structure is also an alternative, where the setpoint for the plate gap is considered as the manipulated variable in the control described in this invention. However, in the sequel P_{hydr} will be used as a variable to describe all such plate gap changes. For some types of refiners the inlet pressure P_{inlet} may also be available as manipulated variable.

[0063] Similarly the corresponding process state variables are given in x_1

$$x_1 = \begin{bmatrix} \xi_1 \\ T_1 \\ C_1 \\ Q_1 \end{bmatrix}$$

where ξ_1 is the force (or soft sensor of force) measured inside the refiner, T_1 an array of temperature measurements along the radius inside the refiner, C_1 the blow-line consistency and Q_1 a vector of pulp quality variables such as Canadian standard freeness CSF and mean fiber length MFL. An alternative to ξ_1 or T_1 is to use the pressure P_1 inside the refiner as a state variable.

[0064] The relationship between u_1 and x_1 may be described by a set of nonlinear differential equations characterized by a vector valued nonlinear function f_1 ;

$$\dot{x}_1(t) = f_1(x_1(t), u_1(t))$$

[0065] The main dynamics of the refiner are those for the actuation and sensing (more about sensing further below). Denoting the output from the controller by u_{1c} the following linear differential equations approximately describe the inputs to the refining zone

$$\dot{u}_1 = -u_1 + u_{1c}$$

[0066] The time constant τ is roughly equal for all inputs and typically in the order of 1-5 seconds.

[0067] Alternatively the relationship may be described by Laplace transforms and transfer functions as

$$U_1 = \frac{1}{s+1} U_{1c}$$

[0068] Figure 2 shows a schematic block diagram for a method of controlling a TMP pulp refiner line. The diagram shows a process with a first refiner 33, and a second refiner 34, which are preferably arranged as a primary and a secondary refiner. A first control unit or control optimiser 32 is supplied with one or more setpoints 30 to the first control unit or, or similar device with the same function. The first control unit, the control optimiser, is arranged to manipulate external process variables such as the hydraulic pressure P_{hydr} , pressing together the refiner plates, flow of wood chips S_{flow} , and dilution water 2' as inputs to the first refiner 33; and hydraulic pressure P_{hydr} and dilution water 2' to the secondary refiner. Pulp from the first refiner is led to the second refiner 34 through a blowline (not shown). Refined pulp P is produced from the secondary refiner 34. The refined pulp is sampled to measure one or more quality parameters Q. External variables 37 representing pulp consistency (C) from the primary refiner and quality 38 (Q) from sampling unit 35 are input to a second control unit, a state estimator 39. Internal values representing a temperature profile or a pressure profile from inside the refiner at T1 (primary) 36 and T2 (secondary) 36" using a sensors as shown 21 in Fig 6, are fed to the state estimator 39. The state estimator calculates and sends a state estimation $\hat{x}$ to the first control unit, the control optimiser 32. In the control optimiser the estimated state is used as a starting point to calculate the future trajectories of all state variables based on the process model. The setpoints are then compared with the model outputs to obtain a control error. This control error is minimised with the future changes of the manipulated variables as free variables in the optimisation.

[0069] Commonly two refiners are arranged together in a process, as described for example in relation to Figure 2 above. For the secondary refiner the manipulated variables are

$$u_2 = \begin{bmatrix} F_D \\ P_{hydr} \end{bmatrix}$$

which again are dynamically related to the controller output as

$$\dot{u}_2 = -u_2 + u_{2c}$$

[0070] Typical process state variables for the secondary refiner are

$$x_2 = \begin{bmatrix} \xi_2 \\ T_2 \\ C_2 \\ Q_2 \end{bmatrix}$$

[0071] Again an alternative state variable is the pressure P_2 inside the refiner.

[0072] If the blow-line between the primary and secondary refiners is considered static

$$\dot{x}_2(t) = f_2(x_1(t-D_1), x_2(t), u_2(t))$$

[0073] However, as indicated in the equation the blow-line itself introduces a time delay D_1 , typically in the order of 5-10 s.

[0074] A typical set of measurements can be

$$y = \begin{bmatrix} T_1 \\ T_2 \\ C_1 \\ Q_2 \end{bmatrix}$$

where T_1 and T_2 are the temperature measurements (possibly vector valued) in primary and secondary refiner, respectively, C_1 the measured blow-line consistency out of the primary refiner and Q_2 the pulp quality after the secondary refiner.

[0075] Here all signals may be measured every second except the final pulp quality Q_2 which is measured using a sampling analyzer equipment, typically needing 5 minutes per sample. Furthermore the same equipment may serve several measurement points why a sampling interval in practice often is 20-30 minutes. The measurement is often preceded by a latency chest, which then acts like an anti-aliasing filter.

[0076] The total model becomes a set of nonlinear Differential and Algebraic Equations (DAE), which are observed in a multi-rate sampled fashion

$$\dot{x}(t) = f(x(t), u(t))$$

$$y(t) = h(x(t), u(t))$$

where

$$u(t) = \begin{bmatrix} u_{1c} \\ u_{2c} \end{bmatrix}$$

and the state variable $x(t)$ is built up by $x_1(t)$ and $x_2(t)$ and possibly additional states to account for actuator and sensor dynamics.

[0077] In each iteration of the control, i.e. any time a new measurement is collected, two optimization problems have to be solved; one to estimate the state vector x and one to optimize the future control variables. Then applying a receding control approach the control variables for the first time instant are sent to the process, and when at the next measurement instant optimizations are repeated.

[0078] For the state estimation the optimization target is to the best estimate of all states of the refiner using the available measurements. This can be done using a Kalman filter [7] (or if the model is nonlinear extended Kalman filter) where a stochastic modelling of the process and measurement noises is deployed. Alternatively we may apply so-called moving horizon estimation [8]. Then the process and measurement noise are introduced using slack variables w and v in a discretized version of the model

$$x_{k+1} = g(x_k, u_k) + w_k$$

$$y_k = h(x_k, u_k) + v_k$$

where the integer k denotes the k :th signal value which is available at time $t = kT_s$, where T_s is the sampling interval, i.e. we have for example $x_k = x(kT_s)$.

[0079] Then moving horizon estimation corresponds to minimizing

$$\min(x_{k-M} - \hat{x}_{k-M})^T P^{-1} (x_{k-M} - \hat{x}_{k-M}) + \sum_{n=k-M}^k w_n^T R_1^{-1} w_n + v_n^T R_2^{-1} v_n$$

subject to, for example,

$$x_{\min} \leq x(k) \leq x_{\max}$$

[0080] Here P , R_1 and R_2 are weight matrices used for tuning of the estimator, which have a similar interpretation and importance as the estimate and noise covariance matrices in Kalman filtering.

[0081] As indicated this optimization is typically done over a horizon $[t - MT_s, t]$, if t is the current measurement time. Since this time interval is in the past we assume access to historic values of the applied manipulated variables u_k . The first penalty term in the criterion is to create a link from one optimization window to the next, where $\hat{x}_{k-M}$ denotes the estimate for this particular time instant from the optimization run at the previous cycle. What makes this problem non-standard, though, is that not all elements of y_k will be available at all sampling instants, creating a multi-rate state estimation problem. The state estimation produces a starting point for the optimization of future manipulated variables, where future setpoints r_k are compared with some subset or combination of the state variables $m(x_k)$ calculated by use of the mathematical process model. A formulation of the optimization objective may be, for example,

$$\min \sum_{k=0}^{N_y} (r_k - m(x_k))^T W_y (r_k - m(x_k)) + \sum_{k=0}^{N_u} \Delta u_k^T W_u \Delta u_k$$

subject to, for example,

$$x_{\min} \leq x_k \leq x_{\max}$$

$$u_{\min} \leq u_k \leq u_{\max}$$

$$\Delta u_{\min} \leq \Delta u_k \leq \Delta u_{\max}$$

[0082] Here the optimization is done using $\Delta u_k = u_k - u_{k-1}$ as free variables, which introduces integral action in the controller.

[0083] In a traditional refiner control concept typical candidate variables to have setpoints for are primary refiner pulp consistency C_1 and the pulp quality after the secondary refiner Q_2 , but the formulation above is in no way restricted to this choice.

[0084] Notice that since the number of manipulated variables are typically more than 2 and sometimes as many as 6, it should be possible to have setpoints on more than two variables. One possibility is, for example, to have setpoints for force and/or peak temperature inside the refiners. The radial location of the peak temperature is yet another candidate for setpoints.

[0085] In the optimization problems described above the nonlinear model is used as an equality constraint, leading to a nonlinear model predictive control problem.

[0086] Alternatively, the model is linearized, resulting in a model of the form

$$x_{k+1} = Ax_k + Bu_k$$

$$y_k = Cu_k$$

[0087] Notice that due to the multi-rate nature of the measurements, the dimension of the matrix C will be time-varying. If such a model is used as equality constraint in the optimization a (multi-rate) linear model predictive control problem is thus solved instead.

[0088] Figure 3 shows a simplified flowchart for one or more methods according to another aspect of the invention. The figure shows that the method begins 50 by initializing the time t . Each cycle starts by retrieving the measured values from the sensors 52. These measured values (and possibly also historic values in a window of length M) are then used together with the process model to calculate 53 a state estimate $\hat{x}$. This state estimate is then used as a starting point in the forward optimisation which produces a sequence of changes 55 to the manipulated variables over a future horizon of length N_u . Applying the receding horizon principle only the first change of manipulated variables is sent to the actuators 57; after which the time is incremented 58 and the procedure (52-57) is repeated.

[0089] The methods of condition monitoring as described above and elsewhere in this specification may be carried out by a computer application comprising computer program elements or software code which, when loaded in a processor or computer, causes the computer or processor to carry out the method steps. The method may be described as comprising:

[0090] The methods of controlling and optimizing as described above and elsewhere in this specification may be carried out by a computer application comprising computer program elements or software code which, when loaded in a processor or computer, causes the computer or processor to carry out the method steps. The functions of the methods, such as the method shown in Figure 3, may be carried out by processing digital functions, algorithms and/or computer programs and/or by analogue components or analogue circuits or by a combination of both digital and analogue functions.

[0091] The methods of the invention may, as previously described, be carried out by means of one or more computer programs comprising computer program code or software portions running on a computer or a processor. The micro-processor (or processors) comprises a central processing unit CPU performing the steps of the method according to one or more facets of the invention. This is performed with the aid of one or more said computer programs, such as, which are stored at least in part in memory and/or and as such accessible by the one or more processors. The or each processor may be in a control unit, or as a separate control optimizer unit or in a state estimator unit or part thereof, or may as well run in a local or central control system in a local or distributed computerised control system. It is to be understood that said computer programs may also be run on one or more general purpose industrial microprocessors or computers instead of one or more specially adapted computers or processors.

[0092] The computer program comprises computer program code elements or software code portions that make the computer perform the method using equations, algorithms, data, stored values and calculations previously described. A part of the program may be stored in a processor as above, but also in a ROM, RAM, PROM, EPROM or EEPROM chip or similar memory means. The program in part or in whole may also be stored on, or in, other suitable computer readable medium such as a magnetic disk, CD-ROM or DVD disk, hard disk, magneto-optical memory storage means, in volatile memory, in flash memory, as firmware, stored on a data server or on one or more arrays of data servers. Other known and suitable media, including removable memory media and other removable flash memories, hard drives etc. may also be used. The computer programs described may also be arranged in part as a distributed application capable of running on several different computers or computer systems at more or less the same time. Programs as well as data such as start positions, or flag-related information may be made available for retrieval, delivery or, in the case of programs, execution over the Internet. Data may be accessed by means of any of: OPC, OPC servers, an Object Request Broker such as COM, DCOM or CORBA, a web service.

[0093] It should be noted that while the above describes exemplifying embodiments of the invention, there are several variations and modifications which may be made to the disclosed solution without departing from the scope of the present invention as defined in the appended claims.

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Claims

1. A method for controlling a process section for thermo-mechanical pulp (TMP) refining, said process section comprising at least one first refiner having a plurality of temperature or pressure sensors (21) arranged in a predetermined position (20) on a refiner plate of said at least one first refiner (33), said method comprising measuring, alternatively estimating, one or more process variables representing external states outside of the refiner (η_1 , Q_1) for said process section and measuring, alternatively estimating, one or more values representing one or more internal states (ζ_1) inside said at least one first refiner, and manipulating one or more variables (u_1), and calculating a change for said at least one manipulated variable (u_1) for said at least one refiner using said measurement of an internal state (ζ_1) of said at least one refiner and a measurement of said one or more process external states (η_1 , Q_1) for said process section by means of a mathematical process model.
2. A method according to claim 1, characterised wherein the mathematical process model is described by a set of nonlinear differential equations or difference equations with a vector valued non linear function.
3. A method according to claim 1, characterised wherein the mathematical process model is described by a set of linear differential equations or difference equations.
4. A method according to claim 1, characterised wherein the mathematical process model is described by Laplace transforms and transfer functions.
5. A method according to claim 1, **characterised by** calculating a process change using a measurement in which said internal state is temperature (T_1) which is calculated using an array of temperature measurements along the radius of a disc inside said at least one refiner.
6. A method according to claim 1, **characterised by** calculating a process change and changing at least one manipulated variable to affect a change in a measure or estimate of pulp quality (Q_1).
7. A method according to claim 1, **characterised by** calculating a process change and changing at least one manipulated variable to affect a change in specific energy input (E_1) to or motor load (M_1) of said at least one first refiner.
8. A method according to claim 1, **characterised by** using the mathematical process model to minimize the deviation between reference values and measured values, or functions, of internal and/or external states.
9. A method according to claim 1, **characterised by** using the mathematical process model to minimize the deviation between reference values and estimated values of internal and/or external states.
10. A method according to claim 1, **characterised by** feeding the output from said at least one first refiner into a second refiner such that said process section comprises a two stage refiner.
11. A method according to claim 10, **characterised by** calculating a process change for at least one manipulated

variable (u_2) for the second refiner using said measurement of an internal state (ζ_2) of the second refiner and a measurement of said one or more external states (η_2 , Q_2) for said process section by means of a mathematical model.

12. A method according to claim 1, **characterised by** calculating a process change for at least one manipulated variable of a process section comprising two or more refiners using said at least one measurement of an internal state (ζ_1 , ζ_2) for each refiner and a measurement of an external state (η_1 , η_2) for each refiner and at least a quality measurement (Q_2) after the second refiner.

13. A method according to claim 1, **characterised by** calculating a process change for at least one manipulated variable of a process section comprising two or more refiners using said measurement of an internal state (ζ_1 , ζ_2) for each refiner and a measurement of an external state (η_1 , η_2) for each refiner and a quality measurement (Q_2) of the second refiner in order to optimize energy input to said process section.

14. A method according to claim 1, **characterised by** calculating a process change using a measurement in which said internal state is pressure (P_1) which is calculated using an array of measurements along the radius of a disc inside said at least one refiner.

15. A computer program for controlling a process section for thermo-mechanical pulp (TMP) refining comprising software code portions or computer code directly loadable into the internal memory of a digital compute to cause a computer or processor to carry out the steps of a method according to claim 1.

16. A system including a process section for thermo-mechanical pulp (TMP) refining, said process section comprising at least one first refiner (33) having a plurality of temperature or pressure sensors (21) arranged in a predetermined position (20) on a refiner plate of said at least one first refiner (33) for measuring one or more internal states (ζ_1) inside said at least one first refiner, alternatively an estimating means arranged for estimating one or more internal states (ζ_1) inside said at least one first refiner, a measurement or an estimating means device for measuring, alternatively estimating, one or more external process variables (η_1 , Q_1) for said process section and, a manipulating means for manipulating one or more variables (u_1), wherein an apparatus is arranged for applying a process change calculated on at least one manipulated variable (u_1) for said at least one refiner using said measurement of an internal state (ζ_1) of said at least one refiner and a measurement of said one or more external process variables (η_1 , Q_1) for said process section by means of a mathematical model to monitor and control said at least one first refiner.

17. A system according to claim 16, **characterized in that** one or more of said plurality of sensors (21) are arranged on an active radius of a beating disc of a refiner in said process section.

18. A system according to claim 16, **characterized in that** said process section comprises two or more refiners (33, 34) which are arranged connected in series.

19. A system according to claim 16, **characterized in that** said process section comprises two or more refiners which are arranged connected in parallel.

20. A system according to claim 16, **characterized in that** the system further comprises one or more control units arranged as a control optimiser (32).

21. A system according to claim 16, **characterized in that** the system further comprises one or more control units arranged as a state estimator (39).

22. A system according to claim 16, **characterized in that** the system further comprises a memory storage device in which are stored one or more computer programs according to claim 15.

23. Use of a system according to any of claims 16 - 22 to monitor and control a process handling any from the list of: pulp, paper, wood pulp, cellulose pulp.

Patentansprüche

1. Verfahren zum Steuern eines Prozessabschnitts für TMP-Refining (Thermo-Mechanical Pulp), wobei der Prozessabschnitt mindestens einen ersten Refiner mit mehreren Temperatur- oder Drucksensoren (21) umfasst, die an

einer vorbestimmten Position (20) auf einer Refinerplatte des mindestens einen ersten Refiners (33) angeordnet sind, wobei das Verfahren das Messen, alternativ Schätzen, einer oder mehrerer Prozessvariablen, die externe Zustände (η_1 , Q_1) außerhalb des Refiners für den Prozessabschnitt darstellen, und Messen, alternativ Schätzen, eines oder mehrerer Werte, die einen oder mehrere interne Zustände (ζ_1) innerhalb des mindestens einen ersten Refiners darstellen, und Manipulieren einer oder mehrerer Variablen (u_1) und Berechnen einer Änderung für die mindestens eine manipulierte Variable (u_1) für den mindestens einen Refiner unter Verwendung der Messung eines internen Zustands (ζ_1) des mindestens einen Refiners und eine Messung des einen oder der mehreren externen Prozesszustände (η_1 , Q_1) für den Prozessabschnitt mit Hilfe eines mathematischen Prozessmodells umfasst.

2. Verfahren nach Anspruch 1, wobei das mathematische Prozessmodell durch eine Menge von nichtlinearen Differentialgleichungen oder Differenzengleichungen mit einer vektorwertigen nichtlinearen Funktion beschrieben wird.
3. Verfahren nach Anspruch 1, wobei das mathematische Prozessmodell durch eine Menge von linearen Differenzialgleichungen oder Differenzengleichungen beschrieben wird.
4. Verfahren nach Anspruch 1, wobei das mathematische Prozessmodell durch Laplace-Transformationen und Transferfunktionen beschrieben wird.
5. Verfahren nach Anspruch 1, **gekennzeichnet durch** Berechnen einer Prozessänderung unter Verwendung einer Messung, bei der der interne Zustand Temperatur (T_1) ist, die unter Verwendung eines Arrays von Temperaturmessungen entlang des Radius einer Scheibe innerhalb des mindestens einen Refiners berechnet wird.
6. Verfahren nach Anspruch 1, **gekennzeichnet durch** Berechnen einer Prozessänderung und Ändern mindestens einer manipulierten Variablen zum Beeinflussen einer Änderung bei einem Maß oder Schätzwert der Faserstoffqualität (Q_1).
7. Verfahren nach Anspruch 1, **gekennzeichnet durch** Berechnen einer Prozessänderung und Ändern mindestens einer manipulierten Variablen zum Beeinflussen einer Änderung bei der spezifischen Energieeingabe (E_1) in den mindestens einen ersten Refiner oder einer Motorlast (M_1) des mindestens einen ersten Refiners.
8. Verfahren nach Anspruch 1, **gekennzeichnet durch** Verwendung des mathematischen Prozessmodells zum Minimieren der Abweichung zwischen Referenzwerten und Messwerten oder Funktionen von internen und/oder externen Zuständen.
9. Verfahren nach Anspruch 1, **gekennzeichnet durch** Verwendung des mathematischen Prozessmodells zum Minimieren der Abweichung zwischen Referenzwerten und Messwerten von internen und/oder externen Zuständen.
10. Verfahren nach Anspruch 1, **gekennzeichnet durch** Zuführen der Ausgabe von dem mindestens einen ersten Refiner in einen zweiten Refiner, so dass der Prozessabschnitt einen zweistufigen Refiner umfasst.
11. Verfahren nach Anspruch 10, **gekennzeichnet durch** Berechnen einer Prozessänderung für mindestens eine manipulierte Variable (u_2) für den zweiten Refiner unter Verwendung der Messung eines internen Zustands (ζ_2) des zweiten Refiners und einer Messung des einen oder der mehreren externen Zustände (η_2 , Q_2) für den Prozessabschnitt mit Hilfe eines mathematischen Modells.
12. Verfahren nach Anspruch 1, **gekennzeichnet durch** Berechnen einer Prozessänderung für mindestens eine manipulierte Variable eines Prozessabschnitts umfassend zwei oder mehr Refiner unter Verwendung der mindestens einen Messung eines internen Zustands (ζ_1 , ζ_2) für jeden Refiner und eine Messung eines externen Zustands (η_1 , η_2) für jeden Refiner und mindestens einer Qualitätsmessung (Q_2) nach dem zweiten Refiner.
13. Verfahren nach Anspruch 1, **gekennzeichnet durch** Berechnen einer Prozessänderung für mindestens eine manipulierte Variable eines Prozessabschnitts umfassend zwei oder mehr Refiner unter Verwendung der Messung eines internen Zustands (ζ_1 , ζ_2) für jeden Refiner und eine Messung eines externen Zustands (η_1 , η_2) für jeden Refiner und einer Qualitätsmessung (Q_2) des zweiten Refiners, um die Energieeingabe in den Prozessabschnitt zu optimieren.
14. Verfahren nach Anspruch 1, **gekennzeichnet durch** Berechnen einer Prozessänderung unter Verwendung einer Messung, bei der der interne Zustand Druck (P_1) ist, der unter Verwendung eines Arrays von Messungen entlang

des Radius einer Scheibe innerhalb des mindestens einen Refiners berechnet wird.

15. Computerprogramm zum Steuern eines Prozessabschnitts für TMP-Refining umfassend Softwarecodeabschnitte oder Computercode, die direkt in den internen Speicher eines digitalen Computers geladen werden können, um zu bewirken, dass ein Computer oder ein Prozessor die Schritte eines Verfahrens nach Anspruch 1 ausführen kann.
16. System mit einem Prozessabschnitt für TMP-Refining, wobei der Prozessabschnitt mindestens einen ersten Refiner (33) mit mehreren Temperatur- oder Drucksensoren (21) umfasst, die an einer vorbestimmten Position (20) auf einer Refinerplatte des mindestens einen ersten Refiners (33) angeordnet sind, zum Messen eines oder mehrerer interner Zustände (ζ_1) in dem mindestens einen ersten Refiner, alternativ ein Schätzmittel ausgelegt zum Schätzen eines oder mehrerer interner Zustände (ζ_1) in dem mindestens einen ersten Refiner, eine Mess- oder ein Schätzmittleinrichtung zum Messen, alternativ Schätzen einer oder mehrerer externer Prozessvariablen (η_1 , Q_1) für den Prozessabschnitt und ein Manipulierungsmittel zum Manipulieren einer oder mehrerer Variablen (u_1), wobei eine Vorrichtung ausgelegt ist zum Anwenden einer berechneten Prozessänderung auf mindestens eine manipulierte Variable (u_1) für den mindestens einen Refiner unter Verwendung der Messung eines internen Zustands (ζ_1) des mindestens einen Refiners und einer Messung der einen oder mehreren externen Prozessvariablen (η_1 , Q_1) für den Prozessabschnitt mit Hilfe eines mathematischen Modells, um den mindestens einen ersten Refiner zu überwachen und zu steuern.
17. System nach Anspruch 16, **dadurch gekennzeichnet, dass** einer oder mehrere der mehreren Sensoren (21) auf einem aktiven Radius einer Mahlscheibe eines Refiners in dem Prozessabschnitt angeordnet sind.
18. System nach Anspruch 16, wobei der Prozessabschnitt zwei oder mehr Refiner (33, 34) umfasst, die seriell geschaltet angeordnet sind.
19. System nach Anspruch 16, wobei der Prozessabschnitt zwei oder mehr Refiner umfasst, die parallel geschaltet angeordnet sind.
20. System nach Anspruch 16, **dadurch gekennzeichnet, dass** das System weiterhin eine oder mehrere Steuereinheiten umfasst, die als ein Steueroptimierer (32) ausgelegt sind.
21. System nach Anspruch 16, **dadurch gekennzeichnet, dass** das System weiterhin eine oder mehrere Steuereinheiten umfasst, die als ein Zustandsschätzer (39) ausgelegt sind.
22. System nach Anspruch 16, **dadurch gekennzeichnet, dass** das System weiterhin eine Speicherungseinrichtung umfasst, in der ein oder mehrere Computerprogramme nach Anspruch 15 gespeichert sind.
23. Verwendung eines Systems nach einem der Ansprüche 16-22 zum Überwachen und Steuern eines Prozesses, der einen beliebigen aus der Liste von Faserstoff, Papier, Holzzellstoff, Zellulosezellstoff verarbeitet.

Revendications

1. Procédé de commande d'une section de processus pour le raffinement de pâte à papier thermomécanique (TMP, Thermo-Mechanical Pulp), ladite section de processus comprenant au moins un premier raffineur ayant une pluralité de capteurs de température ou de pression (21) agencés à une position prédéterminée (20) sur un disque de raffineur dudit au moins un premier raffineur (33), ledit procédé consistant à mesurer, et en variante, à estimer, une ou plusieurs variables de processus représentant des états externes à l'extérieur du raffineur (η_1 , Q_1) pour ladite section de processus et à mesurer, et en variante à estimer, une ou plusieurs valeurs représentant un ou plusieurs états internes (ζ_1) à l'intérieur dudit au moins un premier raffineur, et à manipuler une ou plusieurs variables (u_1), et à calculer une variation de ladite au moins une variable manipulée (u_1) pour ledit au moins un raffineur en utilisant ladite mesure d'un état interne (ζ_1) dudit au moins un raffineur et une mesure desdits un ou plusieurs états externes du processus (η_1 , Q_1) pour ladite section de processus au moyen d'un modèle de processus mathématique.
2. Procédé selon la revendication 1, **caractérisé en ce que** le modèle de processus mathématique est décrit par un système d'équations différentielles non linéaires ou d'équations de différence à l'aide d'une fonction non linéaire à valeur vectorielle.

3. Procédé selon la revendication 1, **caractérisé en ce que** le modèle de processus mathématique est décrit par un système équations différentielles non linéaires ou d'équations de différence.
- 5 4. Procédé selon la revendication 1, **caractérisé en ce que** le modèle de processus mathématique est décrit par des transformées de Laplace et des fonctions de transfert.
5. Procédé selon la revendication 1, **caractérisé par** le calcul d'une modification d'un processus en utilisant une mesure dans laquelle ledit état interne est une température (T_1) qui est calculée en utilisant un ensemble de mesures de température suivant le rayon d'un disque à l'intérieur audit au moins un raffineur.
- 10 6. Procédé selon la revendication 1, **caractérisé par** le calcul d'une modification d'un processus et par la modification d'au moins une variable manipulée pour affecter une modification d'une mesure ou d'une estimée de la qualité d'une pâte à papier (Q_1).
- 15 7. Procédé selon la revendication 1, **caractérisé par** le calcul d'une modification d'un processus et par la modification d'au moins une variable manipulée pour affecter une modification d'une énergie spécifique fournie en entrée (E_1) à une charge motrice (M_1) dudit au moins un raffineur.
- 20 8. Procédé selon la revendication 1, **caractérisé par** l'utilisation du modèle de processus mathématique pour minimiser l'écart entre des valeurs de référence et des valeurs mesurées, ou des fonctions, d'états internes et/ou externes.
9. Procédé selon la revendication 1, **caractérisé par** l'utilisation du modèle de processus mathématique pour minimiser l'écart entre des valeurs de référence et des valeurs estimées d'états internes et/ou externes.
- 25 10. Procédé selon la revendication 1, **caractérisé par** l'envoi de la sortie dudit au moins un premier raffineur à un second raffineur de telle sorte que ladite section de processus comprenne un raffineur à deux étages.
- 30 11. Procédé selon la revendication 10, **caractérisé par** le calcul d'une modification d'un processus pour au moins une variable manipulée (u_2) pour le second raffineur en utilisant ladite mesure d'un état interne (ζ_2) du second raffineur et une mesure desdits un ou plusieurs états externes (η_2 , Q_2) pour ladite section de processus au moyen d'un modèle mathématique.
- 35 12. Procédé selon la revendication 1, **caractérisé par** le calcul d'une modification d'un processus pour au moins une variable manipulée d'une section de processus comprenant deux ou plusieurs raffineurs en utilisant ladite au moins une mesure d'un état interne (ζ_1 , ζ_2) pour chaque raffineur et une mesure d'un état externe (η_1 , η_2) pour chaque raffineur et au moins une mesure de qualité (Q_2) après le second raffineur.
- 40 13. Procédé selon la revendication 1, **caractérisé par** le calcul d'une modification d'un processus pour au moins une variable manipulée d'une section de processus comprenant deux ou plusieurs raffineurs en utilisant ladite mesure d'un état interne (ζ_1 , ζ_2) pour chaque raffineur et une mesure d'un état externe (η_1 , η_2) pour chaque raffineur et une mesure de qualité (Q_2) du second raffineur afin d'optimiser l'énergie fournie en entrée à ladite section de processus.
- 45 14. Procédé selon la revendication 1, **caractérisé par** le calcul d'une modification d'un processus en utilisant une mesure dans laquelle ledit état interne est une pression (P_1) qui est calculée en utilisant un ensemble de mesures suivant le rayon d'un disque intérieur audit au moins un raffineur.
- 50 15. Programme informatique destiné à commander une section de processus pour le raffinement de pâte à papier thermomécanique (TMP) comprenant des parties de code logiciel ou un code informatique pouvant être directement chargé dans la mémoire interne d'un ordinateur numérique afin d'amener un ordinateur ou un processeur à mettre en oeuvre les étapes d'un procédé selon la revendication 1.
- 55 16. Système comportant une section de processus pour le raffinement de pâte à papier thermomécanique (TMP), ladite section de processus comprenant au moins un premier raffineur (33) ayant une pluralité de capteurs de température ou de pression (21) agencés à une position prédéterminée (20) sur un disque de raffineur dudit au moins un premier raffineur (33) pour mesurer un ou plusieurs états internes (ζ_1) à l'intérieur dudit au moins un premier raffineur, et en variante un moyen d'estimation conçu pour estimer un ou plusieurs états internes (ζ_1) à l'intérieur dudit au moins un premier raffineur, un dispositif à moyen de mesure ou d'estimation pour mesurer, et en variante, pour estimer une ou plusieurs variables externes du processus (η_1 , Q_1) pour ladite section de processus, et un moyen de ma-

nipulation pour manipuler une ou plusieurs variables (u_1), dans lequel un appareil est conçu pour appliquer une modification du processus calculée sur au moins une variable manipulée (u_1) pour ledit au moins un raffineur en utilisant ladite mesure d'un état interne (ζ_1) dudit au moins un raffineur et une mesure desdites une ou plusieurs variables externes du processus (η_1 , Q_1) pour ladite section de processus au moyen d'un modèle de processus mathématique afin de surveiller et de commander ledit au moins un premier raffineur.

17. Système selon la revendication 16, **caractérisé en ce qu'**un ou plusieurs de ladite pluralité de capteurs (21) sont agencés sur un rayon actif d'un disque travailleur d'un raffineur dans ladite section de processus.

18. Système selon la revendication 16, **caractérisé en ce que** ladite section de processus comprend deux ou plusieurs raffineurs (33, 34) qui sont agencés en étant reliés en série.

19. Système selon la revendication 16, **caractérisé en ce que** ladite section de processus comprend deux ou plusieurs raffineurs qui sont agencés en étant reliés en parallèle.

20. Système selon la revendication 16, **caractérisé en ce que** le système comprend en outre une ou plusieurs unités de commande conçues en tant qu'optimiseur de commande (32).

21. Système selon la revendication 16, **caractérisé en ce que** le système comprend en outre une ou plusieurs unités de commande conçues en tant qu'estimateur d'état (39).

22. Système selon la revendication 16, **caractérisé en ce que** le système comprend en outre un dispositif de stockage en mémoire dans lequel sont stockés un ou plusieurs programmes informatiques selon la revendication 15.

23. Utilisation d'un système selon l'une quelconque des revendications 16-22 pour surveiller et commander un processus manipulant l'un quelconque d'une pâte à papier, d'un papier, d'une pâte de bois et d'une pâte cellulosique.

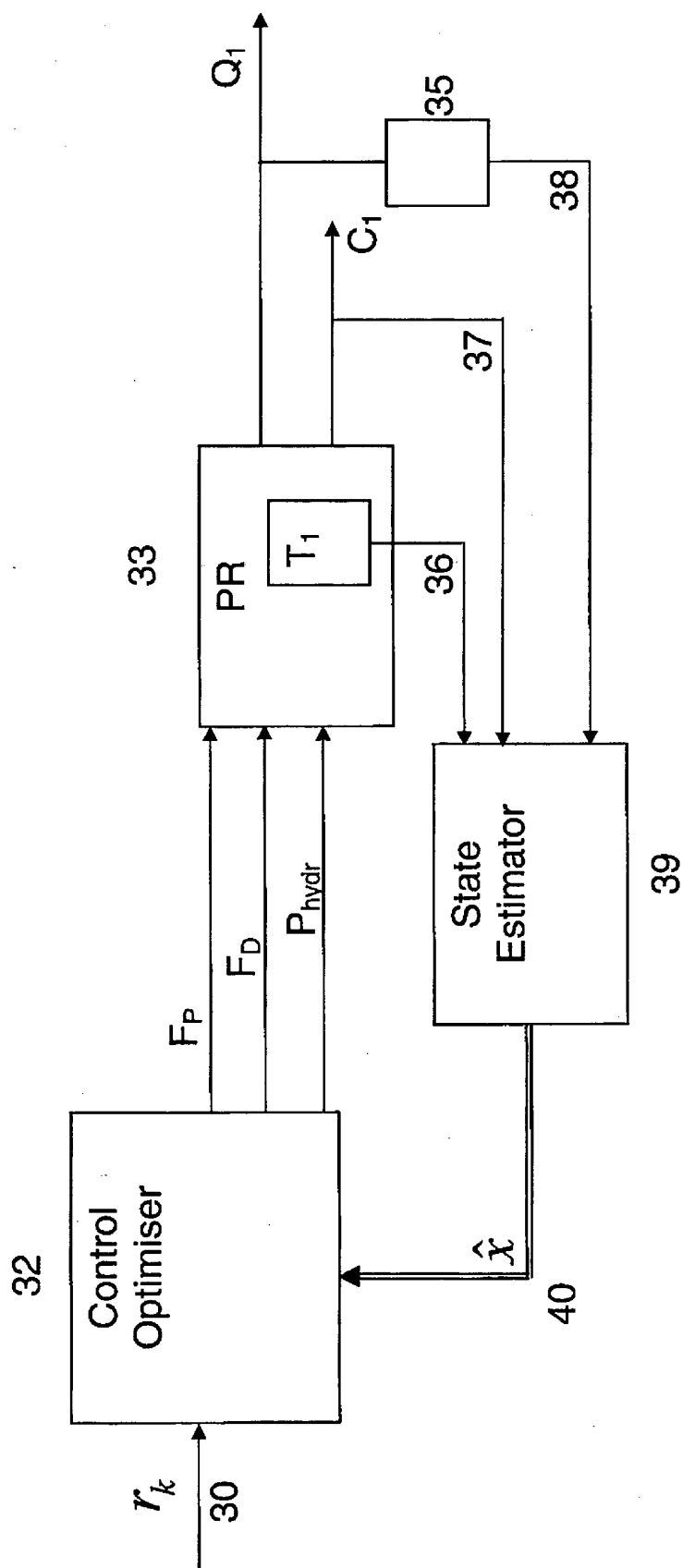


Fig 1

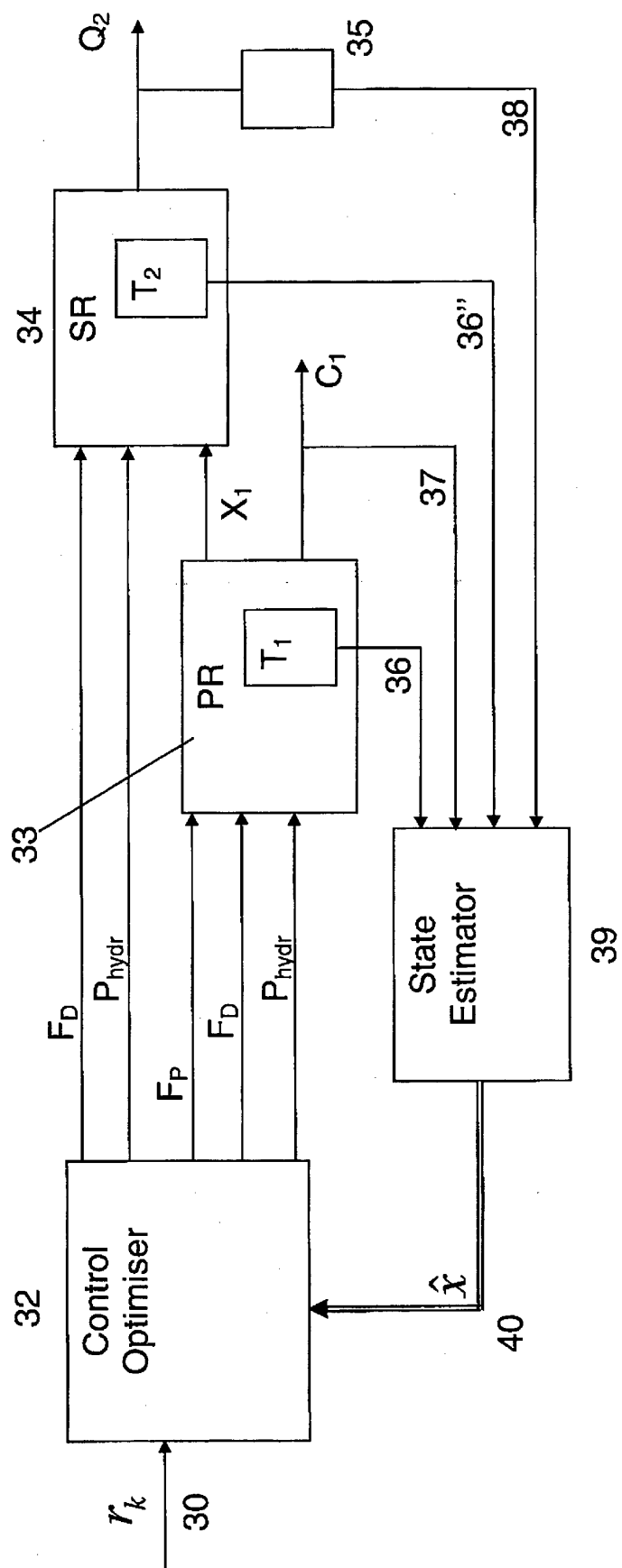


Fig 2

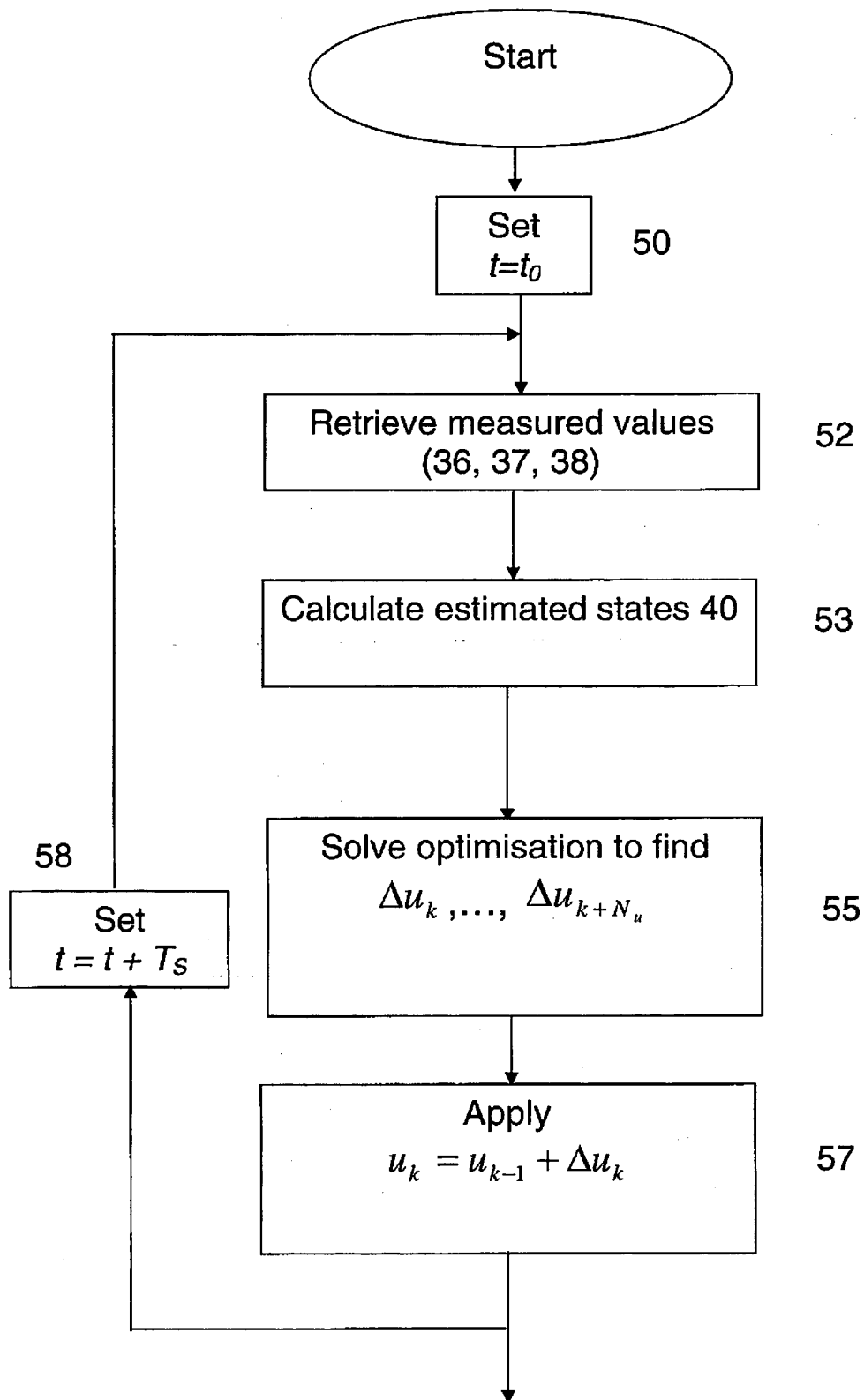


Fig 3

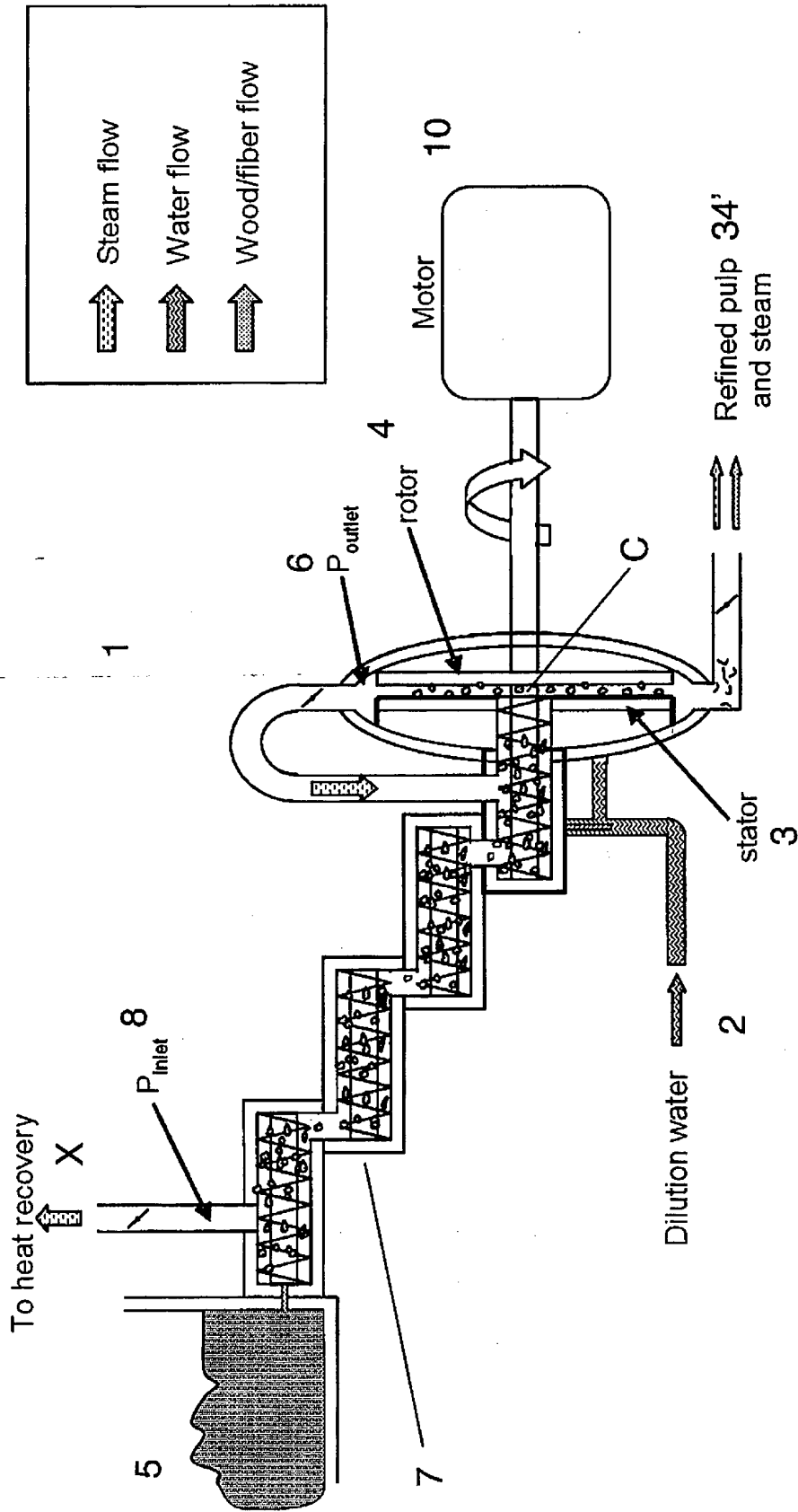


Fig 4

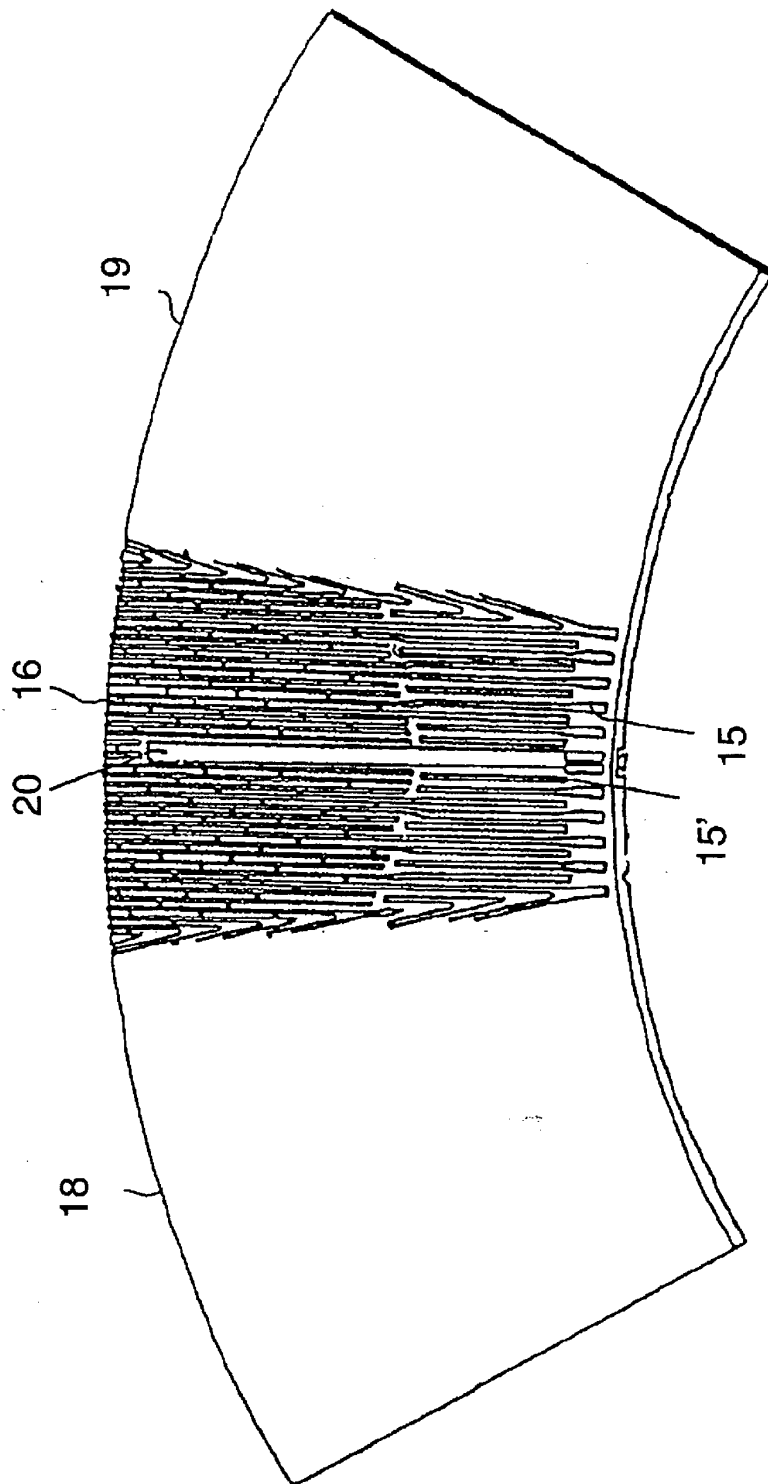


Fig 5

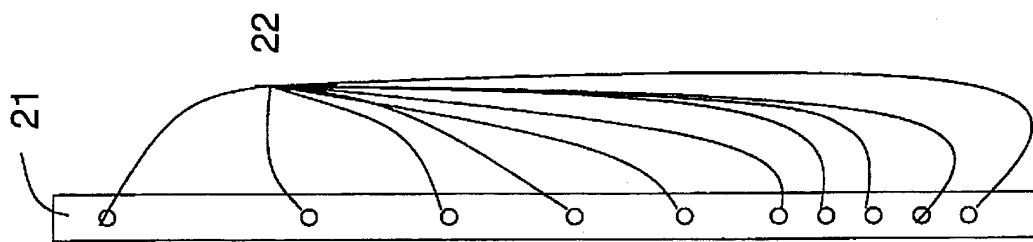


Fig 6

REFERENCES CITED IN THE DESCRIPTION

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