(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 1 892 468 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
27.02.2008 Bulletin 2008/09

(51) Int Cl.:
F22B 35/00 *(2006.01)* ***F22G 5/14*** *(2006.01)*
G05D 23/13 *(2006.01)*

(21) Application number: **06425493.1**

(22) Date of filing: **17.07.2006**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR MK YU

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(54) **System and method for controlling thermodynamic parameters of a steam**

(57) Described herein is a method for controlling thermodynamic parameters of a steam (*ST*) that is supplied to a steam-using unit (3), said steam (*ST*) being obtained by mixing a first regulation steam *(ST_1)* with a second regulation steam *(ST_2),* regulating the respective flow rates (Q_{ST1}, Q_{ST2}) of said first and second regulation steams (ST_1, ST_2), said method being characterized in that it comprises the steps of: controlling the thermodynamic parameters of said steam (*ST*) on the basis of said flow rates (Q_{ST1}, Q_{ST2}) of said first and second regulation steams (ST_1, ST_2) so that to one and the same variation of the flow rates (Q_{ST1}, Q_{ST2}) of said first and second regulation steams (ST_1, ST_2) there always corresponds one and the same variation of said thermodynamic parameters of said steam (*ST*) and so that to a variation of one of said flow rates (Q_{ST1},Q_{ST2}) there corresponds exclusively a variation of one of said thermodynamic parameters of steam (*ST*) that it is intended to control, maintaining all the other thermodynamic parameters of said steam (*ST*) constant.

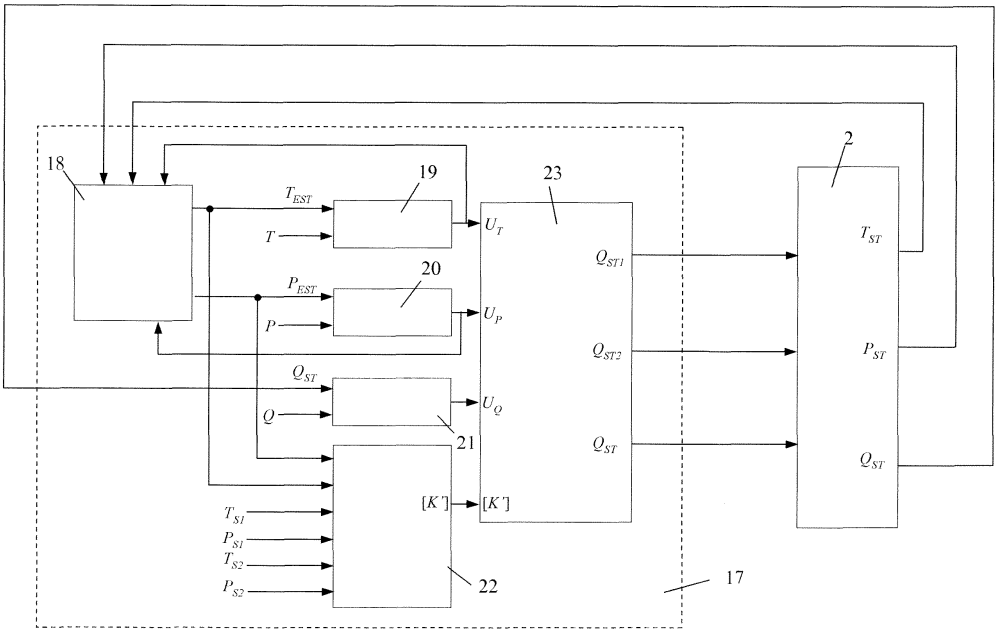

Fig.2

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Description

[0001] The present invention relates to a system and a method for controlling thermodynamic parameters of a steam and, in particular, the temperature, pressure, and flow rate of a steam that is supplied to any steam using apparatus, for example a combustion chamber supplied with steam produced by a combined-cycle plant for the production of electric power.

[0002] As is known, in industrial plants such as, for example, plants for the production of electric power or chemical plants, there is frequently the problem of having to control a set of thermodynamic parameters such as, for example, the pressure, temperature and flow rate of a fluid that flows within a duct or pipe and it supplied to a steam-using unit, for example a combustion chamber.

[0003] In combined-cycle plants for the production of electric power, for example, it is known to control the temperature, pressure, and flow rate of the steam that is introduced into the combustion chamber of the gas turbine in order to reduce the emissions of the plant, appropriately mixing in the duct for supplying the combustion chamber a superheated steam, supplied, for example, by a superheater or by a steam turbine, with a saturated steam or water in conditions of saturation, coming, for example, from an evaporator.

[0004] The amounts of saturated and superheated steam to be introduced into the duct for supplying the combustion chamber are determined according to the flow rate of steam at outlet from the duct, in order to regulate the temperature, pressure, and flow rate of supply steam so that the current values of said parameters always correspond to the desired ones.

[0005] Said regulation is performed, generally, using two distinct regulators, one for the pressure, which controls the pressure of the supply steam, by regulating the flow rate of the first steam for example the saturated one, and one that controls the temperature of the steam, which acts by regulating the flow rate of the other steam, for example the superheated one.

[0006] The regulation of the pressure and temperature of a supply steam for a plant by means of two separate regulators tends, however, to cause the values of the pressure and of the temperature of the steam at outlet from the supply duct to deviate from the desired values and to render the process of supply of the plant unstable principally on account of the fact that a fluid-dynamic system of this sort is nonlinear and presents a marked interaction between the variables involved in the process of regulation.

[0007] Consequently, in the aforesaid type of control, the regulator of the pressure of the supply steam affects also the temperature of the supply steam, whilst the regulator of the temperature of the supply steam affects also the pressure of the supply steam, and there is thus created a static/dynamic coupling between the controlled variables, i.e., the pressure and temperature of the steam of the supply duct, and the control variables, i.e., the flow rate of saturated steam and the flow rate of superheated steam, a fact that tends to render the entire process unstable, above all in the case where the system for supply of steam presents characteristics of marked dynamicity, for example in the case where the flow rate of the outgoing steam varies continuously.

[0008] Consequently, the control systems of a known type for controlling thermodynamic parameters of a fluid, in addition to presenting evident difficulties in the adjustment of the control variables, i.e., of the flow rates of the regulation fluids necessary for guaranteeing a sufficient stablity of the thermodynamic characteristics of the supply fluid of the plant, manage to achieve a good regulation of the thermodynamic parameters of the supply fluid only in the case where the flow rate of the supply fluid remains substantially constant, but are not able to manage in an optimal way the transient regimes, in which the flow rate of the supply fluid tends to vary.

[0009] The aim of the present invention is to provide a system and a method for controlling thermodynamic parameters of a steam and, in particular, the temperature, pressure, and flow rate of a steam that is supplied to a steam-using unit, which will improve the systems and the methods of a known type.

[0010] According to the present invention, a system and a method are provided for controlling thermodynamic parameters of a steam, as defined in the annexed claims.

[0011] For a better understanding of the present invention, there is now described a preferred embodiment, purely by way of nonlimiting example, with reference to the attached drawings, wherein:

- Figure 1 shows a block diagram of the control system according to the invention; and
- Figure 2 shows a functional block diagram of the control method according to the invention.

[0012] Designated as a whole by 1 in Figure 1 is the block diagram of a system for controlling thermodynamic parameters of a system 2 for supplying a fluid to a fluid-using unit 3, for example steam supplied to a combustion chamber, which implements the method according to the invention.

[0013] In particular, for reasons of simplicity of illustration, the ensuing description refers to a system for controlling the temperature, pressure, and flow rate of a steam *ST* that supplies a combustion chamber 3 through a supply system 2 that comprises at least:

- a duct 4, flowing in which is the steam *ST* that supplies the combustion chamber 3 of a combined-cycle plant for the production of electric power (not illustrated in Figure 1);
- a valve 5, coupled to the combustion chamber 3 and the duct 4, for introduction, into the combustion chamber 3, of the steam *ST* that flows in the duct 4;
- a first steam source 6, for example of superheated steam ST_1 at outlet from a superheater;
- a valve 7, coupled to the first steam source 6 and to the duct 4, which regulates the flow rate Q_{ST1} of the superheated steam ST_1 introduced into the duct 4;
- a second steam source 8, for example of saturated steam ST_2 at outlet from an evaporator;
- a valve 9, coupled to the second steam source 8 and to the duct 4, which regulates the flow rate Q_{ST2} of the saturated steam ST_2 introduced into the duct 4.

[0014] In particular, the supply system 2 illustrated in Figure 1 is a variable-regime fluid system, characterized by two incoming currents, namely, the flow of superheated steam ST_1 and the flow of saturated steam ST_2, and by an outgoing current, namely, the flow of steam *ST* that is the result of the sum of the two incoming currents ST_1 and ST_2. A fluid system of this sort is a markedly nonlinear system, i.e., one in which the dependence between the input variables and the output variables varies according to the working point, and is markedly coupled, i.e., one in which to a variation of the input variables there always corresponds a variation of all the thermodynamic parameters of the flows of steam ST_1, ST_2, and *ST*.

[0015] Consequently, in order to be able to control in an optimal way in each working point the temperature, pressure, and rate of flow of steam *ST*, it is necessary to linearize the dependence between the input variables and the output variables of the supply system 2 so that to a variation of an input variable there always corresponds the same variation of the output variable, and to decouple each input variable from the output variables that it is not intended to control via the aforesaid input variable, so that to a variation of an input variable there corresponds exclusively a variation of the output variable associated thereto that it is intended to control.

[0016] The control system 1 is configured for controlling the temperature, pressure, and rate of flow of steam *ST* in a control volume, in a linear and decoupled way and, for this purpose, comprises:

- a pressure sensor 10, set along the duct 4 downstream of the valve 5, for measuring the pressure P_{ST} of the steam *ST* that is introduced into the control volume;
- a temperature sensor 11, set along the duct 4 downstream of the valve 5, for measuring the temperature T_{ST} of the steam *ST* that is introduced into the control volume;
- a flow-rate sensor 12, set in the valve 5 or along the duct 4 downstream of the valve 5, for measuring the flow rate Q_{ST} of steam *ST* that is introduced into the control volume;
- a pressure sensor 13, set along the duct 4, upstream of the valve 7, for measuring the pressure P_{S1} of the superheated steam S_{T1};
- a temperature sensor 14, set along the duct 4, upstream of the valve 7, for measuring the temperature T_{S1} of the superheated steam S_{T1};
- a pressure sensor 15, set along the duct 4, upstream of the valve 9, for measuring the pressure P_{S2} of the saturated steam ST_2;
- a temperature sensor 16, set along the duct 4, upstream of the valve 9, for measuring the temperature T_{S2} of the saturated steam ST_2; and
- a microprocessor electronic control unit 17 and solid-state electronic circuits (neither of which are illustrated in the figures), connected to the sensors 10, 11, 12, 13, 14, 15 and 16 and to the valves 5, 7 and 9 and implementing the method for controlling thermodynamic parameters of a fluid according to the present invention, described in what follows with reference to the functional block diagram of Figure 2.

[0017] In particular, the control system 1 is configured for controlling the temperature T_{ST}, the pressure P_{ST}, and the flow rate Q_{ST} of the steam *ST*, through the appropriate regulation of the flow rates Q_{ST1} and Q_{ST2} of the steams ST_1 and ST_2, and for generating signals for controlling the valves 5, 7 and 9 in order to obtain the desired regulation.

[0018] In particular, the control system 1 is configured for controlling the temperature T_{ST} of the steam *ST*, regulating exclusively, in a linear and decoupled way, the flow rate of one of the two steams ST_1 or ST_2, for example the flow rate Q_{ST1} of the superheated steam ST_1 introduced into the duct 4, and the pressure P_{ST} of the steam *ST*, regulating exclusively, in a linear and decoupled way, the flow rate of the other of the two steams ST_1 or ST_2, for example the flow rate Q_{ST2} of the saturated steam ST_2 introduced into the duct 4.

[0019] For this purpose, in the electronic control unit 17 are stored:

- a desired temperature *T* of the steam *ST*;
- a desired pressure *P* of the steam *ST*; and

- a desired flow rate Q of the steam ST;
- an enthalpy H_1 of the superheated steam ST_1, which is necessary for obtaining the desired temperature T of the steam ST; and
- an enthalpy H_2 of the saturated steam ST_2 necessary for obtaining the desired pressure P of the steam ST; all of which can be set by an operator.

[0020] With reference to the functional block diagram of Figure 2, the electronic control unit 17 comprises:

- an electronic processing unit 18, designed to estimate a temperature T_{EST} and a pressure P_{EST} of the steam ST;
- an electronic processing unit 19, coupled to the electronic processing unit 18, designed to control the temperature T_{ST} of the steam ST;
- an electronic processing unit 20, coupled to the electronic processing unit 18, designed to control the pressure P_{ST} of the steam ST;
- an electronic processing unit 21, designed to control the flow rate Q_{ST} of the steam ST;
- an electronic processing unit 22, coupled to the electronic processing unit 18, designed to calculate, on the basis of thermodynamic parameters of the superheated steam ST_1 and of the saturated steam ST_2 and of desired and estimated thermodynamic parameters of the steam ST, a linearization and decoupling function that enables linear and decoupled control of the thermodynamic parameters of the steam ST, and in particular the temperature T_{ST}, pressure P_{ST}, and flow rate Q_{ST} of the steam ST, as described in detail in what follows;
- an electronic processing unit 23, coupled to the electronic processing units 19, 20, 21 and 22, designed to calculate, on the basis of the aforesaid linearization and decoupling function, a flow rate Q_{TS1} of superheated steam ST_1 and a flow rate Q_{ST2} of saturated steam ST_2 to be introduced into the duct 4, and a flow rate Q_{ST} of the steam ST, which are necessary for the steam ST to have the desired temperature T and the desired pressure P, and to generate at output signals for controlling the valves 5, 7 and 9, as described in detail in what follows.

[0021] In order to be able to calculate a precise linearization and decoupling function, the electronic processing unit 22 should know the instantaneous values of pressure P_{ST} and temperature T_{ST} of the steam ST. Said values cannot, however, be supplied directly to the electronic processing unit 22 on account of the delays introduced by the various elements of the control system 1, for example by the sensors 10 and 11.

[0022] Consequently, it is necessary to estimate the value that the temperature T_{ST} and the pressure P_{ST} of the steam ST will assume at the instant when the electronic processing unit 22 calculates the linearization and decoupling function.

[0023] For this purpose, the electronic processing unit 18 receives at input:

- the signal T_{ST} coming from the sensor 11, indicating the temperature of the steam ST,
- a signal U_T for regulation of the temperature T_{ST}, coming from the electronic processing unit 19, determined on the basis of the temperature T_{EST-1} estimated in the preceding step of calculation and used for calculation of the preceding linearization and decoupling function;
- the signal P_{ST} coming from the sensor 10, indicating the pressure of the steam ST; and
- a signal U_P for regulation of the pressure P_{ST}, coming from the electronic processing unit 20 and determined on the basis of the pressure P_{EST-1} estimated in the preceding step of calculation and used for calculation of the preceding linearization and decoupling function,

and on the basis of the signals T_{ST} and U_T estimates a temperature T_{EST} that the steam ST will assume at the instant when the electronic processing unit 22 calculates the linearization and decoupling function, whilst, on the basis of the signals P_{ST} and U_P, it estimates a pressure P_{EST} that the steam ST will assume at the instant when the electronic processing unit 22 calculates the linearization and decoupling function.

[0024] The electronic processing unit 18 can be implemented in a way in itself known, for example via a so-called "Luenberger observer", or in the form of a single observer that estimates both the temperature and the pressure of the steam ST, or by means of two separate observers, one of which estimates the temperature and the other estimates the pressure of the steam ST.

[0025] The estimated temperature T_{EST} is then supplied to the electronic processing unit 19, which calculates the difference ε_T between the desired temperature T and the estimated temperature T_{EST} of the steam ST and, on the basis of the difference ε_T, calculates a regulation function of a known proportional-integral type, expressed by the signal U_T, indicating the correction to be made to the estimated temperature T_{EST} of the steam ST to compensate for the difference ε_T.

[0026] At the same time, the estimated pressure P_{EST} is supplied to the electronic processing unit 20, which calculates the difference ε_P between the desired pressure P and the estimated pressure $PEST$ of the steam ST and, on the basis of the difference ε_P, calculates a regulation function of a known proportional-integral type, expressed by the signal U_P, indicating the correction to be made to the estimated pressure P_{EST} of the steam ST to compensate for the difference ε_P.

[0027] The electronic processing unit 20 receives at input the signal coming from the sensor 12, indicating the flow rate Q_{ST} of the steam *ST*, calculates the difference ε_Q between the desired flow rate *Q* and the flow rate Q_{ST} of the steam *ST* and, on the basis of the difference ε_Q, calculates a regulation function of a known proportional-integral type, supplying at output a quantity U_Q indicating the correction to be made to the flow rate Q_{ST} of the steam *ST* to compensate for the difference ε_Q.

[0028] In order to be able to calculate the aforesaid linearization and decoupling function, the electronic processing unit 22 receives at input:

- the signals P_{S1} and T_{S1}, indicating, respectively, the pressure and temperature of the superheated steam ST_1;
- the signals P_{S2} and T_{S2}, indicating, respectively, the pressure and temperature of the saturated steam ST_2 and;
- the signals P_{EST} and T_{EST} of the estimated pressure and of the estimated temperature

and, on the basis of the aforesaid quantities, calculates the dynamic equations of a known type, for a control volume of the steam-supply system 2, on the basis of which it calculates the aforesaid linearization and decoupling function.

[0029] In particular, the electronic processing unit 22 calculates an equation that describes the evolution in time of the temperature *T* and of the pressure *P* of the steam *ST* according to the flow rates Q_{ST1}, Q_{ST2} and Q_{ST}, for example an equation of the type:

$$\frac{\partial}{\partial t}\begin{pmatrix} T \\ P \end{pmatrix} = M\left(P_{EST}, T_{EST}\right)\cdot\begin{bmatrix} Q_{ST1} \\ Q_{ST2} \end{bmatrix} + G\left(P_{EST}, T_{EST}\right)\cdot Q_{ST} \qquad (1)$$

where:

- Q_{ST}, Q_{ST1}, and Q_{ST2} are, respectively, the flow rates of the steams *ST*, ST_1 and S_{T2};
- the product $M\ (P_{EST}, T_{EST})$
- $\begin{bmatrix} Q_{ST1} \\ Q_{ST2} \end{bmatrix}$ describes the link between the thermodynamic parameters of the flows of steam ST_1, ST_2 and *ST*, and the flow rates Q_{ST1} and Q_{ST2} of the flows of steam ST_1 and ST_2; and
- the product $G\ (P_{EST}, T_{EST})\cdot Q_{ST}$ describes the link between the thermodynamic parameters and the flow rate Q_{ST} of the flow of steam *ST*.

[0030] In particular, the matrix $M\ (P_{EST}, T_{EST})$ is a matrix of the transfer function of the supply system 2 of the steam *ST*, calculated on the basis of the estimated temperature T_{EST} and of the estimated pressure P_{EST}, of the type:

$$M\left(P_{EST}, T_{EST}\right) = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix} \qquad (2)$$

which describes the link between the thermodynamic parameters of the flow of steam *ST* and the thermodynamic parameters of the flows of steam at input ST_1 and ST_2, the elements m_{11}, m_{12}, m_{21} *and* m_{22} of which are equal to:

$$M(p, T) = \begin{bmatrix} -\rho(p,T)\frac{\partial}{\partial p}H(p,T) + 1 + (H_1 - H(p,T))\frac{\partial}{\partial p}\rho(p,T) & -\rho(p,T)\frac{\partial}{\partial p}H(p,T) + 1 + (H_2 - H(p,T))\frac{\partial}{\partial p}\rho(p,T) \\ \frac{\partial}{\partial T}\rho(p,T).(H_1 - H(p,T)) + \rho(p,T)\frac{\partial}{\partial T}H(p,T) & \frac{\partial}{\partial T}\rho(p,T).(H_2 - H(p,T)) + \rho(p,T)\frac{\partial}{\partial T}H(p,T) \end{bmatrix} \qquad (3)$$

where with *(P, T)* are, respectively, the estimated pressure P_{EST} and the estimated temperature T_{EST};

and

- $G(P_{EST}, TEST)$ is a vector that describes the thermodynamic parameters of the flow of steam ST at output, of the type:

$$G(P_{EST}, T_{EST}) = \begin{pmatrix} g_1 \\ g_2 \end{pmatrix} \quad (4)$$

the elements $g_1(P, T)$ and $g_2(P, T)$ of which are equal to:

$$G(p, T) = \begin{pmatrix} \rho(p, T) \dfrac{\partial}{\partial p} H(p, T) - 1 \\ -\rho(p, T) \dfrac{\partial}{\partial T} H(p, T) \end{pmatrix} \quad (5)$$

where (P, T) are, respectively, the estimated pressure P_{EST} and the estimated temperature T_{EST}; and where:

- $\rho(P, T)$ and $H(P, T)$ are, respectively, the density and the enthalpy of the steam ST calculated, in a way in itself known, as a function of the estimated temperature T_{EST} and of the estimated pressure P_{EST} of the steam ST, for example according to the known Koch and Van der Waals formulas;
- H_1 is the enthalpy of the superheated steam ST_1 stored, obtained by controlling in a way in itself known the temperature T_{S1} and the pressure P_{S1} of the superheated steam ST_1;
- H_2 is the enthalpy of the saturated steam ST_2 stored, obtained by controlling in a way in itself known the temperature T_{S2} and the pressure P_{S2} of the superheated steam S_{T2};
- $\partial/\partial T \cdot \rho(P, T)$ is the partial derivative of the density $\rho(P, T)$ of the steam ST with respect to the estimated temperature T_{EST}, maintaining the estimated pressure P_{EST} constant;
- $\partial/\partial P \cdot \rho(P, T)$ is the partial derivative of the density $\rho(P, T)$ of the steam ST with respect to the estimated pressure P_{EST}, maintaining the estimated temperature T_{EST} constant;
- $\partial/\partial P \cdot H(P, T)$ is the partial derivative of the enthalpy $H(P, T)$ of the steam ST with respect to the estimated pressure P_{EST}, maintaining the estimated temperature T_{EST} constant; and
- $\partial/\partial T \cdot H(P, T)$ is the partial derivative of the enthalpy $H(P, T)$ of the steam ST with respect to the estimated temperature T_{EST}, maintaining the estimated pressure P_{EST} constant.

[0031] The need to linearize the dependence between the input variables and the output variables of the supply system 2 derives principally precisely from the functions that describe the dependence of the density $\rho(P, T)$ and of the enthalpy $H(P, T)$ upon the pressure P_{ST} and the temperature T_{ST}. Said functions are in fact markedly nonlinear and consequently, in order to be able to control the pressure P_{ST}, and the temperature T_{ST} of the steam so that the control is the same in all the working points, it is necessary to linearize said functions.

[0032] As may be noted moreover from the matrix $M(P_{EST}, T_{EST})$, both the density $\rho(P, T)$ and the enthalpy $H(P, T)$ of the flow of steam ST and, consequently, the desired temperature T and the desired pressure P of the steam ST, depend both upon the enthalpy H_1 of the flow of superheated steam ST_1 and upon the enthalpy H_2 of the flow of saturated steam ST_2.

[0033] Consequently, as emerges clearly from the product

$$M(P_{EST}, T_{EST}) \cdot \begin{bmatrix} Q_{ST1} \\ Q_{ST2} \end{bmatrix}$$

of Eq. (1), to a variation of the input variables Q_{ST1} and/or Q_{ST2} there always corresponds a variation of all the thermodynamic parameters of the flows of steam ST_1 and ST_2 and, consequentely, also a variation of all the thermodynamic parameters of the steam ST. For example, in the case where the flow rate Q_{ST1} of the superheated steam ST_1 were varied in order to compensate for a possible variation of the temperature T_{ST} of the steam ST with respect to the desired

temperature *T,* in addition to a variation of the temperature T_{ST} of the steam *ST* there would also occur a variation of the pressure P_{ST} of the steam *ST,* whilst in the case where the flow rate Q_{ST2} of the saturated steam ST_2 were varied in order to compensate for a possible variation of the pressure P_{ST} of the steam *ST* with respect to the desired pressure *P*, in addition to a variation of the pressure P_{ST} of the steam *ST* there would also occur a variation of the temperature T_{ST} of the steam *ST.*

[0034] Equation (1) moreover shows how the temperature *T* and the pressure *P* of the steam *ST* depend also upon the flow rate Q_{ST} and upon the thermodynamic parameters of the flow of steam *ST.*

[0035] Consequently, from an analysis of Eq. (1) it may be deduced that, to obtain that to a variation of the flow rate Q_{ST1} of the superheated steam ST_1 there corresponds exclusively a variation of the temperature T_{ST} of the steam *ST* at constant pressure P_{ST}, and that, likewise, to a variation of the flow rate Q_{ST2} of the saturated steam ST_2 there corresponds exclusively a variation of the pressure P_{ST} of the steam *ST* at constant temperature T_{ST}, it is necessary to decouple:

- the flow rate Q_{ST1} of the superheated steam ST_1 from the pressure P_{ST} of the steam *ST*;
- the flow rate Q_{ST2} of the saturated steam ST_2 from the temperature T_{ST} of the steam *ST*; and
- the flow rate Q_{ST} of the steam *ST* from the temperature T_{ST} and from the pressure P_{ST} of the steam *ST.*

[0036] In order to be able to obtain both the desired linearization and the desired decoupling, the electronic processing unit 21 calculates a matrix $K\,(P_{EST},\ T_{EST})$ by right-handed diagonalizing of the matrix $M\,(P_{EST},\ T_{EST})$, of the type:

$$K\left(P_{EST}, T_{EST}\right)=\begin{pmatrix} 1 & K_{12} \\ K_{21} & 1 \end{pmatrix} \qquad (6)$$

where the elements K_{11} and K_{22} are equal to 1 and the elements K_{12} and K_{21} are equal, respectively, to:

- m_{12}/m_{11} and $-m_{21}/m_{22}$, i.e., a matrix of the type:

$$K(p,T)=\begin{bmatrix} 1 & \dfrac{-m_{21}(p,T)}{m_{11}(p,T)} \\ \dfrac{-m_{21}(p,T)}{m_{22}(p,T)} & 1 \end{bmatrix} \qquad (7)$$

where *(P, T)* are once again, respectively, the estimated pressure P_{EST} and the estimated temperature T_{EST}, where the elements K_{12} and K_{21} are, respectively:

$$K(p,T)=\begin{bmatrix} 1 & \dfrac{\rho(p,T)\left(\frac{\partial}{\partial p}H(p,T)\right)_T.-1-\left(\frac{\partial}{\partial p}\rho(p,T)\right)_T.(H_2-H(p,T))}{-\rho(p,T)\left(\frac{\partial}{\partial p}H(p,T)\right)_T+1+(H_1-H(p,T))_T.\left(\frac{\partial}{\partial p}\rho(p,T)\right)} \\ \dfrac{\left(\frac{\partial}{\partial T}\rho(p,T)\right)_p.(H_1-H(p,T))-\rho(p,T).\left(\frac{\partial}{\partial T}H(p,T)\right)_p}{-\left(\frac{\partial}{\partial T}\rho(p,T)\right)_p.(H_2-H(p,T))+\rho(p,T).\left(\frac{\partial}{\partial T}H(p,T)\right)_p} & 1 \end{bmatrix} \qquad (8)$$

which, multiplied by the matrix $M\ (P_{EST},\ T_{EST})$, would yield a matrix $M\ (P_{EST},\ T_{EST})\cdot K\ (P_{EST},\ T_{EST})$ equal to:

$$K(p,T) = \begin{bmatrix} \dfrac{\left(M(p,T)_{1,1}.M(p,T)_{2,2} - M(p,T)_{2,1}.M(p,T)_{1,2}\right)}{M(p,T)_{2,2}} & 0 \\ 0 & \dfrac{\left(M(p,T)_{1,1}.M(p,T)_{2,2} - M(p,T)_{2,1}.M(p,T)_{1,2}\right)}{M(p,T)_{1,1}} \end{bmatrix} \qquad (9)$$

where the elements $(M\cdot K)_{11}$, $(M\cdot K)_{22}$ are much greater than the elements $(M\cdot K)_{12}$ and $(M\cdot K)_{21}$ which, in this case, would be approximately equal to zero.
Introducing the matrix (9) in Eq. (1), we thus obtain:

$$\frac{\partial}{\partial t}\begin{pmatrix} T \\ P \end{pmatrix} = \begin{pmatrix} \left[M(P_{EST},T_{EST})\cdot K(P_{EST},T_{EST})\right]_{11} & 0 \\ 0 & \left[M(P_{EST},T_{EST})\cdot K(P_{EST},T_{EST})\right]_{22} \end{pmatrix}\cdot\begin{bmatrix} Q_{ST1} \\ Q_{ST2} \end{bmatrix} + G(P_{EST},T_{EST})\cdot Q_{ST} \qquad (10)$$

Equation (10) shows clearly how, but for the component $G\ (P_{EST},\ TEST)\ .Q_{ST}$, to a variation of the flow rate Q_{ST1} of the steam ST_1 there corresponds exclusively a variation of the thermodynamic parameters of the flow of superheated steam ST_1, whilst a variation of the flow rate Q_{ST2} of the saturated steam ST_2 involves only a variation of the thermodynamic parameters of the flow of saturated steam S_{T2}.

[0037] In order to obtain a linearization and a decoupling corresponding to the one expressed in the Eq. (10), and eliminate also the dependence of the output variables T and P upon the flow rate Q_{ST} of the steam ST, the electronic processing unit 21 calculates, in a way in itself known, a matrix $M\ (P_{EST},\ T_{EST})^{-1}$, which is the inverse of the matrix $M\ (P_{EST},\ T_{EST})$, multiplies the inverse matrix $-M\ (P_{EST},\ T_{EST})^{-1}$ with change of sign by the vector $G\ (P_{EST},\ T_{EST})$, and calculates a matrix $K'\ (P_{EST},\ TEST)$ of the type:

$$K'(P_{EST},T_{EST}) = \begin{pmatrix} [K] & -\left[M(P_{EST},T_{EST})^{-1}\cdot G(P_{EST},T_{EST})\right] \\ 0 & 1 \end{pmatrix} \qquad (11)$$

which contains the right-handed diagonalizing matrix $[K]$ of the matrix $M\ (P_{EST},\ T_{EST})$, which enables decoupling of the pressure P_{ST} of the steam ST from the flow rate Q_{ST1} of the superheated steam ST_1 and the temperature T_{ST} of the steam ST from the flow rate Q_{ST2} of the saturated steam ST_2, and the matrix - $[M\ (P_{EST},\ T_{EST})^{-1}.\ G\ (P_{EST},\ T_{EST})]$, which enables elimination also of the dependence of the output variables T and P upon the flow rate Q_{ST} of the steam ST.
Developing the matrix $K'\ (P_{EST},\ T_{EST})$, we obtain:

$$K'(p,T)\ \text{simplify} \rightarrow \begin{pmatrix} 1 & \frac{-m_{12}(p,T)}{m_{11}(p,T)} & \frac{-g_1(p,T)\cdot m_{11}(p,T) + m_{12}(p,T)\cdot g_2(p,T)}{m_{11}(p,T)} \\ \frac{-m_{21}(p,T)}{m_{22}(p,T)} & 1 & \frac{m_{21}(p,T)\cdot g_1(p,T) - g_2(p,T)\cdot m_{22}(p,T)}{m_{22}(p,T)} \\ 0 & 0 & 1 \end{pmatrix} \quad (12)$$

The quantities U_T, U_P and U_Q and the coefficients of the linearization and decoupling matrix $K'(P_{EST}, T_{EST})$ are then supplied to the electronic processing unit 22, which, on the basis of the aforesaid quantities, calculates:

- a flow rate Q_{ST1} of superheated steam ST_1 to be introduced into the duct 4 to compensate for the difference of temperature ε_T and re-establish the desired temperature T of the steam ST, without varying the pressure P_{ST} of the steam ST;
- a flow rate Q_{ST2} of saturated steam ST_2 to be introduced into the duct 4 to compensate for the difference of temperature ε_P and re-establish the desired pressure P of the steam ST, without varying the temperature T_{ST} of the steam ST; and
- a flow rate Q_{ST} of steam ST at outlet from the duct 4 to compensate for the difference of flow rate ε_Q and re-establish the desired flow rate Q of the steam ST, without varying the temperature T_{ST} and the pressure P_{ST} of the steam ST; and

generating respectively, on the basis of the flow rates Q_{ST1}, Q_{ST2} and Q_{ST}, signals for controlling the valves 5, 7 and 9.

[0038] The main advantage of the device according to the invention is that it enables an optimal regulation of the thermodynamic parameters of a fluid for supply of a plant and, in particular, of the temperature, pressure, and flow rate of the fluid, in so far as it enables control of said thermodynamic parameters in a linear and decoupled way.

[0039] Finally, it is clear that modifications and variations can be made to the method and system described and illustrated herein, without thereby departing from the sphere of protection of the present invention, as defined in the annexed claims.

[0040] The algorithms implemented by the electronic processing units 18-23 could, for example, be integrated in a single centralized calculating unit.

Claims

1. A method for controlling thermodynamic parameters of a steam (ST) that is supplied to a steam-using unit(3), said steam (ST) being obtained by mixing a first regulation steam (ST_1) with a second regulation steam (ST_2), regulating the respective flow rates (Q_{ST1}, Q_{ST2}) of said first and second regulation steams (ST_1, ST_2), said method being **characterized in that** it comprises the step of:

   • controlling said thermodynamic parameters of said steam (ST) on the basis of said flow rates (Q_{ST1}, Q_{ST2}) of said first and second regulation steams (ST_1, ST_2) so that to one and the same variation of the flow rates (Q_{ST1}, Q_{ST2}) of said first and second regulation steams (ST_1, ST_2) there always corresponds one and the same variation of said thermodynamic parameters of said steam (ST) and so that to a variation of one of said flow rates (Q_{ST1}, Q_{ST2}) there corresponds exclusively a variation of one of said thermodynamic parameters of steam (ST) that it is intended to control, maintaining constant all the other thermodynamic parameters of said steam (ST).

2. The control method according to Claim 1, in which said thermodynamic parameters of said steam comprise a temperature (T_{ST}, T_{EST}), a pressure (P_{ST}, P_{EST}), and a flow rate (Q_{ST}) of said steam (ST) that it supplied to said steam-using unit (3).

3. The control method according to Claim 2 moreover comprising:

   • controlling said temperature (T_{ST}, T_{EST}) of said steam (ST) by controlling exclusively said flow rate (Q_{ST1}) of said first regulation steam (ST_1);
   • controlling said pressure (P_{ST}, P_{EST}) of said steam (ST) by controlling exclusively said flow rate (Q_{ST1}) of said

second regulation steam (ST_2); and
• controlling said flow rate (Q_{ST}) of said steam (ST) on the basis of the flow rates (Q_{ST1}, Q_{ST2}) of said first and second regulation steams (ST_1, ST_2) .

4. The control method according to Claim 3, in which controlling said temperature (T_{ST}, T_{EST}), said pressure (P_{ST}, P_{EST}), and said flow rate (Q_{ST}) of said steam (ST) comprises:

• determining a function (U_T) for regulation of said temperature (T_{ST}, T_{EST}) ;
• determining a function (U_P) for regulation of said pressure (P_{ST}, P_{EST}) ;
• determining a function (U_Q) for regulation of said flow rate (Q_{ST}) ;
• determining a function (K' (P_{EST}, T_{EST})) that linearizes the relation that links said temperature (T_{EST}), pressure (P_{EST}) and flow rate (Q_{ST}) with said flow rates (Q_{ST1}, Q_{ST2}) of said first and second regulation steams (ST_1, ST_2) and that decouples: said temperature (T_{EST}) of said steam (ST) from a variation of said flow rate (Q_{ST2}) of said second regulation steam (ST_2), said pressure (P_{EST}) of said steam (ST) from a variation of said flow rate (Q_{ST1}) of said first regulation steam (ST_1), and said temperature (T_{EST}) and pressure (P_{EST}) from a variation of said flow rate (Q_{ST}) of said steam (ST); and
on the basis of said functions of regulation (U_T, U_P, U_Q) and of said linearization and decoupling function (K' (P_{EST}, T_{EST})), determining:
• a flow rate (Q_{ST1}) of said first regulation steam such as to compensate for a possible deviation of said temperature (T_{EST}) with respect to a pre-set temperature (T), and such as to maintain the pressure (P_{EST}) of the steam (ST) constant;
• a flow rate (Q_{ST2}) of said second regulation steam such as to compensate for a possible deviation of said pressure (P_{EST}) with respect to a pre-set pressure (P), and such as to maintain the temperature (T_{EST}) of the steam (ST) constant; and
• a flow rate (Q_{ST}) of said steam (ST) such as to compensate for a possible deviation of said flow rate (Q_{ST}) with respect to a pre-set flow rate (Q), and such as to maintain the temperature (T_{EST}) and the pressure (P_{EST}) of the steam (ST) constant.

5. The control method according to Claim 4, in which determining said functions (U_T, U_P) for regulation of said temperature (T_{ST}, T_{EST}) and pressure (P_{ST}, P_{EST}) comprises:

• estimating a temperature (T_{EST}) and a pressure (P_{EST}) of said steam (ST) at the instant when calculation of said linearization and decoupling function (K' (P_{EST}, T_{EST})) is made; and
• determining said function (U_T), for regulation of said temperature on the basis of said estimated temperature (T_{EST}), and said function (U_P) for regulation of said pressure (P_{ST}) on the basis of said estimated pressure (P_{EST}).

6. The control method according to Claim 4, in which determining said functions (U_T, U_P) for regulation of said temperature (T_{ST}, T_{EST}) and pressure (P_{ST}, P_{EST}) comprises:

• estimating a temperature (T_{EST}) and a pressure (P_{EST}) of said steam (ST) at the instant when calculation of said linearization and decoupling function (K' (P_{EST}, T_{EST})) is made;
• calculating the difference (ε_T) between said estimated temperature (T_{EST}), and said desired temperature (T) and the difference (ε_P) between said estimated pressure (P_{EST}), and said desired pressure (P); and
• determining said function (U_T), for regulation of said temperature (T_{ST}) on the basis of said difference of temperature (ε_T), and said function (U_P) for regulation of said pressure (P_{ST}) on the basis of said difference of pressure (ε_P).

7. The control method according to Claim 6, in which determining said function (U_Q) for regulation of said flow rate (Q_{ST}) comprises:

• acquiring said flow rate (Q_{ST}) of the steam (ST);
• calculating the difference (ε_Q) between said flow rate (Q_{ST}), and said desired flow rate (Q); and
• determining said function (U_Q), for regulation of said flow rate (Q_{ST}) on the basis of said difference of flow rate (ε_Q).

8. The control method according to Claims 5 and 6, in which estimating a temperature (T_{EST}) and a pressure (P_{EST}) of said steam (ST) at the instant when calculation of said linearization and decoupling function is made comprises:

- acquiring said temperature (T_{ST}) and flow rate (Q_{ST}) of the steam (ST); and
- acquiring a function (U_T) for regulation of temperature calculated on the basis of an estimated temperature (T_{EST-1}) of said steam (ST) used for calculating the preceding linearization and decoupling function ($K'(P_{EST}, T_{EST})$).

9. The control method according to any one of the preceding claims, in which said steam-using unit (3) is a combustion chamber of a plant for the production of electric power.

10. A system for controlling thermodynamic parameters of a steam (ST) that supplies a combustion chamber of a plant for the production of electric power, said steam (ST) being obtained by mixing a first regulation steam (ST_1) and a second regulation steam (ST_2), regulating the respective flow rates (Q_{ST1}, Q_{ST2}) of said first and second regulation steams (ST_1, ST_2), comprising electronic processing means (22, 23) that are configured for implementing the control method according to Claims 1 to 9.

11. A computer product that can be loaded into the memory of a digital processor, said computer product comprising portions of software code that are able to implement the method according to any one of Claims 1 to 7 when said computer product is run on said digital processor.

12. A plant for the production of electric power equipped with the control system implementing the method, as described in Claims 1 to 9.

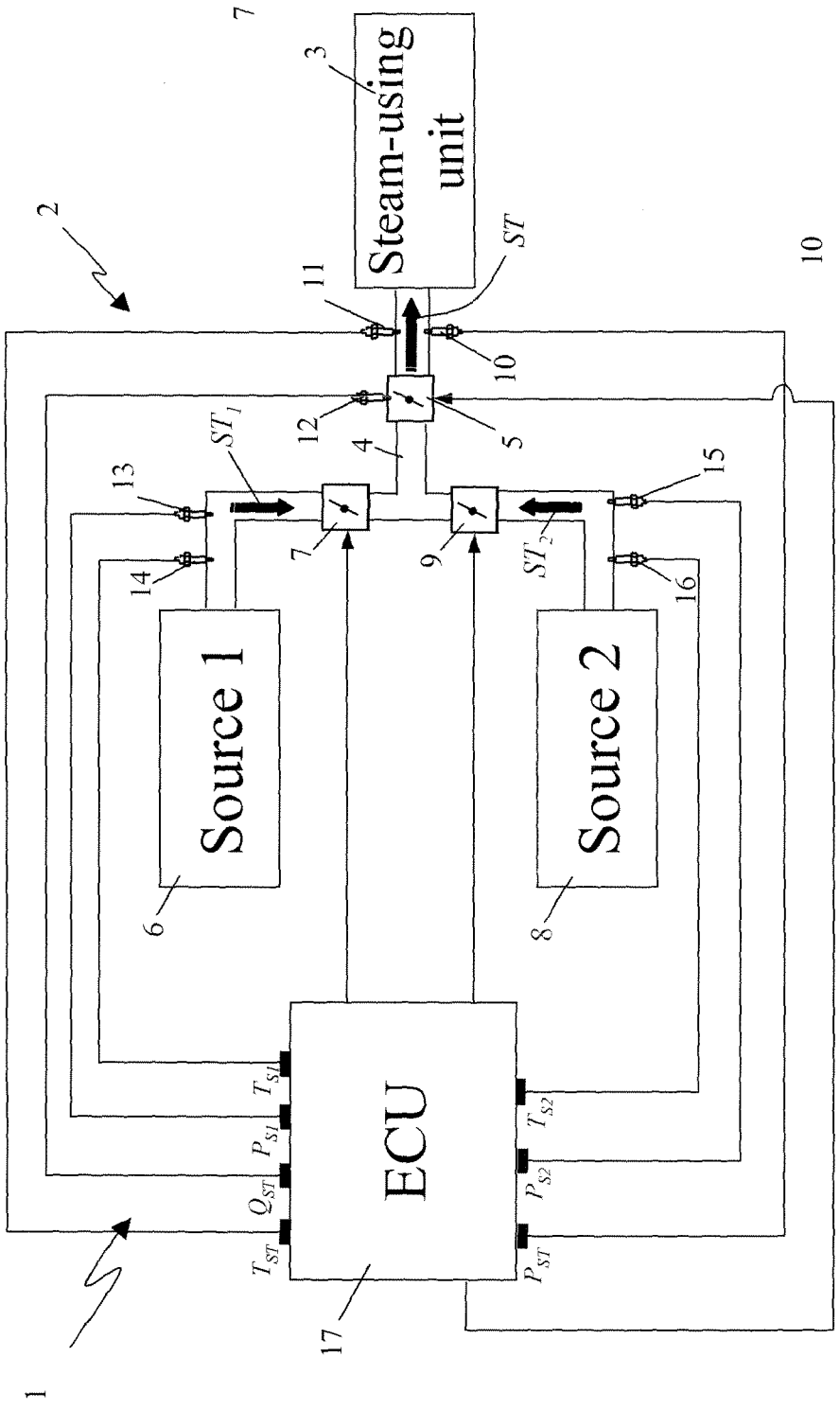
Steam-using unit
Source 1
Source 2
ECU
ST
ST_1
ST_2
T_{S1}
P_{S1}
Q_{ST}
T_{ST}
T_{S2}
P_{S2}
P_{ST}
1
2
3
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Fig.1

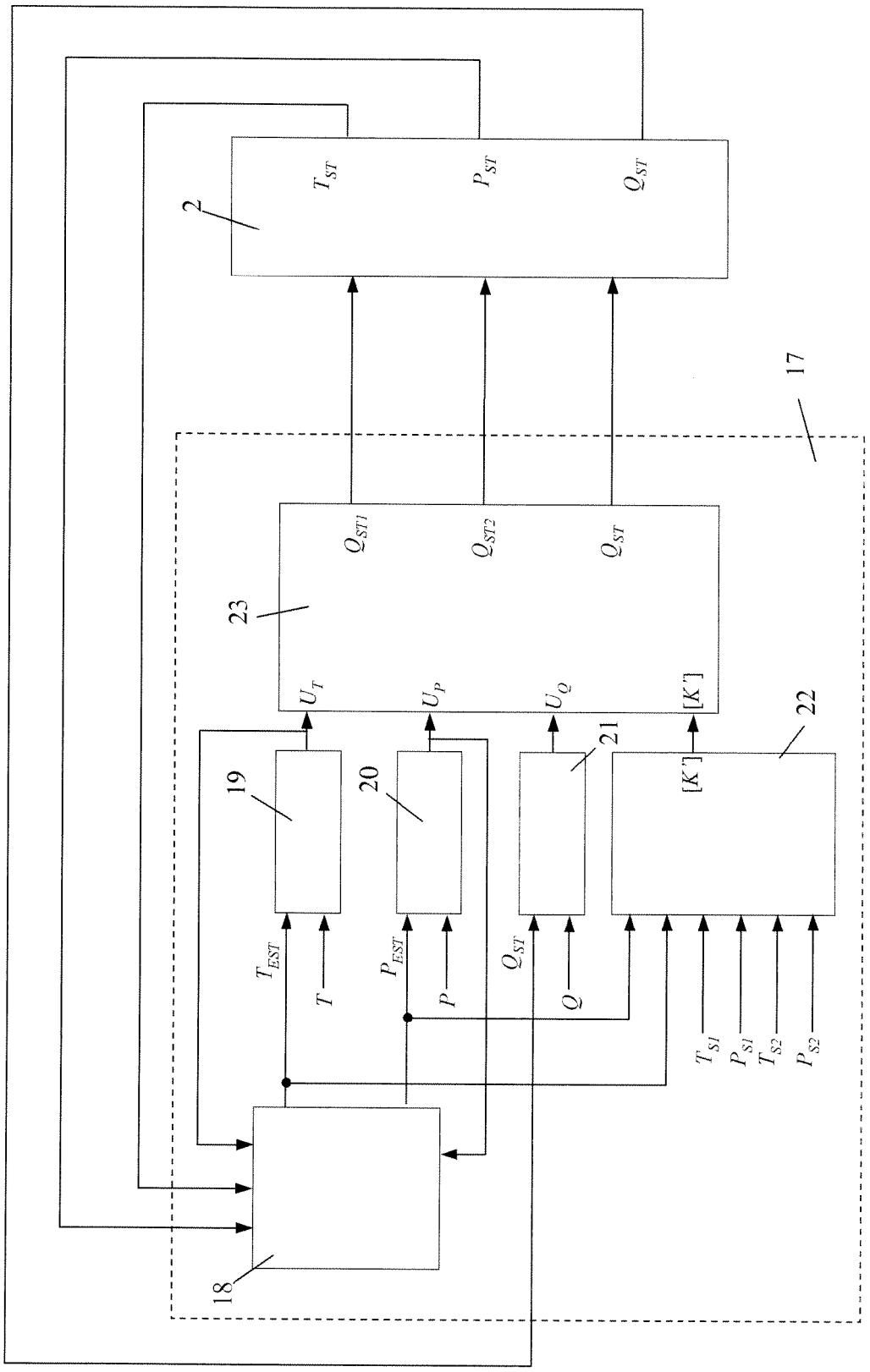
2
T_{ST}
P_{ST}
Q_{ST}
17
23
Q_{ST1}
Q_{ST2}
Q_{ST}
U_T
U_P
U_Q
[K']
22
21
19
20
T_{EST}
T
P_{EST}
P
Q_{ST}
Q
T_{S1}
P_{S1}
T_{S2}
P_{S2}
18

Fig.2

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EUROPEAN SEARCH REPORT

Application Number
EP 06 42 5493

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G05D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	18 May 2007	Zerf, Georges

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