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(71) Applicant: **MERLONI TERMOSANITARI S.p.A.**
60044 Fabriano (Ancona) (IT)

(72) Inventors:
- **Marchetti, Ruggero**
  60044 Fabriano (Ancona) (IT)
- **Marra, Lorenzo**
  60044 Fabriano (Ancona) (IT)
- **Andreucci, Andrea**
  60044 Fabriano (Ancona) (IT)

(74) Representative: **Cerreta, Caterina**
GIDIEMME S.r.l,
474/M, Via Giardini
41100 Modena (IT)

(54) **Combustion control method with guided set point search**

(57) The invention relates to the field of systems suitable for controlling combustion in devices such as boilers, blown burners and similar. The set point value of the ionisation current J is measured in a combustion situation in which it is held that the value of λ is the desired value.

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Description

Technical field

[0001] The invention relates to a combustion control method with guided set point search.

[0002] In particular, the present invention relates to a system suitable for controlling combustion in heat-producing devices such as, for example, gas-powered boilers and water heaters, said system being based on the measurement of the ionisation current taken in proximity to the flame for the regulation of the quantity λ which indicates the air/combustible ratio in a combustion process.

Background Art

[0003] The heat-producing devices in which the control system in question is applicable are of the type in which the mixture of comburent air and combustible, whether liquid or gas, is not determined, at least not completely, by a mechanical/pneumatic type connection between an air delivery means and a combustible delivery means, instead, it is determined electronically, by means of the knowledge or estimation of aforesaid λ ratio. For the sake of an example, said delivery means can be constituted, respectively, of a ventilating element and a valve suitable to deliver the gas.

[0004] It should be noted that the quantity λ takes on notable importance: in fact, once the parameters relating to the burner typology, the geometry of the combustion chamber and the geometry of the primary heat exchanger have been established, intervals of the λ value are identified at which the best compromise between the polluting emissions and thermal yield of the combustion is obtained; in consequence, it appears particularly important to be able to vary λ throughout the entire modulation interval of the thermal power expressible by a given boiler.

[0005] Solely for exemplificative purposes, in the heating devices in which there is a pneumatic/mechanical air-gas connection, the value of λ is fixed mechanically for the reference gas from a given family thereof and therefore, if the composition of the gas used is varied, there is, consequently, a variation in the aforesaid λ value.

[0006] In the commonly known types of heating devices capable of operating the ventilating element and the gas delivery valve element separately, for the purpose of obtaining, contemporaneously, the regulation of the both the temperature of the water used as the vehicle for the heat and the parameter λ, it is necessary for there to be an alternative possibility of measuring/estimating either the massive flows of comburent and combustible available for the combustion process (constituting methods upstream of said combustion) or the excess of air during combustion by means of reading the feedback signals (inside the combustion chamber or in the fumes).

[0007] For example, with reference to the situation inside the combustion chamber, it is known that if two electric conductors are inserted in said chamber, one of which is connected to the metal frame of said chamber, and an electrical field is applied to said conductors, a current is obtained known as an ionisation current and referred to hereinafter with the symbol J, whose course as a function of the λ value varies, and often greatly, depending on further factors: the regulation of aforesaid chamber, the quality of aforesaid electric conductors, their positioning within said combustion chamber, the measurement circuit adopted and the surrounding environmental conditions. Hereinafter, instead of the term 'electric conductor', the term 'electrode' will be used, meaning thereby a device featuring one conductive part, powered by a relative electronic circuit, and a second conductive part, usually connected to the metal frame of the combustion chamber.

[0008] The devices realized until now using the ionisation current value for the regulation of λ intervene on the combustible delivery valve element or the ventilating valve element in order to maintain the said value essentially equal to a preset reference point, (hereinafter referred to as set point or, in symbols, as SP). Various prior documents describe and claim both methods for identifying the said ionisation current value and electronic/mechanical devices suitable for functional control.

[0009] Document US 5,924,859 deals with a procedure suitable for controlling a gas burner fitted with a blower in which an ionisation electrode sends either a variable signal derived from the combustion temperature or the value of λ to a control circuit which compares the variable signal with a selected electrical set point value in order to balance the value of λ with the corresponding set point value of λ. The electrical set point is regulated with the maximum value at λ=1.

[0010] Document DE 198 31 648 deals with a system in which a gas burner combustion control element has as its aim the adaptation of the mixture of air and combustible in proportions dependant on an ionisation signal measured in the combustion chamber; before combustion, said control element is harmonized with the particular type of burner in order to distinguish between the output signals from the combustion process and the corresponding data stored in the control element memory. In the start-up phase, the gas power supply is increased by means of a ramp and, after that phase, the control element reduces the flow of air, maintaining a constant flow of gas by carrying out a calibration action.

[0011] Document DE 198 39 160 describes and claims a system for controlling feedback in a gas burner in which a control element pilots both a ventilating element and a gas delivery valve element on the basis of the ionisation signals entering the said control element and the two ionisation signals coming from two electrodes located in the flame are compared with a calibrated ionisation value.

[0012] Document US 5,899,683 deals with a procedure and a device in which a control element detects an ionisation signal and, in order to guarantee a low emission of combustion products in different operating conditions, an ionisation signal interval is set whose upper limit is below the maximum ionisation value and whose lower limit is above the value capable of guaranteeing low emissions.

[0013] Document WO 2004/015333 submitted by the present applicant describes and claims a method for controlling combustion in units powered by gas with automatic premixing which envisage the estimation of the value of λ using at least two physical state quantities of combustion.

[0014] Essentially, in the majority of commonly known combustion control systems reference is made to the concept by which the thermal power is set by means of the velocity of the ventilating element which, generating a certain air flow, induces a certain combustible flow which, during combustion, produces the required thermal power; in general, if the ionisation current which is measured proves to be equal to the desired value, i.e. it proves to correspond essentially to the set point value this means the value of λ ratio is essentially identical to that desired and in the event that the ionisation current measured proves different from the set point value, then the system would intervene on the combustible delivery valve element, either increasing or decreasing the combustible depending on the case in question.

[0015] In the majority of the background art, the ionisation current set point, which is considered to be the image of a corresponding λ set point, is calculated as a fraction of the maximum value identified during the passage from $\lambda>1$ to $\lambda<1$ effectuated during the periodic recalibration cycle.

[0016] One drawback of the background art utilizing a fraction of the maximum value of the ionisation current as a set point for the said ionisation current is constituted by the fact that, in normal functioning conditions, said set point is identified empirically.

Disclosure of Invention

[0017] A first aim of this invention is to identify a method which permits, at a preset power, the set point of the ionisation current J to be acquired in correspondence with a known value of λ.

[0018] A further aim is to identify said λ value within the framework of a calibration process, by means of the identification of a law of correspondence between ω and λ at said preset power.

[0019] In particular, the method in question in the present invention for controlling combustion in a heat-producing device fitted with a burner, a ventilating element, a heat exchanger and a valve element suitable for delivering, in variable quantities, a liquid or gas combustible, said method utilizing the knowledge of at least one ionisation current J in proximity to the flame in order to regulate the parameter λ expressing the air/combustible ratio during the combustion and said method also being of the type comprising at least one electrode, a control system inputted into which there are, at least, signals supplied by at least one electrode, the heat exchanger and the ventilating element, and outputted from which there are, at least, signals towards the ventilating element and towards the valve element, is characterised by the fact that the value of at least one ionisation current J utilised as a set point for the subsequent regulation of λ measured by at least one electrode is identified in combustion conditions in which a known and desired λ value is fixed, the knowledge thereof being based on an experimental observation with the result that, at a preset thermal power value, the velocity ω of the ventilating element presents a course which is slightly shifted from a linear type course of the function $\omega=f(\lambda)|_{p=cosi}$, by the fact that a periodic calibration of the system is realised during which the valve element piloting is maintained constant in order to realise the process at an almost constant power and the velocity of the ventilating element is varied in order to identify the characteristic points of the line, identifying said function $\omega=f(\lambda)|_{p=cosi}$, and by the fact that acceptability tests are realised on the basis of the values of ω and J identified both during normal functioning and during said periodic system calibration process.

[0020] These and other characteristics will better emerge in the description that follows of a preferred embodiment illustrated, purely in the form of a non-limiting example, in the plate enclosed, in which:

- figure 1 illustrates the qualitative course of an ionisation current as a function of λ ;
- figure 2 illustrates the qualitative course of the rotation velocity of a ventilating element as a function of λ;
- figure 3 illustrates the contents of the previous figure in the event of an extension of the lines towards the theoretical point $\lambda=0$;
- figure 4 illustrates the course of two ionisation currents as a function of λ, a first current referring to the ionisation sensor closest to the surface of the burner and a second current referring to the ionisation sensor furthest from the surface of the burner;
- figures 5 and 6 illustrate the course, respectively, of the difference and the ratio between the two ionisation currents in the previous figure, with a constant power, as a function of λ;
- figure 7 illustrates the positioning of five notable points in a rotation diagram of the velocity of the ventilating element as a function of λ, said points being found within the scope of a practical process;

- figure 8 illustrates the function block diagram of a gas boiler;
- figure 9 illustrates the function block diagram of a subsystem contained within the combustion control system, said system dealing with the regulation of λ and the delivery water temperature;
- figure 10 illustrates, in a graph, the course of the characteristic quantities of a calibration process;
- figure 11 illustrates, in tabular form, an example of values, measured in the laboratory: gas delivery valve element aperture percentage, ventilating element velocity and ionisation current;
- figure 12 illustrates, in tabular form, the values of the ratios between the velocities of the ventilating element and the ionisation currents in correspondence with the various gas delivery valve element aperture percentages and the respective values of the VGcal position of the gas delivery valve element;
- figure 13 illustrates a calibration table;
- figure 14 illustrates, in diagram form, the piecewise linear course of the velocity of the ventilating element in set point conditions as a function of the aperture percentage of the gas delivery valve element;
- figure 15 illustrates, in diagram form, the piecewise linear course of the ionisation current in set point conditions as a function of the aperture percentage of the gas delivery valve element.

Unlike the commonly known embodiments, in the present invention the ionisation current set point value is measured in a combustion situation in which it is deemed that the λ value is the desired value (e.g. λ =1.3). The presupposition that the lambda value is known, obviously allowing for a certain degree of approximation, is due to the particular behaviour of a ventilating element. The experiment results show, in fact, that for set thermal power values, and for a certain temperature of the boiler intake air, the course of the velocity ω of the ventilating element as a function of lambda is essentially comparable to a linear course, or at least in the lambda interval concerned by the combustion that is (for example, in the interval from 1.1 to 1.6), as shown in figure 2.

[0021] Extending the lines geometrically towards the purely theoretical point, at λ =0, one notes that these converge, if not at one point, then in one limited region, as emerges clearly from observation of figure 3.

[0022] From this limited region of convergence, it is possible to identify an intermediary value ω (ωλ=0) between a certain number of extensions of the lines of the said ventilating element at the various powers.

[0023] These lines do not shift significantly in the event of small variations in the intake air temperature around the temperature considered the reference.

[0024] An interesting characteristics lies in the fact that, by maintaining one valve element in the same position (and therefore delivering the same flow of gas) and obstructing the passageway of the intake air or output fumes, it is found that the curves do not shift in a parallel fashion, instead their gradient varies (the gradient increases in the obstruction case) and they rotate around the region of convergence for λ=0. The practical significance is that more velocity is required at the rotor of said ventilating element to supply the air flow necessary to reach said lambda.

[0025] The utility of this information lies in the fact that, given a certain thermal power, and in fixed environmental conditions, it is possible to discover the velocity to set for the rotor of the ventilating element to reach said lambda, when the function $\omega=f(\lambda)|_{P=cosi}$ is known. This function, since it is comparable to a line, can be calculated when two points (ω0, λ0) and (ω1, λ1) are known. In the event that further points are known, the line can be synthesised with an interpolation method (e.g. with the minimum squares method), bearing in mind that in practice it is improbable to have two experimentally found points lying on the same line at one's disposal. It is commonly known, as mentioned earlier, that the course of the ionisation currents presents a maximum for λ≈1. Knowing this corresponding figure, whose exact value in λ must be ascertained for the various combustion chamber, burner and electrode configurations, allows a point to be obtained which is useful in calculating one of the lines $\omega=f(\lambda)|_{P=cosi}$. In fact, running along the lambda axis at constant velocity (by means of variation of the ventilating element's velocity) from values at λ>1 to the zone at λ<1 (or vice versa), it is possible to store the value of ω in correspondence with which the ionisation reaches its maximum. The main information supplied by the maximum is no longer, therefore, its value in terms of current, but the velocity of aforesaid ventilating element at which said maximum is measured. This point (ω, λ) will be identified as (ωλ=1, λ≈1).

[0026] With two electrodes at one's disposal for measuring the ionisation current in the combustion chamber, positioned at different distances from the burner, it is possible to combine the information supplied by two aforesaid electrodes in order to identify further points, which can be entered in an interpolation relationship for the synthesis of one of the lines of the ventilating element. From document WO 2004/015333 there emerges three further additional points (ω, λ), with constant power, which can be found utilising two flame sensors. Figure 4, which follows, shows the course of the two currents, for λ>1, where J1 refers to the current measured by the electrode nearest the burner, while J2 refers to the one measured by the furthest electrode.

[0027] Notable points can be identified in the two functions ΔJ=J1 - J2 and J1/J2, traced out with a constant power and shown in figures 5 and 6 respectively.

[0028] In the graph illustrated in figure 5 one notes the presence of a maximum and a crossing through 0, respectively, for example, for λ = 1.15 and λ =1.45. The graph illustrated in figure 6 presents a maximum situated, for example, at λ=1.30. The position in lambda of these notable points is not the same in all cases, on the contrary, it is typical of every setup which includes burner, heat exchanger, combustion chamber and measuring electrodes.

[0029] Therefore, utilising two measuring electrodes, there are six points (ω, λ) available in total to utilise for the synthesis of a line $\omega=f(\lambda)|_{P=cosi}$:

1- the point at λ=0, with ω identified as the 'average' of the zone of intersection of the extensions of the lines of the ventilating element at the various powers: (ω with λ =0, λ=0). This point is identified once only in the laboratory and is not calculated again during the boiler calibration process;

2- the point whose ω is registered in correspondence with the maximum of the single ionisation current (J1 or J2): (ω with max-J, $\lambda \approx 1$);

3- the point whose ω is registered in correspondence with the maximum of the ΔJ=J1 - J2: (ω with max-ΔJ, e.g. λ = 1.15);

4- the point whose ω is registered in correspondence with the maximum of the relationship J1/J2: (ω with max-J1/J2, e.g. λ = 1.30);

5- the point whose ω is registered in correspondence with the zero of the ΔJ=J1 - J2: (ω with zero-ΔJ, e.g. λ = 1.45);

6- the point whose ω is registered, for example, upon the occurrence of one of the following conditions:

- attainment of a fraction of the max of J (for example 5%) of the max ionisation value;
- attainment of an absolute value of J, which is small in entity (for example, 2μA) and just above the value at which the flame is deemed present, said value being called the detection threshold.

[0030] Finally, it can be said that, by means of the use of a sole electrode, the previous points 2 and 6 can be identified, while with two electrodes, all the previous points can be identified.

[0031] One example of the layout of the points identifying said five ordinate pairs (ω, λ) which, being found within the scope of a practical process, will most likely not be perfectly aligned along a line, is shown graphically in the diagram in figure 7.

[0032] By means of an interpolation calculation, it is possible to find the line $\omega=f(\lambda)|_{P=cosi.}$, thanks to which the value of ω is known, said value being necessary to obtain a given value of lambda, given the power. If, for example, one wishes to work at λ = 1.25, this value must be entered in the formula and the value ω (and likewise ω_Cal) is obtained therefrom. Once boiler functioning has been brought up to a condition characterised by the fact that the power is the power at which the points have been identified and the velocity of the ventilating element is equal to ω_Cal, which provides the lambda desired (with a certain tolerance), one can now proceed with the measurement of the ionisation current (for example, J1), whose value in this condition constitutes the set point for said ionisation, at that power, which will be set for all the thermal power modulation cycles until the subsequent calibration.

The set point calculation procedure of ionisation at other powers will be described later on.

[0033] During the periodic calibration described in the present invention, the piloting of the gas delivery valve element will be maintained constant, so that this process can be realised at an almost constant power, and the velocity of the ventilating element is varied to identify the characteristic points.

[0034] The number of points one intends to identify can range from one to five. In total, there are six points at one's disposal but the choice of how many and which points to utilise for the synthesis of the line $\omega=f(\lambda)|_{P=cosi}$ is left to the manufacturer, who can evaluate whether adding more points than the two minimum points necessary for the identification of a line will have the capacity to bring advantages in terms of accuracy in the effective attainment of the λ desired, supplied by the ω calculated using the function $\omega=f(\lambda)|_{P=cosi.}$

[0035] Until now reference has been made to "constant power" but, in actual fact, by managing the thermal power directly with the valve element, the sole method by which the power can be maintained almost constant is by maintaining the piloting of said valve element constant, so that the gas flow is maintained at approximately the same level. Hereinafter, therefore, reference will be made to the "constant gas valve element aperture".

[0036] A notable property of the characteristic point relating to the ionisation curves and the respective combinations described previously lies in the fact that the positions in λ of the points "J maximum", "ΔJ maximum", "J1/J2 maximum" and "ΔJ zero" do not vary substantially in the event of variations in the type of gas, at least, within the same family that is, (e.g. from G231 to G21). Thanks to this property, the λ values which intervene in the synthesis of the line expressed by the function $\omega=f(\lambda)|_{P=cosi}$ depend solely on the setup of the combustion chamber and are valid for all the gases, at least within aforesaid family that is.

[0037] Considering figure 8, 1 and 2 refer to a first and second electrode for measuring the ionisation current, located at two different distances from a burner 3. A ventilating element 4 consents the measurement of the velocity thereof, which is variable. A gas delivery valve element 5 is also modulating. The outlet of said valve element 5 is downstream of the ventilating element 4, but could also be positioned at the inlet of said ventilating element. A control system 6 features input of at least the measurement of temperature of the water coming out of the primary exchanger 7, of at least one measured flame current and of at least the velocity of said ventilating element. The output of the control system

6 includes at least the commands for the velocity of the ventilating element 4 and for the aperture of the valve element 5. Inside the control system 6 there is a subsystem, illustrated in figure 9, which deals with the regulation of λ and water delivery temperature, during the normal thermal power modulation cycles, whose purpose is to produce hot water. In said subsystem, there are two counter-reaction loops present, one main one for the delivery temperature called Tflow and a secondary one for the measurement of the ionisation current J1; the latter could also be J2 in the event that two ionisation electrodes are utilised instead of one only. Said subsystem is fitted with two regulators, in the case illustrated, two PIDs.

[0038] In the main loop, the delivery temperature measured in the boiler is compared with its set point (usually set directly by the user, for example with a handgrip on the front of the boiler). The difference (temperature control error) between the water delivery temperature and the set point thereof is processed by said PID, which outputs the command signal "Vgas" to open the valve element 5. This signal reaches the input of two blocks which implement the same number of linking relations between the degree of aperture of the valve element 5 and the expected value of the velocity of the ventilating element 4 and the ionisation current set point. The ionisation set point is compared with the effective current reading and the difference (ionisation control error) is inputted to a second regulator (for example, said PID) which outputs a correction signal for the velocity of the ventilating element 4, with the aim of maintaining the ionisation reading equal to the relative set point.

[0039] The two functions "ω_SP = f(Vgas)" and "J_SP = g(Vgas)" constitute the result of the calibration process, which is described herein, and the course of the quantities characteristic of said calibration is illustrated in figure 10. During the functioning of the combustion unit, the control system 6 brings the valve element 5 to a preset degree of aperture VGcal, which realises the gas flow deemed optimal for the realisation of said calibration. The gas delivery valve element 5 is commanded to the VGcal position with a suitable ramp and the ventilating element 4 is brought to a rotation velocity ω which assures a relatively high excess of air, so that the boiler is made to function in a zone of the ionisation curve which is extremely distant from its maximum. To reach this condition, one can control the velocity of the ventilating element 4 so that the ionisation objective is a value just above the current threshold under which it is deemed that there is no flame present. This point of the work is where the descending ramp of said ventilating element's velocity starts, the purpose thereof being to find the maximum of one, the other or both the ionisation currents J1 and/or J2. This maximum, which is a descending maximum represented by the point A2 in the graph in figure 10, is deemed identified when, travelling along the descending section of the ionisation curve, a certain percentage of the maximum value identified is reached (e.g. 90%).

The reaching of this maximum is first of all taken as a reference, to make certain that the current situation is $\lambda<1$. Once the ionisation maximum has been reached and exceeded, the control system 6 commands the ascending ramp of the velocity of the ventilating element 4, the purposes of said ramp being to find the characteristics points of one or both the ionisations, at which the ω to which these characteristic points correspond (which the boiler's manufacturer has chosen to use) must be memorised. Supposing one wanted to identify, for example, four of aforesaid characteristic points, and supposing also that these are positioned in λ as in figures 1, 5 and 6, these will be found, during the ascending ramp of the ventilating element 4, in the following order, for example:

- maximum of single ionisation (J_max) (A2' in the graph);
- ΔJ maximum (A3), (ΔJ_max);
- J1/J2 maximum (A4), (RJ_max);
- ΔJ zero (A5), (ΔJ_=0).

The characteristic points identified, in correspondence with which the respective values of ω are memorised, can be utilised for the synthesis of the line of the ventilating element 4, in correspondence with the chosen position of the valve element 5 for the calibration in order to identify the function $\omega=f(\lambda)|_{VGcal}$. Supposing that, at the calibration power, one intends to achieve a λ equaling 1.3, one enters this value in the formula and obtains the value "ω_Cal", which is the velocity of the ventilating element 4 which supplies $\lambda=1.3$ when the valve element 5 is in the VGcal position. Also with the valve element 5 in the VGcal position, the ventilating element 4 is controlled at the velocity ω_Cal which corresponds to the point Acal in the graph illustrated by figure 10. After a stabilisation time (e.g. 5 s), the ionisation current (J_Cal) is read, which becomes the ionisation set point at the valve element 5 VGcal position. The number of revolutions ω_Cal supplied by the line of the valve element 5 corresponds to the velocity which, during a normal thermal power modulation cycle, one expects to find when the ionisation current is around the set point, with the valve element in position VGcal.

[0040] In order to have a characterisation of the boiler regarding combustion, certain references parameters are identified in the laboratory, which will serve for the calculation of the functions "ω_Sp = f(Vgas)" and "J_SP = g(Vgas)". First and foremost, a reference functioning condition is identified, in which the valve element 5 is found in the position VGcal and the excess of air desired is present (e.g. 1.3). The value of the ω (for example 300 rpm = revolutions per minute) and the ionisation (for example 20μA) are registered. Subsequently, other power levels are selected (for example, three others, but their quantity is left to the manufacturer's discretion) in which, once the desired λ values are reached, both the relative values of ω of the ventilating element 4 and those of the ionisation can be noted. The first table illustrated in figure 11 shows an example of the result of this characterisation.

[0041] From the table illustrated in figure 11 one can obtain the fractions which will permit the determination of the expected ω and ionisation set point values, following a calibration, in correspondence with any positions of the valve element 5 other than VGcal. For example, for the 100% position of the said valve element, the coefficient of the ω will be 4000/3000 = 4/3, and that of the ionisation will be 25/20 = 5/4. By following this calculation method, the table of the coefficients which ensues is illustrated in figure 12, characterised by the fact that the fractions are obtained by dividing, respectively, the values of ω and of J in correspondence with the various positions of the valve element 5 with the values obtained at the VGcal position.

[0042] During the calibration process, after the ventilating element 4 is positioned in "ω_Cal" and the ionisation "J_ Cal" has been measured, these values are multiplied by the coefficients of the various powers shown in figure 12 to obtain, as mentioned earlier, the following values:

- the expected value of the velocity of the ventilating element 4 at the various apertures of the valve element 5;
- the set point of the ionisation current at the various apertures of the valve element 5;

[0043] The third table, namely the calibration table, is illustrated in figure 13. Said table is obtained by multiplying the coefficients of figure 12 by the values of ω_Cal and of J_Cal; in other words, the calibration result is, so to speak, "coupled" with the model of the combustion unit expressed by the aforesaid table 12.

[0044] Obviously, during normal boiler functioning, the value expected of the velocity of the ventilating element 5 and the ionisation set point must be available for each aperture value admissible for the valve element 5, which can generally vary continuously. To this end, for the expected ω for example, the four or more points (ω, valve element position) can be connected by line segments until a piecewise linear is realised. The same procedure can be followed for the ionisation. The result of this procedure is illustrated in figures 14 and 15. These two functions, as mentioned earlier, are entered in the temperature and λ control cycle after each new calibration.

[0045] It should be noted that this practical calibration process, although brief in duration, is not instantaneous. It is therefore possible that, over the span of the entire process, a variation may occur in the environmental conditions, which will modify the final result of said process (the ionisation current set point and a maximum valve of the velocity of the ventilating element 4). However, the same way of fmding more points for determining the functions $\omega = f(\lambda)|_{VGcal}$ lends the process notable soundness, since eventual effects of the variations in the environmental conditions are mediated by the interpolation procedures. Once the function $\omega = f(\lambda)|_{VGcal}$ is identified, the ventilating element 4 is immediately brought to the velocity $\omega\_Cal = f(\lambda_{opt}|_{VGcal})|_{VGcal}$ and the corresponding ionisation value is registered. In this very brief lapse of time, the variety in the surrounding conditions, which can alter suddenly and greatly, is reduced to almost solely the combustible supply pressure. Also following variations in the aforesaid surrounding conditions in this phase, during a normal modulation cycle effectuated on the basis of the calibration and acceptability controls which will be described hereinafter, the boiler system never reaches working conditions in which combustion is poor or hazardous. This method is certainly not worse than those which utilise a fraction of the maximum value of J itself as the ionisation current set point, since in this case the determining of this sole point can plausibly be influenced in a comparable way. The improvement lies in the fact that, in normal functioning conditions, the ionisation set point is not obtained empirically, but is measured directly in the desired λ condition. Between one calibration and the subsequent one, the quality and quantity range of environmental conditions that can vary is extremely broad (for example, the air and gas temperature, the quality of the gas, the obstruction of the fume outlet etc). With the variability of these conditions, the ionisation maintains a good biuniqueness with the excess air value (intending obviously in the λ>1 zone), while the velocity of the ventilating element 4 at which the desired ionisation is obtained, which is equal to the set point, can shift, even notably, from that of ω_SP envisaged at the given power. Therefore, while the ionisation current continues to testify to the excess of air, the velocity of the ventilating element 4 acts as indication of the maximum, to help reach the well known control objectives of the automatic control theory. As described hereinafter, around the maximum velocity of the ventilating element 4, there is a band of tolerance within which it is deemed that the environmental conditions have not altered too greatly since the previous calibration.

[0046] The aim of the calibration is to adapt the combustion control system to the surrounding conditions, which can, naturally, alter over time, with the ultimate aim being to obtain good performance in terms of combustion quality and yield. Concerning this, the calibrations can be requested by the control system 6 both following particular diagnostics events, as described hereinafter, and on a periodic basis (temporal or relating to the number of cycles of the burner).

[0047] The description above outlines a calibration procedure and calculation of the two functions ω_SP = f(Vgas) and J_SP = g(Vgas). According to these indications, once the two optimal values of the velocity of the ventilating element 4 and the ionisation current at a reference power have been found experimentally, these are extrapolated by means of multiplication by coefficients at other powers. To render the calculation of the functions ω_SP = f(Vgas) and J_SP = g (Vgas) more reliable though, the procedures to find the characteristic points - for the synthesis of the function of ventilating element $\omega=f(\lambda)|_{VGcal}$, for the identification of the velocity corresponding to the desired value of λ: $\omega\_Cal = f(\lambda_{opt}|_{VGcal})|_{VGcal}$ and to read the value of J_Cal - can be carried out at two or more reference powers rather than one only. This choice, which must be made once only in the laboratory, can be particularly useful in the case of a boiler equipped with this calibration and control system which has a high ratio between the maximum and minimum thermal power. In this case, in fact, the accuracy required in controlling the actuators (valve element 5 and ventilating element 4) to maintain stable combustion even at the low powers generated during the combustion process, is certainly greater than at high powers. That is why it can be useful to identify the ionisation set point J_SP at the minimum power directly by means of calibration at that power, rather than obtaining it empirically as a fraction of the calibration result at the sole reference power, as described hereinabove. From time to time, depending on the quantity of the power levels by means of which one intends to realise the calibration process, a specific method will be developed for the generation of the coefficients and extrapolation of the functions ω_SP = f(Vgas) and J_SP = g(Vgas) for all the power levels.

[0048] As described earlier, the result of the calibration process consists in the two functions ω_SP = f(Vgas) and J_SP = g(Vgas), which, when entered in the control scheme, consent the valve element 5 and the ventilating element 4 to be controlled so that the desired λ objective can be achieved, throughout the boiler's thermal power modulation range. In order to delimit a range of safe and good combustion, certain acceptability tests can be carried out on the values read for one or two ionisation currents and on the effective velocity of the ventilating element 4.

1. Acceptability test for velocity values of ventilating element 4 ω_Cal and ionisation current J_Cal identified following calibration.
One checks that the two identification values are found within a certain band of tolerance, with reference to the velocity and ionisation values read in correspondence with point A2 in figure 10, which corresponds to the maximum ionisation value identified during the descending ramp of the ventilating element 4. The numbers in the following relationships are shown as in the following example:

$$1.2 * \omega_{J\_max\text{-}A2'} < \omega\ Cal < 2.4 * \omega_{J\_max\text{-}A2'}$$

$$0.3 *_{J\_max\text{-}A2'} < J\_Cal < 2.2 * J_{J\_max\text{-}A2'}$$

If at least one of the two tests fails, for example because serious anomalies have occurred, one can, for example, decide to request a new calibration. Alternatively, if it is found that J_Cal >2.2 * $J_{J\_max\text{-}A2'}$ (the value found is greater than the value consented), one can decide to saturate the value to its maximum, i.e. to set : J_Cal = 2.2 *$J_{J\_max\text{-}A2'}$.
Furthermore, for the ionisation current identified, one can set an absolute band of tolerance. For example, one can realise the following test identified from 5μA<J_Cal<50μA. In the event that said test fails, one can proceed to ensure the control system determines a non-volatile burner lock.
2. Acceptability test on reaching the effective absolute maximum and minimum velocity limits of the ventilating element, and of the absolute ionisation current maximum limit measured.
As mentioned, the function ω_SP = f(Vgas) generated following a calibration provides a maximum value for the velocity of the ventilating element 4, at the various degrees of aperture of the valve element 5. Nevertheless, the velocity effectively set for the ventilating element is also composed of the value given by the shift between the desired ionisation current J_SP = g(Vgas) and that effectively measured. This global value ω_fan must not exceed an absolute tolerance band delimited by two functions that depend on the aperture of the valve element 5: max_ω =f (Vgas) and min_ω =f(Vgas). If, for example, the function that delimits the absolute upper limit of the band of tolerance is exceeded, this can mean that the environmental conditions have altered, involving a power overload or an obstruction in the fume outlet. As a countermeasure, one can temporarily reduce the maximum degree of aperture of the valve element 5, so that the airflow necessary to achieve the ionisation current set point is reduced. If the problem persists even after a recalibration, a non-volatile boiler lock can be commanded. Similar countermeasures, but this time temporarily increasing the minimum degree of valve aperture, can be adopted in the event that the effective velocity of the ventilating element drops below the absolute lower limit.
Likewise, an absolute upper limit can be set, which depends solely on the degree of aperture of the valve element 5 in the ionisation current conditions measured. If this value is exceeded, during the normal boiler modulation cycles, a new calibration is commanded. If the problem still persists after this operation, a non-volatile boiler lock is commanded.
3. Acceptability test on reaching the maximum and minimum limits relating to the effective velocity of the ventilating element 4.

Around the function ω_SP = f(Vgas) there is a relative band of tolerance set, which is set as a percentual fraction of said ω_SP. For example, one could set it so that during the normal boiler modulation cycle, the effective velocity ω_fan required of the ventilating element 4 satisfies the following condition:

$$0.6*\omega\_SP<\omega\_fan<1.4*\omega\_SP.$$

Failure to satisfy this test condition can occur if the environmental conditions alter with respect to those in which the previous calibration was carried out, thus suggesting a new calibration to adapt the functioning to the new surrounding conditions (for example, the quality of the gas has changed).

4. Acceptability test on values for measured ionisation currents J1 and J2.

Figure 4 shows the qualitative course of the two ionisation currents J1 and J2. The courses and the values really assumed depend not only on the geometry and nature of the combustion chamber, but also the flame circuit, the quality of the gas and on the power. In the event that two electrodes are utilised for the measurements of just as many ionisation currents, one can check the plausibility of the two measurement values by comparing one with the other. In the excess air interval in which the combustion is good, the value of J2 is less than that of J1. A function coeff_J2 = f(Vgas) dependant on the power, ranging from 0 to 1, can be defined, which delimits the value of J2 with respect to J1 deemed plausible for the given degree of aperture of the valve element. Converting this into symbols, the following must happen: J2< J1*coeff_J2. If it does not happen, a further calibration can be commanded. If the problem still persists after said further calibration has been effectuated, a non-volatile boiler lock can be commanded.

5. Acceptability test on inverse ionisation currents.

[0049] It is well known that the flame has a rectifying effect on the electrical field (voltage) applied to the ionisation electrodes. This leads, in an ideal case, to the ionisation current being able to flow one way only. In reality, if the polarity of the voltage applied to the flame is inverted, the positive in correspondence with the metal parts connected to the earth and the negative in correspondence with the other conductor on the same electrode exposed to the flame, a weak inverse current can be detected. The utility of measuring the inverse current is obvious in the event that one considers the practical possibility of insulation losses experienced by the ionisation electrodes and/or the cables connecting them to the measuring circuit. In this case, the continuous current is altered (the real impact depends on the structure of the measuring circuit) and a, possibly notable, increase in the inverse current is determined. The valuation of the inverse current can prove useful to determine any type of anomaly which may occur in the event of a distorted reading of the continuous ionisation current which, since said current is the image of the excess air λ, can lead to an abnormal, non-combustion situation. Utilising the opportune electronic circuits, it is possible, for one or for both the ionisation currents eventually measured, to detect both the continuous component, which is the component just described, and the inverse component. Thus, it proves possible to compare the value of the continuous current measured with the relative inverse current value measured. If the inverse current exceeds a certain fraction deemed indicative of malfunctioning of the respective continuous current, which can depend on the power, a non-volatile boiler lock can be commanded.

[0050] It should also be considered, furthermore, that situations can arise in which it is not possible to complete the calibration process as described hereinabove. It may happen, for example, that the power at which this procedure is realised is superabundant for the actual necessities, thereby determining the deactivation of the boiler due to output water temperature limits being reached. To assure the user the service nevertheless while awaiting the moment at which a complete calibration can be effectuated, it is possible to effectuate a quick calibration by identifying the values of ω_Cal and J_Cal from the respective values taken in correspondence with point A2 in figure 10, namely, the ionisation current maximum found during the descending ramp of the ventilating element velocity. If the values of ω_Cal and J_Cal relating to the previous complete calibration are found within a certain interval of the respective values found in correspondence with said point A2, these values will be accepted as the current values; otherwise, the extreme point values of the band of tolerance, which have been exceeded, will be taken as the current values. In symbols:

$$\omega\_Cal = \begin{cases} \omega\_Cal_{old} \text{ if } 1.2 * \omega J_{\_max\text{-}A2} < \omega\_Cal_{old} < 2.4 * \omega_{Jmax\text{-}A2} \\ 1.2 * \omega_{\_Jmax\text{-}A2} \text{ if } < \omega\_Cal_{old} < 1.2 * \omega_{Jmax\text{-}A2} \\ 2.4 * \omega_{\_Jmax\text{-}A2} \text{ if } \omega\_Cal_{old} > 2.4 * \omega_{Jmax\text{-}A2} \end{cases}$$

[0051] The value of J_Cal is set similarly.

[0052] Over the course of the description, reference has been made to the fact that the search for the characteristic points is effectuated, within the scope of the calibration process, within an ascending ramp of the velocity ω of a ventilating element, but said search can also clearly be effectuated advantageously in a descending ramp while still remaining within the scope of the present invention.

[0053] Also over the course of the description reference has been made to the fact that the request for power expressed by the heat transfer fluid error directly controls, via a regulator, the valve element 5, while said ventilating element 4 is controlled in such a way as to achieve the ionisation current objective, and therefore that of λ. Clearly though it is also possible to operate advantageously in an inverse direction, i.e. so that the request for power expressed by the heat transfer fluid error initially controls the ventilating element 4, while still remaining within the scope of the present invention.

[0054] Since, in any case, it is the gas flow which effectively determines the power generated by the combustion process, the system reaches the equilibrium condition in which the power is that requested, and is supplied by the gas flow to such an extent that even the ionisation current error is cancelled out. Obviously, the functions ω_SP = f(Vgas) and J_SP = g(Vgas) entered in the control scheme according to the main description must become, respectively, Vgas_SP = f(ω) and J_SP = g(ω). The calibration process, which serves to synthesise the two control functions, remains identical, with the sole addition of the further calculation which generates the two functions Vgas_SP = f(ω) and J_SP = g(ω) directly from ω_SP = f(Vgas) and J_SP = g(Vgas). In fact, the function Vgas_SP = f(ω) is simply the inverse of ω_SP = f(Vgas), which must be rendered monotone in the event that it is not. By combining the function J_SP = g(Vgas) with Vgas_SP = f(ω), one obtains: J_SP = g(Vgas_SP =f(ω)), i.e. J_SP = g(ω).

[0055] A first advantage of the present invention is constituted of the identification of a method which permits, at a preset power, the ionisation current set point J to be acquired in correspondence with a known λ value.

[0056] A further advantage of the present invention is constituted of the fact that said invention identifies the value λ, within the scope of a calibration process, by means of the identification of a correspondence law between ω and λ at the said preset power.

Captions	
Fig. 9	
Flow times	Vgas to the valve
	ω_fan
	T flow
Fig.10	
ωfan	
Fig. 11	
Gas valve position	
Fig. 12	
Gas valve position	ω - ratios J ratios
Fig. 13	
Gas valve position	

Claims

1. A method for controlling combustion in a heat-producing device fitted with a burner (3), a ventilating element (4), a heat exchanger (7) and a valve element (5) suitable for delivering, in variable quantities, a liquid or gas combustible,

said method utilising the knowledge of at least one ionisation current J in proximity to the flame in order to regulate the parameter λ expressing the air/combustible ratio during the combustion and said method also being of the type comprising at least one electrode (1, 2), a control system (6) inputted into which there are, at least, signals supplied by at least one electrode (1 or 2), the heat exchanger (7) and the ventilating element (4) and outputted from which there are, at least, signals towards the ventilating element and towards the valve element, **characterised by** the fact that the value of the at least one ionisation current J utilised as a set point for the subsequent regulation of λ measured by at least one electrode (1 or 2) is identified in combustion conditions in which a known and desired λ value is fixed, the knowledge thereof being based on an experimental observation with the result that, at a preset thermal power value, the velocity ω of the ventilating element (4) presents a course which is slightly shifted from a linear type course of the function $\omega=f(\lambda)|_{p=cosi,}$ **characterised by** the fact that a periodic calibration of the system is realised during which the piloting of the valve element (5) is maintained constant in order to realise the process at an almost constant power and the velocity of the ventilating element (4) is varied in order to identify the characteristic points of the line, identifying said function $\omega=f(\lambda)|_{p=cosi,}$ and **characterised by** the fact that acceptability tests are realised on the basis of the values of ω and J identified both during normal functioning and during said periodic system calibration process.

2. A method according to claim 1 **characterised by** the fact that by means of the use of two electrodes, at least six points can be identified which are utilisable to synthesise the line representing, substantially, the function $\omega=f(\lambda)|_{P=cosi,}$ and more precisely:

- the point at λ=0 with ω identified as the 'average' of the zone of intersection of the extensions of the lines of the ventilating element (4) at the various powers: (ω with λ =0, λ=0); this point is identified once only in the laboratory and is not calculated again during the boiler calibration process;
- the point whose ω is registered in correspondence with the maximum of the single ionisation current (Jl or J2): (ω with max-J, $\lambda \approx 1$);
- the point whose ω is registered in correspondence with the maximum of the ΔJ=J1 - J2: (ω with max-ΔJ);
- the point whose ω is registered in correspondence with the maximum of the relationship J1/J2: (ω with max -J1/J2);
- the point whose ω is registered in correspondence with the zero of the relationship ΔJ=J1 - J2: (ω with zero-ΔJ);
- the point whose ω is identified in correspondence, for example, with the occurrence of one of the following conditions:
- attainment of a fraction of the max of J of the max ionisation value or attainment of an absolute value of J, which is small in entity and just above the value at which the flame is deemed present, said value being called the detection threshold.

3. A method according to claims 1 and 2 **characterised by** the fact that by means of the use of one sole electrode, three points can be identified which are utilisable to synthesise the line representing the function $\omega=f(\lambda)|_{P=cosi}$, and more precisely:

- the point at λ= 0 with ω identified as the 'average' of the zone of intersection of the extensions of the lines of the ventilating element (4) at the various powers: (ω with λ =0, λ=0); this point is identified once only in the laboratory and is not calculated again during the boiler calibration process;
- the point whose ω is registered in correspondence with the maximum of the single ionisation current (J1 or J2): (ω with max-J, $\lambda \approx 1$);
- the point whose ω is registered in correspondence, for example, with the occurrence of one of the following conditions:
- attainment of a fraction of the max of J of the max ionisation value or attainment of an absolute value of J, which is small in entity and just above the value at which the flame is deemed present, said value being called the detection threshold.

4. A method according to claim 1 **characterised by** the fact that the calibration is performed according to the following succession of phases, all of which are managed by the control system (6):

- during the functioning of the combustion unit, the control system (6) brings the valve element (5) to a preset degree of aperture VGcal which realises the gas flow deemed optimal for the realisation of said system calibration and the ventilating element (4) is brought to a number of revolutions which assures an excess of air, in order to make the boiler function in a zone of the ionisation curve which is extremely distant from its maximum;
- the activation of a descending ramp of the velocity of the ventilating element (4), in order to find the maximum

value of solely one of the ionisation currents J1, or the second one J2, or, also, of both said ionisation currents; said maximum value is deemed identified when, running along the descending stretch of the ionisation curve, one reaches a certain percentage of the maximum value identified, for example, 90%, and the attainment of said maximum value is taken as the reference point;
- the activation of an ascending ramp of the velocity of the ventilating element (4), said ramp being aimed at finding the characteristic points of one or both the ionisation currents which the manufacturer has chosen to utilise;
- the synthesis of the line representing the function $\omega=f(\lambda)|_{VGcal}$ in preset aperture conditions of the valve element (5);
- the calculation of the velocity of the ventilating element (4) ω_Cal based on the formula $\omega=f(\lambda)|_{VGcal}$ corresponding to the desired value of λ at the power corresponding to the preset degree of aperture VGcal of the valve element (5);

- piloting of the ventilating element (4) at the velocity ω_Cal;
- actuation of a preset stabilisation time;
- reading of the value of the ionisation current J_Cal which is assumed as the ionisation current set point value in correspondence with the position of the valve element (5) VGcal, the two functions "velocity of the ventilating element (4) in the set point conditions as a function of the command signal for the valve element (5)" and "ionisation current in set point conditions as a function of the command signal for the valve element (5)", respectively: ω_SP=f(VGas) and J_SP=g(VGas), constituting the result of said calibration procedure.

5. A method according to claims 1 and 4 **characterised by** the fact that, certain parameters are identified in the laboratory which are indispensable for the calculation of the functions ω_SP=f(VGas) and J_SP=g(VGas), and more precisely:

- the expected value of the velocity of the ventilating element (4) at the various apertures of the valve element (5) in correspondence with the desired λ;
- the value of the ionisation current J at the various apertures of the said valve element, in correspondence with the desired λ; the identification of the said parameters comprising, in succession, the following first series of operations:
- the identification of a reference functioning condition, in which the valve element (5) is found in the position VGcal and the desired excess of air is present;
- the registration of the values of the ω of the rotation velocity of the ventilating element (4) and of the ionisation;
- the selection of other power levels in which to note, once the desired λ values have been reached, both the relative values of ω and the ionisation values;
- the drafting of a first table grouping together the results of the said first series of operations.

6. A method according to claims 1 and 5 **characterised by** the fact that the identification, in the laboratory, of the further parameters comprises, in succession, the following second series of operations:

- the obtainment of the fractions suitable to determine the relationships between the value of ω and the ionisation value for the various chosen positions of the ventilating element (5), and the value of ω and the ionisation value taken at VGcal;
- the drafting of a second table grouping together the results of the said second series of operations.

7. A method according to claims 1, 4 and 6 **characterised by** the fact that the identification of the further parameters comprises, in succession, the following third series of operations:

- the multiplication of the values ω_Cal and J_Cal by the results obtained from the second series of operations, i.e. by the coefficients of ω and J for the various powers;
- the drafting of a third table, known as the calibration table;
- the determination of the set point of the ionisation current J_SP at all the powers by means of the synthesis of piecewise linear;
- the determination of the set point of the expected velocity of the ventilating element (4) ω_SP at all the powers by means of the synthesis of a piecewise linear.

8. A method according to claims 1 and 7 **characterised by** the fact that the control of the combustion during normal functioning is performed by means of the use of the piecewise linears synthesised for the determination of both the set point of the ionisation current J_SP and the set point of the expected velocity of the ventilating element (4) ω_SP at all the powers.

9. A method according to claims 1, 4 and 5 **characterised by** the fact that, in order to render the calculation of the functions ω_SP = f(Vgas) and J_SP = g(Vgas) more reliable, two or more reference powers can be used instead of one sole power, thereby identifying the ionisation set point J_SP directly by means of the calibration at said two or more powers; depending on the number of power levels by means of which one wishes to realise the calibration process, a specific method will be developed to generate the coefficients and extrapolate aforesaid functions ω_SP = f(Vgas) and J_SP = g(Vgas) for all the power levels taken into consideration.

10. A method according to claims 1 and 4 **characterised by** the fact that said method envisages a first acceptability test consisting in the checking that the two values identified as ω_Cal and J_Cal at the calibration power are found within a band of tolerance, referring therewith to the velocity and ionisation current values read in correspondence with a point recorded as the ionisation current maximum identified during the descending ramp of the ventilating element (4); in the event that the acceptability test fails, the calibration is refused and a further one is requested; alternatively, the new values to attribute to ω_Cal and J_Cal will be the extreme points, which have been exceeded, of the bands of tolerance.

11. A method according to claim 1 **characterised by** the fact that said method envisages a second acceptability test consisting in the checking that a value ω_fan of the velocity of the ventilating element (4), said value being constituted of the set of the velocity value obtainable from the function ω_SP = f(Vgas) and from the correction contribution given by the shifting of the desired ionisation current obtainable from the function J_SP = g(Vgas) from that effectively measured, does not exceed an absolute band of tolerance delimited by two functions which depend on the aperture of the valve element, said two functions being max_ω=f(Vgas) and min_ω=f(Vgas).

12. A method according to claims 1 and 11 **characterised by** the fact that, in the event of failure of the second acceptability test on max_ω, the maximum degree of aperture of the gas valve is temporarily reduced in order to reduce the maximum power; in the event that said second acceptability test continues to fail, a new calibration will be requested; in the event that the test fails again, the control system will request a non-volatile burner lock.

13. A method according to claims 1 and 11 **characterised by** the fact that, in the event of failure of the second acceptability test on min_ω, the minimum degree of aperture of the gas valve is temporarily increased in order to increase the minimum power; in the event that said second acceptability test continues to fail, a new calibration will be requested; in the event that the test fails again, the control system will request a non-volatile burner lock.

14. A method according to claim 1 **characterised by** the fact that said method envisages a third acceptability test consisting in the defmition of a band of tolerance relating to the value ω_fan around the function ω_SP = f(Vgas), said band being defined as a percentual fraction of said ω_SP; in the event that test fails, a new calibration will be requested.

15. A method according to claim 1 **characterised by** the fact that said method envisages a fourth acceptability test consisting in the definition of a function coeff_J2 = f(VGas) dependant on the power and ranging from 0 to 1, which delimits the value of J2 with respect to J1 deemed plausible for a given degree of aperture of the valve element (5); in the event that the test results prove negative, the control system will command a non-volatile boiler lock.

16. A method according to claim 1 **characterised by** the fact that said method envisages a fifth acceptability test consisting in the detection of both the continuous component and the inverse component of the ionisation current and the comparison of the value of the continuous current measured with the relative value of the inverse current; in the event that the test results prove negative, the control system will command a non-volatile boiler lock.

17. A method according to claims 1 and 4 **characterised by** the fact that a quick calibration is actuated, thereby identifying the values ω_Cal and J_Cal from their respective values assumed in correspondence with the point representing the maximum value of the ionisation current found during the descending ramp of the velocity of the ventilating element (4), said quick type of calibration envisaging, in the event that the ω_Cal and J_Cal values relating to the complete calibration executed previously are found within a certain interval of the respective values found in correspondence with said point representing the maximum value of the ionisation current, said previous values being accepted as current values; in the contrary case, the current values assumed will be the extreme points, which have been exceeded, of the bands of tolerance.

18. A method according to the previous claims **characterised by** the fact that a calibration can be executed, not only in correspondence with diagnostics events but also on a periodic basis.

19. A method according to claims 1 and 4 **characterised by** the fact that the search for the characteristic points is effectuated, within the scope of the calibration, inside a descending ramp of the speed ω of the ventilating element (4).

20. A method according to the previous claims **characterised by** the fact that it is possible to make the system operate in the inverse mode so, that is, that the request for power expressed by the temperature error initially commands the ventilating element, while the gas flow is regulated so that it reaches the λ objective; by following this inverse operative mode, the functions $\omega\_SP = f(Vgas)$ and $J\_SP = g(Vgas)$ must become, respectively, $Vgas\_SP = f(\omega)$ and $J\_SP = g(\omega)$, the calibration process remaining identical, with the sole addition of the further calculation which generates the two functions $Vgas\_SP = f(\omega)$ and $J\_SP = g(\omega)$ directly from $\omega\_SP = f(Vgas)$ and $J\_SP = g(Vgas)$.

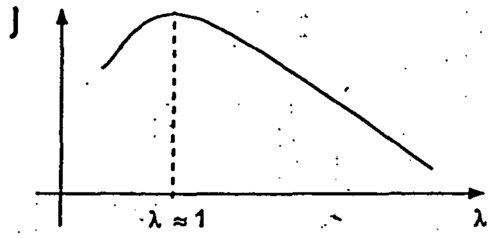


FIG.1

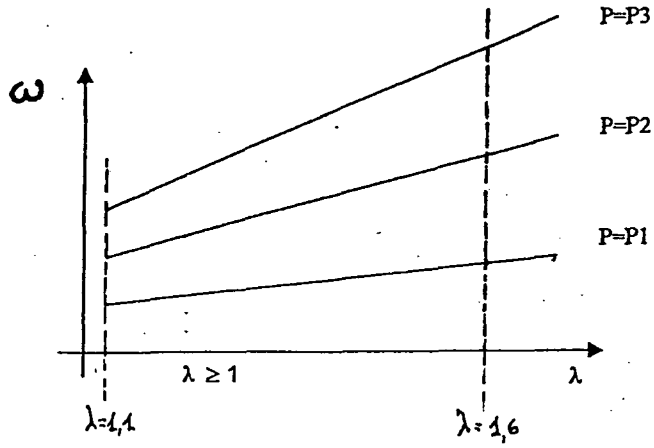


FIG.2

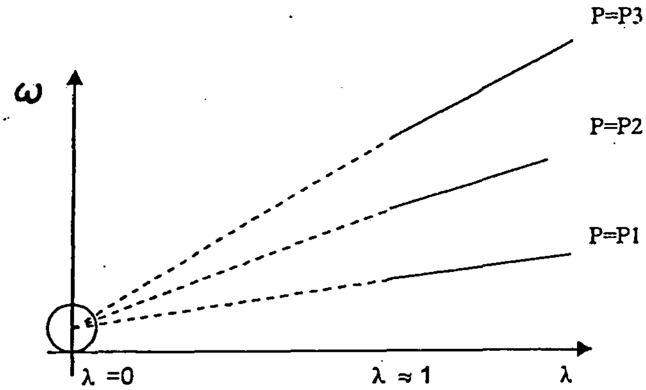


FIG.3

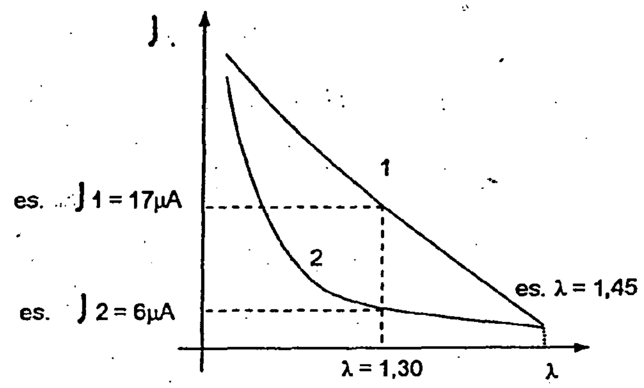


FIG.4

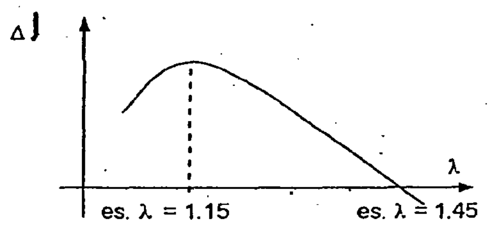


FIG.5

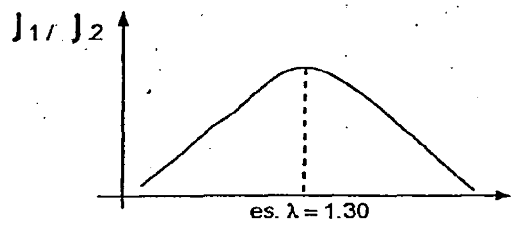


FIG.6

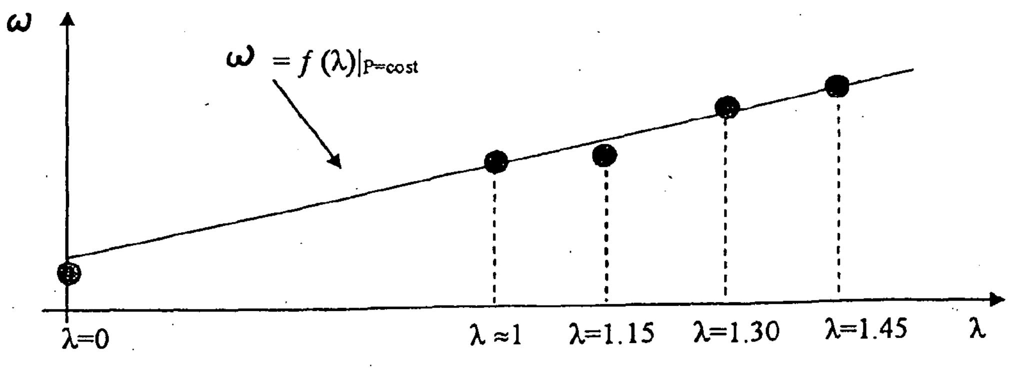


FIG.7

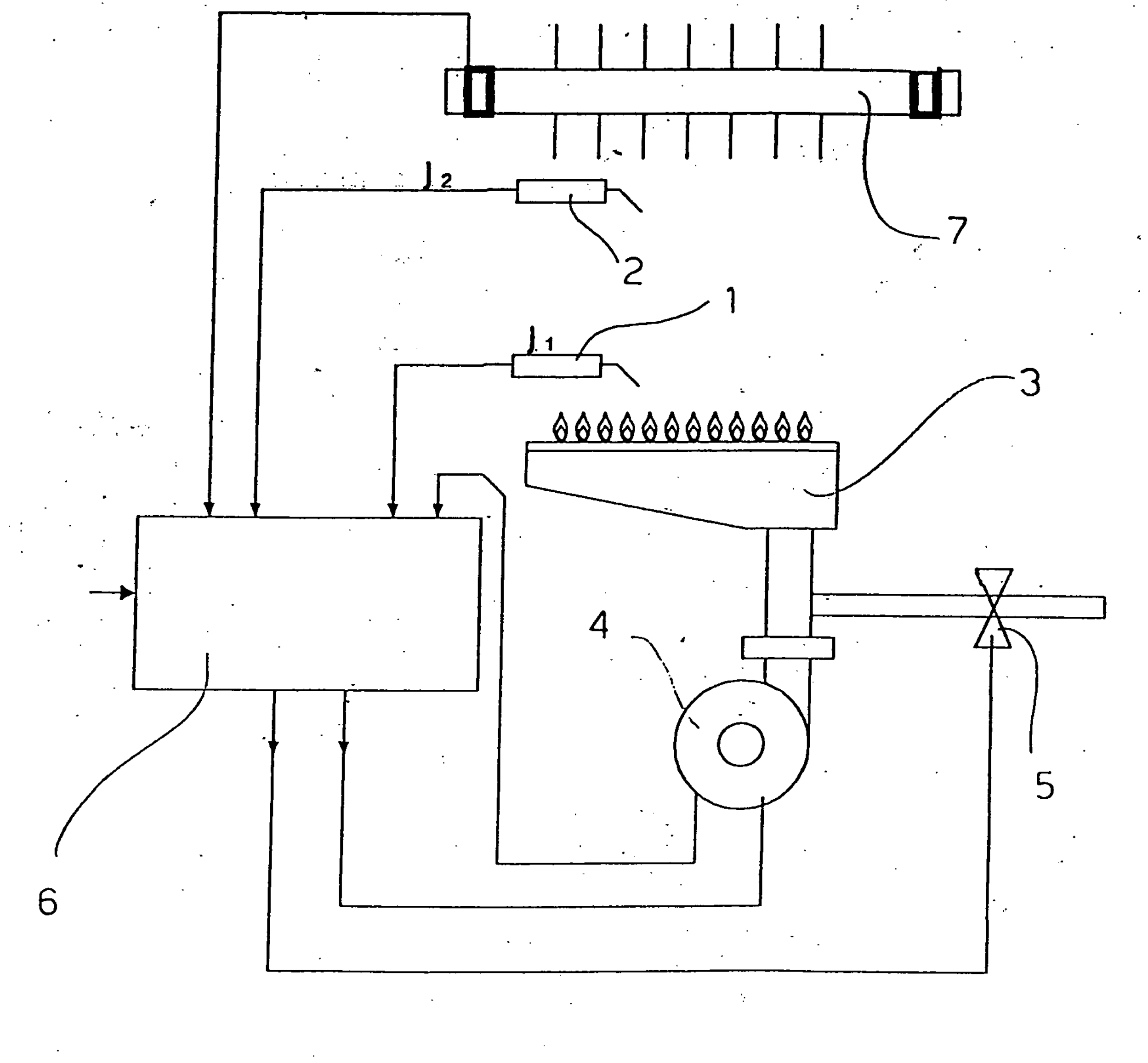
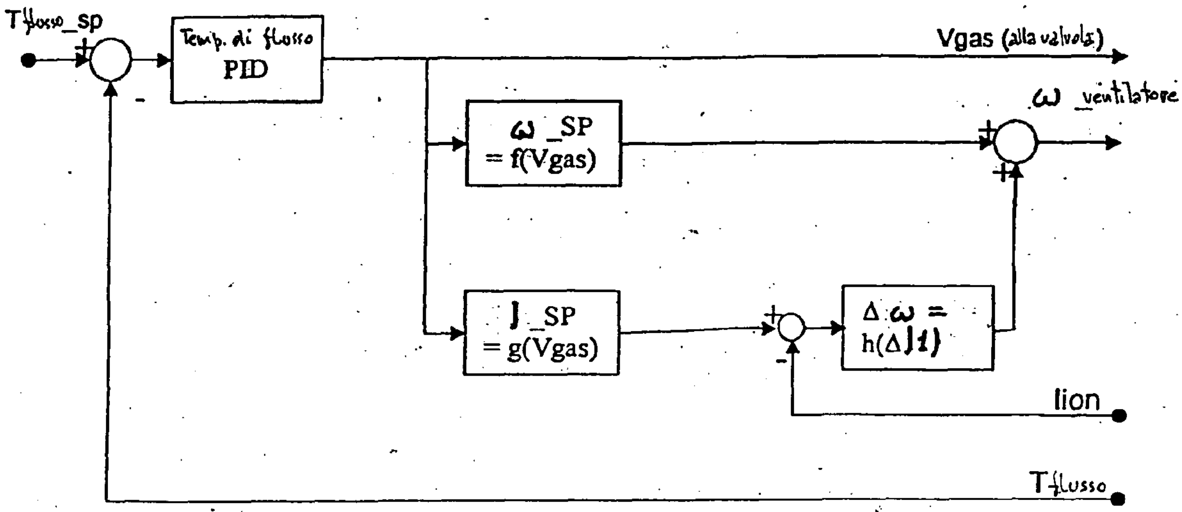
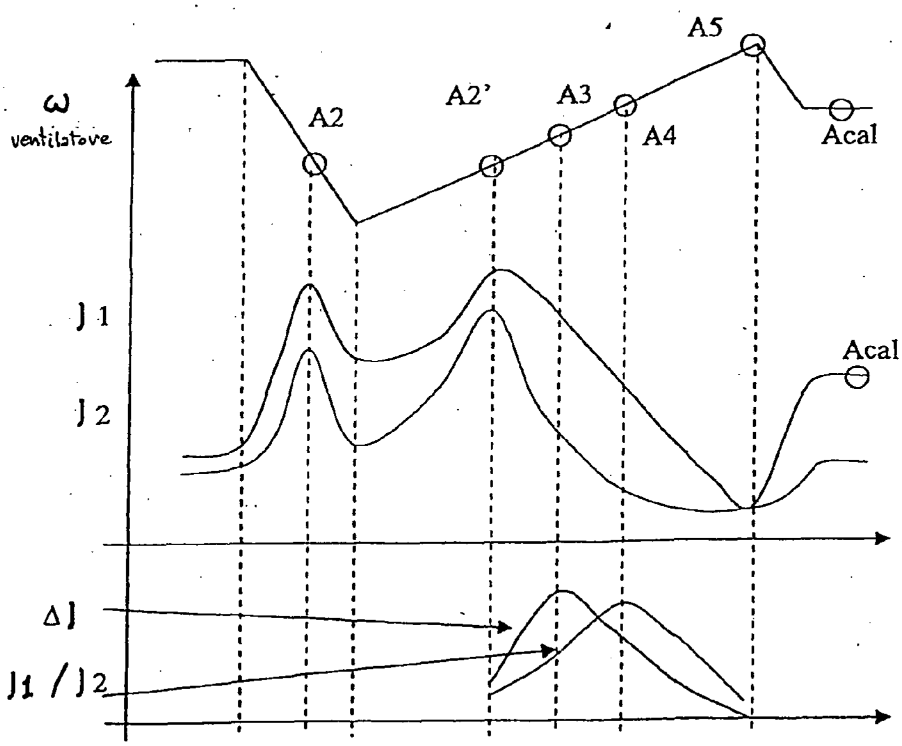


FIG. 8



Tflusso_sp
Temp. di flusso PID
Vgas (alla valvola)
ω_SP = f(Vgas)
ω_ventilatore
J_SP = g(Vgas)
Δω = h(ΔJ1)
Iion
Tflusso

FIG. 9



ω ventilatore
A2
A2'
A3
A4
A5
Acal
J1
J2
Acal
ΔJ
J1 / J2

FIG.10

Posizione valvola gas	ω (RPM)	J (μA)
100%	4000	25
VGcal	3000	20
25%	2000	15
10%	1000	10

FIG.11

Posizione valvola gas	ω - rapporti	J - rapporti
100%	4/3	5/4
VGcal	1	1
25%	2/3	¾
10%	1/3	½

FIG.12

Posizione valvola gas	ω_SP (RPM)	J_SP (μA)
100%	4/3 * ω_Cal	5/4 * J_Cal
VGcal	1 * ω_Cal	1 * J_Cal
25%	2/3 * ω_Cal	¾ * J_Cal
10%	1/3 * ω_Cal	½ * J_Cal

FIG.13

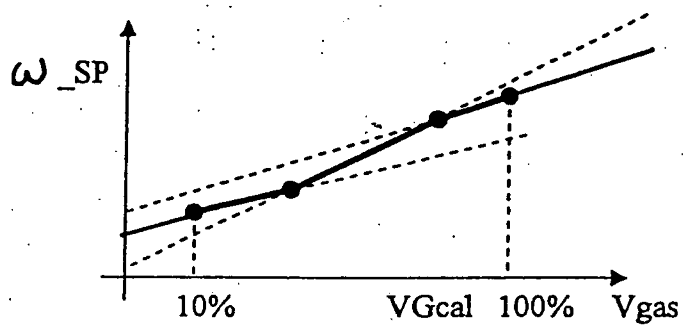


FIG. 14

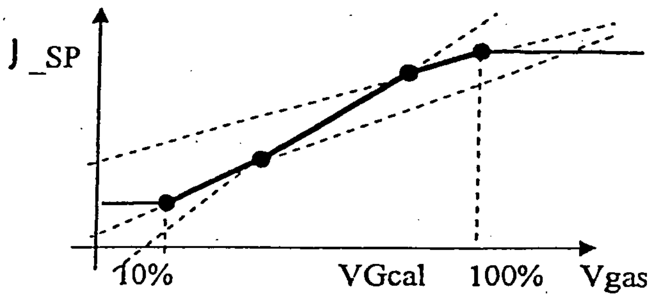


FIG. 15

REFERENCES CITED IN THE DESCRIPTION

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