

Description

Technical Field

5 **[0001]** 0001 The present invention relates to a surface hardening treatment device and a surface hardening treatment method which can perform a surface hardening treatment, such as nitriding, nitrocarburizing, nitriding quenching (austenitic nitriding), and the like, for a work made of metal.

Background Art

10 **[0002]** 0002 Among various surface hardening treatments for a work made of metal such as steel, there is a strong need for nitriding because it is a low distortion treatment. As a specific nitriding method, there are a gas method, a salt bath method, a plasma method, and the like.

15 **[0003]** 0003 Among these methods, the gas method is comprehensively superior when considering quality, environmental properties, mass productivity, and the like. Carburizing, carbonitriding or induction hardening (quenching) involved in hardening a mechanical part causes distortion, but the distortion can be improved when a nitriding treatment by a gas method (gas nitriding treatment) is used. A nitrocarburizing treatment by a gas method (gas nitrocarburizing treatment) involved in carburizing is also known as a treatment of the same kind as the gas nitriding treatment.

20 **[0004]** 0004 The gas nitriding treatment is a process in which only nitrogen is permeated and diffused into a work, in order to harden a surface of the work. In the gas nitriding treatment, an ammonia gas alone, a mixed gas of an ammonia gas and a nitrogen gas, a mixed gas of an ammonia gas and an ammonia decomposition gas (which consists of 75% hydrogen and 25% nitrogen, and is also called an AX gas), or a mixed gas of an ammonia gas, an ammonia decomposition gas and a nitrogen gas, is introduced into a processing furnace in order to perform a surface hardening treatment.

25 **[0005]** 0005 On the other hand, the gas nitrocarburizing treatment is a process in which carbon is secondarily permeated and diffused into a work together with nitrogen, in order to harden a surface of the work. For example, in the gas nitrocarburizing treatment, a mixed gas of an ammonia gas, a nitrogen gas and a carbon dioxide gas (CO_2) or a mixed gas of an ammonia gas, a nitrogen gas, a carbon dioxide gas and a carbon monoxide gas (CO) is introduced into a processing furnace in order to perform a surface hardening treatment, as a plurality of furnace introduction gases.

30 **[0006]** 0006 The basis of an atmosphere control in the gas nitriding treatment and in the gas nitrocarburizing treatment is to control a nitriding potential (K_N) in a furnace. By controlling the nitriding potential (K_N), it is possible to control a volume fraction of the γ' phase (Fe_4N) and the ϵ phase ($\text{Fe}_{2.3}\text{N}$) in a compound layer generated on a surface of a steel material and/or to achieve a process in which such a compound layer is not generated. That is to say, it is possible to obtain a wide range of nitriding qualities. For example, according to JP-A-2016-211069 (Patent Document 1), the bending fatigue strength and/or the wear resistance of a mechanical part may be improved by selecting the γ' phase and increasing its thickness, which can achieve a further high functionality of the mechanical part.

35 **[0007]** 0007 On the other hand, the nitrocarburizing treatment is used for making positive use of the ϵ phase which is hard, for example in order to improve the wear resistance ("Nitriding and Nitrocarburizing on Iron Materials", second edition (2013), pages 81-86 (Dieter Liedtke et al., Agune Technical Center) : Non-Patent Document 1).

40 **[0008]** 0008 In the gas nitriding treatment and the gas nitrocarburizing treatment as described above, in order to control an atmosphere in the processing furnace in which the work is arranged, an in-furnace atmospheric gas concentration measurement sensor configured to measure a hydrogen concentration in the furnace or an ammonia concentration in the furnace is installed. Then, the in-furnace nitriding potential is calculated from the measured value of the in-furnace atmospheric gas concentration measurement sensor, and is compared with a target (set) nitriding potential, in order to control the flow rate of each furnace introduction gas ("Heat Treatment", Volume 55, No. 1, pages 7-11 (Yasushi Hiraoka, Yoichi Watanabe): Non-Patent Document 2). As for the method of controlling each furnace introduction gas, a method of controlling the total amount while keeping the flow rate ratio between the respective furnace introduction gases constant is well known ("Nitriding and Nitrocarburizing on Iron Materials", second edition (2013), pages 158-163 (Dieter Liedtke et al., Agune Technical Center) : Non-Patent Document 3).

45 **[0009]** 0009 JP-B-5629436 (Patent Document 2) has disclosed a device which can perform both a first control step of controlling a total introduction amount of a plurality of furnace introduction gases while keeping a flow rate ratio between the plurality of furnace introduction gases constant and a second control step of controlling an introduction amount of each of the plurality of furnace introduction gases while changing a flow rate ratio between the plurality of furnace introduction gases (either one of the first control step and the second control step is selectively performed at a time) (JP-B-5629436: Patent Document 2). However, JP-B-5629436 (Patent Document 2) has disclosed only one example of nitriding treatment in which the first control step is effective (paragraphs 0096 and 0099 of JP-B-5629436 (Patent Document 2) : the nitriding potential 3.3 is precisely controlled "by controlling the total introduction amount of the ammonia gas and the nitrogen gas while keeping the flow rate ratio of NH_3 (ammonia gas) : N_2 (nitrogen gas) = 80 : 20"), but there is no description as to what kind of nitriding treatment or nitrocarburizing treatment for which the second control

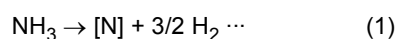
step should be adopted. In addition, JP-B-5629436 (Patent Document 2) has disclosed no specific example of the second control step.

[0010] 0010 The method of controlling a total introduction amount of a plurality of furnace introduction gases while keeping a flow rate ratio between the plurality of furnace introduction gases constant is advantageous in that the total used amount of the plurality of furnace introduction gases may be made smaller. However, it has been known that the controllable range of nitriding potential by means of this method is narrow. In order to cope with this problem, the present inventor has already developed a control method that can achieve a wide controllable range of nitriding potential on the side of lower nitriding potential (for example, about 0.05 to 1.3 at 580 °C) and has obtained JP-B-6345320 (Patent Document 3). According to the control method disclosed in JP-B-6345320 (Patent Document 3), an introduction amount of each of the plurality of furnace introduction gases is controlled by changing a flow rate ratio between the plurality of furnace introduction gases while keeping a total introduction amount of the plurality of furnace introduction gases constant, such that the nitriding potential in the processing furnace is brought close to the target nitriding potential.

[0011] 0011

(Fundamentals of the Gas Nitriding Treatment)

[0012] The fundamentals of the gas nitriding treatment are chemically explained. In the gas nitriding treatment, in the processing furnace (gas nitriding furnace) in which the work is arranged, a nitriding reaction represented by the following formula (1) occurs.

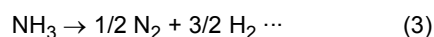


[0013] 0012 At this time, the nitriding potential K_N is defined by the following formula (2).

$$K_N = [P_{\text{NH}_3} / P_{\text{H}_2}] \cdots \quad (2)$$

[0014] Herein, the partial pressure of ammonia in the furnace is represented by P_{NH_3} , and the partial pressure of hydrogen in the furnace is represented by P_{H_2} . The nitriding potential K_N is well known as an index representing the nitriding ability of the atmosphere in the gas nitriding furnace.

[0015] 0013 On the other hand, in the furnace during the gas nitriding treatment, a part of the ammonia gas introduced into the furnace is thermally decomposed into a hydrogen gas and a nitrogen gas according to a reaction represented by the following formula (3).



[0016] 0014 In the furnace, the thermal decomposition reaction represented by the formula (3) mainly (dominantly) occurs, and the nitriding reaction represented by the formula (1) is almost negligible quantitatively. Therefore, if the in-furnace ammonia concentration consumed in the reaction represented by the formula (3) or the hydrogen gas concentration generated in the reaction represented by the formula (3) is known, the nitriding potential can be calculated. That is to say, since 1.5 mol of hydrogen and 0.5 mol of nitrogen are generated from 1 mol of ammonia, if the in-furnace ammonia concentration is measured, the in-furnace hydrogen concentration can also be known and thus the nitriding potential can be calculated. Alternatively, if the in-furnace hydrogen concentration is measured, the in-furnace ammonia concentration can also be known, and thus the nitriding potential can also be calculated.

[0017] 0015 The ammonia gas that has been introduced (flown) into the gas nitriding furnace is circulated through the furnace and then discharged outside the furnace. That is to say, in the gas nitriding treatment, a fresh (new) ammonia gas is continuously flown into the furnace with respect to the existing gases in the furnace, so that the existing gases are continuously discharged out of the furnace (extruded at the supply pressure).

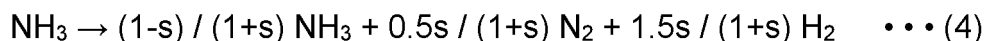
[0018] 0016 Herein, if the flow rate of the ammonia gas introduced into the furnace is small, the gas residence time thereof in the furnace becomes long, so that the amount of the ammonia gas to be thermally decomposed increases, which increases the amount of the sum of the nitrogen gas and the hydrogen gas generated by the thermal decomposition reaction. On the other hand, if the flow rate of the ammonia gas introduced into the furnace is large, the amount of the ammonia gas to be discharged outside the furnace without being thermally decomposed increases, which decreases the amount of the sum of the nitrogen gas and the hydrogen gas generated by the thermal decomposition reaction.

[0019] 0017

(Fundamentals of the Flow Rate Control)

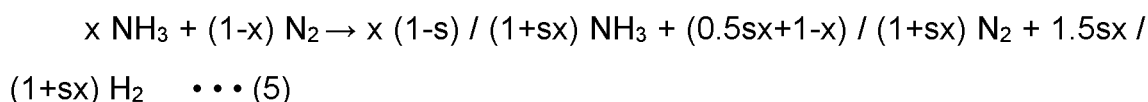
[0020] Next, the fundamentals of the flow rate control are explained in the case wherein an ammonia gas is used as

a solo (single) furnace introduction gas. When the degree of thermal decomposition of the ammonia gas introduced into the furnace is represented by s ($0 < s < 1$), the gas reaction in the furnace is represented by the following formula (4).



Herein, the left side represents the furnace introduction gas (ammonia gas only), the right side represents the in-furnace atmospheric gases (gas composition) including a part of the ammonia gas remained without being thermally decomposed, and the nitrogen gas and the hydrogen gas generated in the ratio of 1:3 by the thermal decomposition of the ammonia gas. Therefore, when the hydrogen concentration in the furnace is measured by means of a hydrogen sensor, $1.5s / (1+s)$ on the right side corresponds to the measured value of the hydrogen sensor, and thus the degree of the thermal decomposition s of the ammonia gas introduced into the furnace can be calculated from the measured value. Thereby, the ammonia concentration in the furnace corresponding to $(1-s) / (1+s)$ on the right side can also be calculated. That is to say, the in-furnace hydrogen concentration and the in-furnace ammonia concentration can be known only from the measured value of the hydrogen sensor. Thus, the nitriding potential can be calculated.

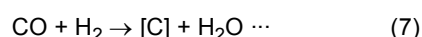
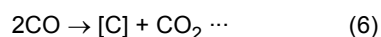
[0021] 0018 Similarly, even when a plurality of furnace introduction gases are used, it is possible to control the nitriding potential K_N . For example, when an ammonia gas and a nitrogen gas are used as two furnace introduction gases and the introduction ratio therebetween is $x : y$ (both x and y are known, and $x + y = 1$. For example, if $x = 0.5$, $y = 1 - 0.5 = 0.5$ ($\text{NH}_3 : \text{N}_2 = 1 : 1$), the gas reaction in the furnace is represented by the following formula (5).



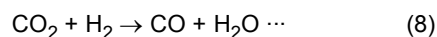
[0022] 0019 Herein, the right side represents the in-furnace atmospheric gases (gas composition) including a part of the ammonia gas remained without being thermally decomposed, the nitrogen gas and the hydrogen gas generated in the ratio of 1:3 by the thermal decomposition of the ammonia gas, and the nitrogen gas remained as introduced on the left side (without being decomposed in the furnace). Now, in the hydrogen concentration on the right side, i.e., $1.5sx / (1+sx)$, x is known (for example, $x = 0.5$), and thus only the degree of the thermal decomposition s of the ammonia gas introduced into the furnace is unknown. Therefore, in the same way as in the formula (4), the degree of the thermal decomposition s of the ammonia gas introduced into the furnace can be calculated from the measured value of the hydrogen sensor. Thereby, the ammonia concentration in the furnace can also be calculated. Thus, the nitriding potential can be calculated.

[0023] 0020 When the introduction ratio between the respective furnace introduction gases is not fixed, the in-furnace hydrogen concentration and the in-furnace ammonia concentration include two variables, i.e., the degree of the thermal decomposition s of the ammonia gas introduced into the furnace and the introduction ratio x of the ammonia gas. In general, a mass flow controller (MFC) is used as a device for controlling each gas flow rate. Thus, the introduction ratio x of the ammonia gas can be continuously read out as a digital signal based on flow rate values of the respective gases. Therefore, the nitriding potential can be calculated based on the formula (5) by combining this introduction ratio x and the measured value of the hydrogen sensor.

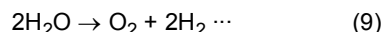
[0024] 0021 On the other hand, the fundamentals of the gas nitrocarburizing treatment are chemically explained. In the gas nitrocarburizing treatment, in the processing furnace (gas nitrocarburizing furnace) in which the work is arranged, a carbon supply reaction represented by the following formulas (6) and (7) occurs.



[0025] 0022 As clearly seen from the formulas (6) and (7), the carbon supply source is a carbon monoxide gas. The carbon monoxide gas may be directly introduced into the processing furnace, or may be generated in the processing furnace from a carbon dioxide gas. Herein, in the processing furnace, an equilibrium reaction represented by the following formula (8) is established.



[0026] 0023 In addition, in the processing furnace, regarding H_2O , another equilibrium reaction represented by the following formula (9) is established.



[0027] 0024 As seen from the above explanation, an amount of hydrogen (whose mole ratio is represented by w) consumed by the reactions represented by the formulas (8) and (9) is correlated to an amount of oxygen in the processing furnace. Thus, it is preferable to obtain the degree of the thermal decomposition s of the ammonia gas after calculating the mole ratio w based on a measured value of an oxygen sensor on the assumption that a measured value of the hydrogen sensor corresponds to $(1.5sx-w)/(1+sx)$, rather than to directly substitute a measured value of the hydrogen sensor for $1.5sx/(1+sx)$ in the formula (5).

[0028] 0025 An equilibrium constant of the formula (9) is $K = p_{\text{H}_2\text{O}} / (p_{\text{H}_2} \cdot p_{\text{O}_2}^{1.5})$, wherein $p_{\text{H}_2\text{O}}$, p_{H_2} and p_{O_2} are partial pressures of H_2O , H_2 and O_2 in the processing furnace, respectively. Thus, from an equilibrium constant K known correspondingly to an in-furnace temperature condition and measured values of both the oxygen sensor and the hydrogen sensor ($=p_{\text{H}_2}$, p_{O_2}), it is possible to calculate the value of $p_{\text{H}_2\text{O}}$. Then, as clearly seen from the formulas (8) and (9), the amount of hydrogen w consumed by those reactions corresponds to the value of $p_{\text{H}_2\text{O}}$. Therefore, it is possible to obtain the value of w , and thus in turn it is possible to obtain the degree of the thermal decomposition s of the ammonia gas.

Patent Document

[0029] 0026

The Patent Document 1 cited in the present specification is JP-A-2016-211069.

The Patent Document 2 cited in the present specification is JP-B-5629436.

The Patent Document 3 cited in the present specification is JP-B-6345320.

Non-patent Document

[0030] 0027

The Non-patent Document 1 cited in the present specification is "Nitriding and Nitrocarburizing on Iron Materials", second edition (2013), pages 81-86 (Dieter Liedtke et al., Agune Technical Center).

The Non-patent Document 2 cited in the present specification is "Heat Treatment", Volume 55, No. 1, pages 7-11 (Yasushi Hiraoka, Yoichi Watanabe).

The Non-patent Document 3 cited in the present specification is "Nitriding and Nitrocarburizing on Iron Materials", second edition (2013), pages 158-163 (Dieter Liedtke et al., Agune Technical Center).

The Non-patent Document 4 cited in the present specification is "Effect of Compound Layer Thickness Composed of γ' -Fe₄N on Rotated-Bending Fatigue Strength in Gas-Nitrided JIS-SCM435 Steel", Materials Transactions, Vol. 58, No. 7 (2017), pages 993-999 (Y. Hiraoka and A. Ishida).

The Non-patent Document 5 cited in the present specification is "The Special Steel", Volume 61, No. 3, pages 17-19 (Hitoshi Kabasawa)

Summary of Invention

Technical Problem

[0031] 0028 The present inventor has repeated diligent examination and various experiments about the gas nitrocarburizing treatment in which a plurality of furnace introduction gases including an ammonia gas and an ammonia decomposition gas are introduced into a processing furnace. As a result, the present inventor has found that a control of nitriding potential which is sufficient for practical use can be achieved by changing an introduction amount of each of the plurality of furnace introduction gases except for the ammonia decomposition gas while keeping an introduction amount of the ammonia decomposition gas constant, as a control for bringing the nitriding potential in the processing furnace close to the target nitriding potential.

[0032] 0029 The present invention has been made based on the above findings. It is an object of the present invention to provide a surface hardening treatment device and a surface hardening treatment method which are capable of achieving a control of nitriding potential which is sufficient for practical use, in a gas nitrocarburizing treatment in which a plurality of furnace introduction gases including an ammonia gas and an ammonia decomposition gas are introduced into a processing furnace.

Solution to Problem

[0033] 0030 The present invention is a surface hardening treatment device for performing a gas nitrocarburizing treatment as a surface hardening treatment for a work arranged in a processing furnace by introducing a plurality of furnace introduction gases including an ammonia gas and an ammonia decomposition gas, the surface hardening treatment device including: an in-furnace atmospheric gas concentration detector configured to detect a hydrogen concentration or an ammonia concentration in the processing furnace; an in-furnace nitriding potential calculator configured to calculate a nitriding potential in the processing furnace based on the hydrogen concentration or the ammonia concentration detected by the in-furnace atmospheric gas concentration detector; and a gas-introduction-amount controller configured to change an introduction amount of each of the plurality of furnace introduction gases except for the ammonia decomposition gas while keeping an introduction amount of the ammonia decomposition gas constant, based on the nitriding potential in the processing furnace calculated by the in-furnace nitriding potential calculator and a target nitriding potential, such that the nitriding potential in the processing furnace is brought close to the target nitriding potential.

[0034] 0031 According to the present invention, it has been confirmed that a control of nitriding potential of a relatively wider range (in particular, a control of nitriding potential which is relatively lower) can be achieved by changing the introduction amount of each of the plurality of furnace introduction gases except for the ammonia decomposition gas while keeping the introduction amount of the ammonia decomposition gas constant.

[0035] 0032 It is desirable that the introduction amount of the ammonia decomposition gas, which is to be kept constant, has been predetermined in advance by conducting a preliminary experiment before an actual operation. This is because, in fact, the degree of the thermal decomposition of the ammonia gas may be also influenced by in-furnace environment of the furnace to be used or the like.

[0036] 0033 Preferably, the surface hardening treatment device of the present invention further includes: an in-furnace oxygen concentration detector configured to detect an oxygen concentration in the processing furnace, wherein the in-furnace nitriding potential calculator is configured to calculate the nitriding potential in the processing furnace based on the hydrogen concentration or the ammonia concentration detected by the in-furnace atmospheric gas concentration detector and the oxygen concentration detected by the in-furnace oxygen concentration detector.

[0037] 0034 As described above, in the nitrocarburizing treatment, hydrogen is consumed in a carbon supply reaction such that water (H_2O) is generated. The generated amount of the water (H_2O) establishes an equilibrium with the amount of the oxygen in the processing furnace. Thus, a more precise nitriding potential can be achieved by detecting the oxygen concentration in the processing furnace by the in-furnace oxygen concentration detector and using the oxygen concentration for calculating the nitriding potential in the processing furnace.

[0038] 0035 In addition, it is preferable that the gas-introduction-amount controller is configured to control the introduction amount $C_1, \dots, C_N$ (N is an integer of one or more) of each of the plurality of furnace introduction gases except for the ammonia gas and the ammonia decomposition gas, using a factor of proportionality $c_1, \dots, c_N$ assigned to each of the plurality of furnace introduction gases except for the ammonia gas and the ammonia decomposition gas, such that $C_1 = c_1 \times (A + x \times B)$, $\dots$, $C_N = c_N \times (A + x \times B)$ wherein the introduction amount of the ammonia gas is represented by A , the introduction amount of the ammonia decomposition gas is represented by B , and a predetermined constant is represented by x .

[0039] 0036 According to the actual experiments conducted by the present inventor, it has been confirmed that, when the above control conditions are adopted, a control of nitriding potential of a relatively wider range (in particular, a control of nitriding potential which is relatively lower) can be achieved.

[0040] 0037 For example, the value of x is 0.5. This is because the amount of hydrogen generated in the processing furnace by the thermal decomposition of the ammonia gas of 1 mol is 1.5 mol while the amount of hydrogen supplied from the ammonia decomposition gas of 1 mol into the processing furnace is 0.75 mol ($3/4$ mol), and thus $1.5 : 0.75 = 1 : 0.5$. The value is explained as a factor for converting the introduction amount of the ammonia decomposition gas B into the introduction amount of the ammonia gas A with regard to the amount of hydrogen.

[0041] 0038 However, the value of x does not have to be strictly 0.5. If the value of x is roughly within a range of 0.4 to 0.6, a control of nitriding potential which is sufficient for practical use can be achieved.

[0042] 0039 The plurality of furnace introduction gases includes a carbon dioxide gas as a carburizing gas. Alternatively, the plurality of furnace introduction gases includes a carbon monoxide gas as a carburizing gas.

[0043] 0040 Alternatively, the plurality of furnace introduction gases includes a carbon dioxide gas and a nitrogen gas, or includes a carbon monoxide gas and a nitrogen gas.

[0044] 0041 In addition, the present invention can be recognized as a surface hardening treatment method. That is to say, the present invention is a surface hardening treatment method of performing a gas nitrocarburizing treatment as a surface hardening treatment for a work arranged in a processing furnace by introducing a plurality of furnace introduction gases including an ammonia gas and an ammonia decomposition gas, the surface hardening treatment method including: an in-furnace atmospheric gas concentration detecting step of detecting a hydrogen concentration or an ammonia concentration in the processing furnace; an in-furnace nitriding potential calculating step of calculating a nitriding potential

in the processing furnace based on the hydrogen concentration or the ammonia concentration detected at the in-furnace atmospheric gas concentration detecting step; and a gas-introduction-amount controlling step of changing an introduction amount of each of the plurality of furnace introduction gases except for the ammonia decomposition gas while keeping an introduction amount of the ammonia decomposition gas constant, based on the nitriding potential in the processing furnace calculated at the in-furnace nitriding potential calculating step and a target nitriding potential, such that the nitriding potential in the processing furnace is brought close to the target nitriding potential.

[0045] 0042 In addition, the present invention is a surface hardening treatment device for performing a gas nitrocarburizing treatment as a surface hardening treatment for a work arranged in a processing furnace by introducing a plurality of furnace introduction gases including an ammonia gas, an ammonia decomposition gas and a carburizing gas, the surface hardening treatment device including: an in-furnace atmospheric gas concentration detector configured to detect a hydrogen concentration or an ammonia concentration in the processing furnace; an in-furnace nitriding potential calculator configured to calculate a nitriding potential in the processing furnace based on the hydrogen concentration or the ammonia concentration detected by the in-furnace atmospheric gas concentration detector; and a gas-introduction-amount controller configured to change an introduction amount of each of the ammonia gas and the carburizing gas while keeping an introduction amount of the ammonia decomposition gas constant, based on the nitriding potential in the processing furnace calculated by the in-furnace nitriding potential calculator and a target nitriding potential, such that the nitriding potential in the processing furnace is brought close to the target nitriding potential.

[0046] 0043 The feature of the above invention is to change the introduction amount of each of the ammonia gas and the carburizing gas while keeping the introduction amount of the ammonia decomposition gas constant, while an introduction amount of each of the rest of the plurality of furnace introduction gases is not conditioned. Accordingly, the scope of the above invention can clearly cover any manner in which a certain minute amount of gas (whose flow ratio is about 1 % or less) is introduced to an extent that it does not substantially involve the reactions. For example, when two or more kinds of carburizing gases are introduced, the above invention is applicable, in which an introduction amount of the main carburizing gas may be changed and an introduction amount of the other carburizing gas minutely introduced may be constant, according to which a control of nitriding potential of a relatively wider range (in particular, a control of nitriding potential which is relatively lower) can be achieved.

[0047] 0044 In this case, it is preferable that the gas-introduction-amount controller is configured to control the introduction amount C1 of the carburizing gas, using a factor of proportionality c1 assigned to the carburizing gas, such that $C1 = c1 \times (A + x \times B)$, wherein the introduction amount of the ammonia gas is represented by A, the introduction amount of the ammonia decomposition gas is represented by B, and a predetermined constant is represented by x.

[0048] 0045 In addition, the present invention is a surface hardening treatment device for performing a gas nitrocarburizing treatment as a surface hardening treatment for a work arranged in a processing furnace by introducing a plurality of furnace introduction gases including an ammonia gas, an ammonia decomposition gas, a carburizing gas and a nitrogen gas, the surface hardening treatment device including: an in-furnace atmospheric gas concentration detector configured to detect a hydrogen concentration or an ammonia concentration in the processing furnace; an in-furnace nitriding potential calculator configured to calculate a nitriding potential in the processing furnace based on the hydrogen concentration or the ammonia concentration detected by the in-furnace atmospheric gas concentration detector; and a gas-introduction-amount controller configured to change an introduction amount of each of the ammonia gas, the carburizing gas and the nitrogen gas while keeping an introduction amount of the ammonia decomposition gas constant, based on the nitriding potential in the processing furnace calculated by the in-furnace nitriding potential calculator and a target nitriding potential, such that the nitriding potential in the processing furnace is brought close to the target nitriding potential.

[0049] 0046 The feature of the above invention is to change the introduction amount of each of the ammonia gas, the carburizing gas and the nitrogen gas while keeping the introduction amount of the ammonia decomposition gas constant, while an introduction amount of each of the rest of the plurality of furnace introduction gases is not conditioned. Accordingly, the scope of the above invention can clearly cover any manner in which a certain minute amount of gas (whose flow ratio is about 1 % or less) is introduced to an extent that it does not substantially involve the reactions. For example, when two or more kinds of carburizing gases are introduced, the above invention is applicable, in which an introduction amount of the main carburizing gas may be changed and an introduction amount of the other carburizing gas minutely introduced may be constant, according to which a control of nitriding potential of a relatively wider range (in particular, a control of nitriding potential which is relatively lower) can be achieved.

[0050] 0047 In this case, it is preferable that the gas-introduction-amount controller is configured to control the introduction amount C1 of the carburizing gas and the introduction amount C2 of the nitrogen gas, using a factor of proportionality c1 assigned to the carburizing gas and a factor of proportionality c2 assigned to the nitrogen gas, such that $C1 = c1 \times (A + x \times B)$ and $C2 = c2 \times (A + x \times B)$, wherein the introduction amount of the ammonia gas is represented by A, the introduction amount of the ammonia decomposition gas is represented by B, and a predetermined constant is represented by x.

Effects of Invention

[0051] 0048 According to the present invention, it has been confirmed that a control of nitriding potential of a relatively wider range (in particular, a control of nitriding potential which is relatively lower) can be achieved by changing the introduction amount of each of the plurality of furnace introduction gases except for the ammonia decomposition gas while keeping the introduction amount of the ammonia decomposition gas constant.

Brief Description of Drawings

[0052] 0049

Fig. 1 is a schematic view showing a surface hardening treatment device according to a first embodiment of the present invention;

Fig. 2 is a graph showing a control of furnace introduction gases according to an example 1-1;

Fig. 3 is a graph showing a control of nitriding potential according to the example 1-1;

Fig. 4 is a graph showing a control of furnace introduction gases according to an example 1-3;

Fig. 5 is a graph showing a control of nitriding potential according to the example 1-3;

Fig. 6 is a table comparing the examples 1-1 to 1-3 with their respective comparative examples;

Fig. 7 is a schematic view showing a surface hardening treatment device according to a second embodiment of the present invention;

Fig. 8 is a graph showing a control of furnace introduction gases according to an example 2-2;

Fig. 9 is a graph showing a control of nitriding potential according to the example 2-2;

Fig. 10 is a table comparing the examples 2-1 to 2-3 with their respective comparative examples;

Fig. 11 is a schematic view showing a surface hardening treatment device according to a third embodiment of the present invention;

Fig. 12 is a graph showing a control of furnace introduction gases according to an example 3-2;

Fig. 13 is a graph showing a control of nitriding potential according to the example 3-2;

Fig. 14 is a table comparing the examples 3-1 to 3-3 with their respective comparative examples;

Fig. 15 is a schematic view showing a surface hardening treatment device according to a fourth embodiment of the present invention;

Fig. 16 is a table comparing the examples 4-1 to 4-3 with their respective comparative examples;

Fig. 17 is a schematic view showing a surface hardening treatment device according to a fifth embodiment of the present invention; and

Fig. 18 is a table comparing the examples 5-1 to 5-3 with their respective comparative examples.

Description of Embodiments

[0053] 0050 Hereinafter, a preferable embodiment of the present invention will be described. However, the present invention is not limited to the embodiment.

[0054] 0051

(Structure)

[0055] Fig. 1 is a schematic view showing a surface hardening treatment device according to an embodiment of the present invention. As shown in Fig. 1, the surface hardening treatment device 1 of the present embodiment is a surface hardening treatment device for performing a gas nitrocarburizing treatment as a surface hardening treatment for a work S arranged in a processing furnace 2 by introducing an ammonia gas, an ammonia decomposition gas and a carbon dioxide gas into the processing furnace 2.

[0056] 0052 The ammonia decomposition gas is a gas called AX gas, and is a mixed gas composed of nitrogen and hydrogen in a ratio of 1 : 3. The work S is made of metal. For example, the work S is a steel part or a mold.

[0057] 0053 As shown in FIG. 1, the processing furnace 2 of the surface hardening treatment device 1 of the present embodiment includes: a stirring fan 8, a stirring-fan drive motor 9, a in-furnace temperature measuring device 10, a furnace body heater 11, an atmospheric gas concentration detector 3, a nitriding potential adjustor 4, a temperature adjustor 5, a programmable logic controller 31, a recorder 6, and a furnace introduction gas supplier 20.

[0058] 0054 The stirring fan 8 is disposed in the processing furnace 2 and configured to rotate in the processing furnace 2 in order to stir atmospheric gases in the processing furnace 2. The stirring-fan drive motor 9 is connected to the stirring fan 8 and configured to cause the stirring fan 8 to rotate at an arbitrary rotation speed.

[0059] 0055 The in-furnace temperature measuring device 10 includes a thermocouple and is configured to measure

a temperature of the in-furnace gases existing in the processing furnace 2. In addition, after measuring the temperature of the in-furnace gases, the in-furnace temperature measuring device 10 is configured to output an information signal including the measured temperature (in-furnace temperature signal) to the temperature adjustor 5 and the recorder 6.

[0060] 0056 The atmospheric gas concentration detector 3 is composed of: a sensor capable of detecting a hydrogen concentration or an ammonia concentration in the processing furnace 2 as an in-furnace atmospheric gas concentration; and an oxygen sensor capable of detecting an oxygen concentration in the processing furnace 2 as an in-furnace oxygen concentration. A main body of each of the above sensors communicates with an inside of the processing furnace 2 via an atmospheric gas pipe 12. In the present embodiment, the atmospheric gas pipe 12 is formed as a single-line path that directly communicates the sensors' main bodies of the atmospheric gas concentration detector 3 and the processing furnace 2. An on-off valve 17 is provided in the middle of the atmospheric gas pipe 12, and configured to be controlled by an on-off valve controller 16.

[0061] 0057 In addition, after detecting the in-furnace atmospheric gas concentration and the in-furnace oxygen concentration, the atmospheric gas concentration detector 3 is configured to output an information signal including the detected concentrations to the nitriding potential adjustor 4 and the recorder 6.

[0062] 0058 The recorder 6 includes a CPU and a storage medium such as a memory. Based on the signals outputted from the in-furnace temperature measurement device 10 and the atmospheric gas concentration detector 3, the recorder 6 is configured to record the temperature and/or the atmospheric gas concentration and the oxygen concentration in the processing furnace 2, for example in correspondence with the date and time when the surface hardening treatment is performed.

[0063] 0059 The nitriding potential adjustor 4 includes an in-furnace nitriding potential calculator 13 and a gas flow rate output adjustor 30. The programmable logic controller 31 includes a gas introduction controller 14 and a parameter setting device 15.

[0064] 0060 The in-furnace nitriding potential calculator 13 is configured to calculate a nitriding potential in the processing furnace 2 based on the hydrogen concentration or the ammonia concentration and the oxygen concentration detected by the atmospheric gas concentration detector 3. Specifically, calculation formulas for the nitriding potential are programmed dependent on the actual furnace introduction gases in accordance with the same theory as the above formulas (5) to (9), and incorporated in the in-furnace nitriding potential calculator 13, so that the nitriding potential is calculated from the value of the in-furnace atmospheric gas concentration and the value of the oxygen concentration.

[0065] 0061 In the present embodiment, the introduction amount C1 of the carbon dioxide gas, which is a furnace introduction gas except for (other than) the ammonia gas and the ammonia decomposition gas, is controlled using a factor of proportionality c1 assigned to the carbon dioxide gas, such that $C1 = c1 \times (A + x \times B)$, wherein the introduction amount of the ammonia gas is represented by A, the introduction amount of the ammonia decomposition gas is represented by B, and a predetermined constant is represented by x.

[0066] 0062 The parameter setting device 15 is composed of a touch panel, for example. Through the parameter setting device 15, the target nitriding potential, the processing temperature, the processing time, the introduction amount of the ammonia decomposition gas, the predetermined constant x, the factor of proportionality c1, and so on can be set and inputted for the same work. In addition, through the parameter setting device 15, setting parameter values for a PID control method can be set and inputted for each different value of the target nitriding potential. Specifically, "a proportional gain", "an integral gain or an integration time", and "a differential gain or a differentiation time" for the PID control method can be set and inputted for each different value of the target nitriding potential. The set and inputted setting parameter values are transferred to the gas flow rate output adjustor 30.

[0067] 0063 The gas flow rate output adjustor 30 is configured to perform the PID control method in which respective gas introduction amounts of the ammonia gas and the carbon dioxide gas among the three kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. More specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential by changing the introduction amount of the ammonia gas and the introduction amount of the carbon dioxide gas while keeping the introduction amount of the ammonia decomposition gas constant. In addition, in the present PID control method, the setting parameter values that have been transferred from the parameter setting device 15 are used.

[0068] 0064 Before the setting and inputting operation against the parameter setting device 15, it is preferable to perform pilot processes to obtain in advance candidate values for the setting parameter values of the PID control method. According to the present embodiment, even if (1) a state of the processing furnace (a state of a furnace wall and/or a jig), (2) a temperature condition of the processing furnace and (3) a state of the work (type and/or the number of parts) are the same, it is possible to obtain in advance candidate values for the setting parameter values (4) for each different value of the target nitriding potential, by an auto-tuning function that the nitriding potential adjustor 4 has in itself. In order to embody the nitriding potential adjustor 4 having such an auto-tuning function, a "UT75A" manufactured by Yokogawa Electric Co., Ltd. (a high-functional digital indicating controller, <http://www.yokogawa.co.jp/ns/cis/utup/utadvanced/ns-ut75a-01-ja.htm>) or the like can be used.

[0069] 0065 The setting parameter values (a set of "the proportional gain", "the integral gain or the integration time" and "the derivative gain or the derivative time") obtained as the candidate values can be recorded in some manner, and then can be manually inputted to the parameter setting device 15. Alternatively, the setting parameter values obtained as the candidate values can be stored in some storage device in a manner associated with the target nitriding potential, and then can be automatically read out by the parameter setting device 15 based on the set and inputted value of the target nitriding potential.

[0070] 0066 Before performing the PID control method, the gas flow rate output adjustor 30 is configured to determine an introduction amount of the ammonia decomposition gas, which is kept constant, and respective initial introduction amounts of the ammonia gas and of the carbon dioxide gas, which are subsequently changed. It is preferable to perform pilot processes to obtain in advance candidate values for these introduction amounts, so that the obtained values can be automatically read out by the parameter setting device 15 from some storage device or can be manually inputted to the parameter setting device 15. Thereafter, according to the PID control method, the introduction amount of the ammonia gas and the introduction amount of the carbon dioxide gas are changed (while the introduction amount of the ammonia decomposition gas is kept constant) such that the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the above relationship of $C1 = c1 \times (A + x \times B)$ is maintained. The output values from the gas flow rate output adjustor 30 are transferred to the gas introduction amount controller 14.

[0071] 0067 The gas introduction amount controller 14 is configured to transmit a control signal to a first supply amount controller 22 for the ammonia gas.

[0072] 0068 The furnace introduction gas supplier 20 of the present embodiment includes a first furnace introduction gas supplier 21 for the ammonia gas, the first supply amount controller 22, a first supply valve 23 and a first flow meter 24. In addition, the furnace introduction gas supplier 20 of the present embodiment includes a second furnace introduction gas supplier 25 for the ammonia decomposition gas (AX gas), a second supply amount controller 26, a second supply valve 27 and a second flow meter 28. Furthermore, the furnace introduction gas supplier 20 of the present embodiment includes a third furnace introduction gas supplier 61 for the carbon dioxide gas, a third supply amount controller 62, a third supply valve 63 and a third flow meter 64.

[0073] 0069 In the present embodiment, the ammonia gas, the ammonia decomposition gas and the carbon dioxide gas are mixed in a furnace introduction gas pipe 29 before entering the processing furnace 2.

[0074] 0070 The first furnace introduction gas supplier 21 is formed by, for example, a tank filled with a first furnace introduction gas (in this example, the ammonia gas).

[0075] 0071 The first supply amount controller 22 is formed by a mass flow controller (which can finely change a flow rate within a short time period), and is interposed between the first furnace introduction gas supplier 21 and the first supply valve 23. An opening degree of the first supply amount controller 22 changes according to the control signal outputted from the gas introduction amount controller 14. In addition, the first supply amount controller 22 is configured to detect a supply amount from the first furnace introduction gas supplier 21 to the first supply valve 23, and output an information signal including the detected supply amount to the gas introduction amount controller 14 and the recorder 6. This information signal can be used for correction or the like of the control performed by the gas introduction amount controller 14.

[0076] 0072 The first supply valve 23 is formed by an electromagnetic valve configured to switch between opened and closed states according to a control signal outputted from the gas introduction amount controller 14, and is interposed between the first supply amount controller 22 and the first flow meter 24.

[0077] 0073 The first flow meter 24 is formed by, for example, a mechanical flow meter such as a flow-type flow meter, and is interposed between the first supply valve 23 and the furnace introduction gas pipe 29. The first flow meter 24 detects a supply amount from the first supply valve 23 to the furnace introduction gas pipe 29. The supply amount detected by the first flow meter 24 can be provided for an operator's visual confirmation.

[0078] 0074 The second furnace introduction gas supplier 25 is formed by, for example, a tank filled with a second furnace introduction gas (in this example, the ammonia decomposition gas).

[0079] 0075 The second supply amount controller 26 is formed by a mass flow controller (which can finely change a flow rate within a short time period), and is interposed between the second furnace introduction gas supplier 25 and the second supply valve 27. An opening degree of the second supply amount controller 26 changes according to the control signal outputted from the gas introduction amount controller 14. In addition, the second supply amount controller 26 is configured to detect a supply amount from the second furnace introduction gas supplier 25 to the second supply valve 27, and output an information signal including the detected supply amount to the gas introduction amount controller 14 and the recorder 6. This information signal can be used for correction or the like of the control performed by the gas introduction amount controller 14.

[0080] 0076 The second supply valve 27 is formed by an electromagnetic valve configured to switch between opened and closed states according to a control signal outputted from the gas introduction amount controller 14, and is interposed between the second supply amount controller 26 and the second flow meter 28.

[0081] 0077 The second flow meter 28 is formed by, for example, a mechanical flow meter such as a flow-type flow

meter, and is interposed between the second supply valve 27 and the furnace introduction gas pipe 29. The second flow meter 28 detects a supply amount from the second supply valve 27 to the furnace introduction gas pipe 29. The supply amount detected by the second flow meter 28 can be provided for an operator's visual confirmation.

[0082] 0078 Herein, in the present invention, the introduction amount of the ammonia decomposition gas is not changed finely. Thus, the second supply amount controller 26 may be omitted, and a flow rate (an opening degree) of the second flow meter 28 may be manually adjusted correspondingly to the control signal outputted from the gas introduction amount controller 14.

[0083] 0079 The third furnace introduction gas supplier 61 is formed by, for example, a tank filled with a third furnace introduction gas (in this example, the carbon dioxide gas).

[0084] 0080 The third supply amount controller 62 is formed by a mass flow controller (which can finely change a flow rate within a short time period), and is interposed between the third furnace introduction gas supplier 61 and the third supply valve 63. An opening degree of the third supply amount controller 62 changes according to the control signal outputted from the gas introduction amount controller 14. In addition, the third supply amount controller 62 is configured to detect a supply amount from the third furnace introduction gas supplier 61 to the third supply valve 63, and output an information signal including the detected supply amount to the gas introduction amount controller 14 and the recorder 6. This information signal can be used for correction or the like of the control performed by the gas introduction amount controller 14.

[0085] 0081 The third supply valve 63 is formed by an electromagnetic valve configured to switch between opened and closed states according to a control signal outputted from the gas introduction amount controller 14, and is interposed between the third supply amount controller 62 and the third flow meter 64.

[0086] 0082 The third flow meter 64 is formed by, for example, a mechanical flow meter such as a flow-type flow meter, and is interposed between the third supply valve 63 and the furnace introduction gas pipe 29. The third flow meter 64 detects a supply amount from the third supply valve 63 to the furnace introduction gas pipe 29. The supply amount detected by the third flow meter 64 can be provided for an operator's visual confirmation.

[0087] 0083

(Operation: Example 1-1)

[0088] Next, with reference to Figs. 2 and 3, an operation of the surface hardening treatment device 1 according to the present embodiment is explained. First, a work S to be processed is put into the processing furnace 2, and then the processing furnace 2 starts to be heated. In the example shown in Figs. 2 and 3, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570°C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m^2 was used as the work S.

[0089] 0084 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas and the carbon dioxide gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20 according to their respective initial introduction amounts. In this example, as shown in Fig. 2, the initial introduction amount of the ammonia gas was set to 13 [l / min] , the initial introduction amount of the ammonia decomposition gas was set to 19 [l / min] , the initial introduction amount of the carbon dioxide gas was set to 1.03 [l / min] , $x = 0.5$ was set, and $c1 = 0.053$ was set. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0090] 0085 In the initial state, the on-off valve controller 16 closes the on-off valve 17. In general, as a pretreatment for the gas nitriding treatment, a treatment for activating a steel surface to make it easy for nitrogen to enter may be performed. In this case, a hydrogen chloride gas and/or a hydrogen cyanide gas or the like may be generated in the furnace. These gases may deteriorate the atmospheric gas concentration detector (sensors) 3, and thus it is effective to keep the on-off valve 17 closed.

[0091] 0086 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0092] 0087 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (0.6 in this example: see Fig. 3) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1 .

[0093] 0088 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (0.7 in this example) of the

target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0094] 0089 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0095] 0090 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas and the carbon dioxide gas among the three kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationship of $C1 = c1 \times (A + x \times B)$ is maintained, by changing the introduction amount of the ammonia gas and the introduction amount of the carbon dioxide gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0096] 0091 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas and the introduction amount of the carbon dioxide gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant) and the third supply amount controller 62 for the carbon dioxide gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0097] 0092 According to the control as described above, as shown in Fig. 3, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. As a specific example, in the example shown in Figs. 2 and 3, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (0.6) with extremely high precision since a timing of about 30 minutes after starting the treatment. (In the example shown in Figs. 2 and 3, recording of the respective gas introduction amounts and the nitriding potential was stopped at a timing of about 190 minutes after starting the treatment.)

[0098] 0093

(Operation: Example 1-2)

[0099] Next, another case is explained as an example 1-2, in which the surface hardening treatment device 1 according to the present embodiment is used and the target nitriding potential is set to 0.4. In the example 1-2 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0100] 0094 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas and the carbon dioxide gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20 according to their respective initial introduction amounts. In this example, the initial introduction amount of the ammonia gas was set to 5.5 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 25 [l / min], the initial introduction amount of the carbon dioxide gas was set to 0.95 [l / min], $x = 0.5$ was set, and $c1 = 0.053$ was set. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0101] 0095 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0102] 0096 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0103] 0097 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (0.4 in this example) and a standard

margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0104] 0098 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (0.5 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0105] 0099 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0106] 0100 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas and the carbon dioxide gas among the three kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationship of $C1 = c1 \times (A + x \times B)$ is maintained, by changing the introduction amount of the ammonia gas and the introduction amount of the carbon dioxide gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0107] 0101 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas and the introduction amount of the carbon dioxide gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant) and the third supply amount controller 62 for the carbon dioxide gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0108] 0102 According to the control as described above, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (0.4) with extremely high precision since a timing of about 30 minutes after starting the treatment.

[0109] 0103

(Operation: Example 1-3)

[0110] Next, further another case is explained as an example 1-3, in which the surface hardening treatment device 1 according to the present embodiment is used and the target nitriding potential is set to 0.2. In the example 1-3 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0111] 0104 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas and the carbon dioxide gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20 according to their respective initial introduction amounts. In this example, as shown in Fig. 4, the initial introduction amount of the ammonia gas was set to 2 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 29 [l / min], the initial introduction amount of the carbon dioxide gas was set to 0.87 [l / min], $x = 0.5$ was set, and $c1 = 0.053$ was set. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0112] 0105 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0113] 0106 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0114] 0107 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace),

but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (0.2 in this example: see Fig. 5) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0115] 0108 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (0.3 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0116] 0109 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0117] 0110 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas and the carbon dioxide gas among the three kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationship of $C1 = c1 \times (A + x \times B)$ is maintained, by changing the introduction amount of the ammonia gas and the introduction amount of the carbon dioxide gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0118] 0111 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas and the introduction amount of the carbon dioxide gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant) and the third supply amount controller 62 for the carbon dioxide gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0119] 0112 According to the control as described above, as shown in Fig. 5, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. As a specific example, in the example shown in Figs. 4 and 5, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (0.2) with extremely high precision since a timing of about 30 minutes after starting the treatment. (In the example shown in Figs. 4 and 5, recording of the respective gas introduction amounts and the nitriding potential was stopped at a timing of about 160 minutes after starting the treatment.)

[0120] 0113

(Explanation of Comparative Examples)

[0121] 45 As comparative examples, controls of nitriding potential were performed. In each of them, the ammonia decomposition gas was not introduced, the ratio of the introduction amounts of the ammonia gas and the carbon dioxide gas was always maintained at 95 : 5, and the total introduction amount thereof was changed.

[0122] 0114 Specifically, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculated the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performed the PID control method in which the respective gas introduction amounts of the ammonia gas and the carbon dioxide gas were input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 was an output value, and the target nitriding potential (the set nitriding potential) was a target value. More specifically, in the present PID control method, the nitriding potential in the processing furnace 2 was brought close to the target nitriding potential, by changing the total introduction amount of the ammonia gas and the carbon dioxide gas while keeping the ratio of the introduction amounts of the ammonia gas and the carbon dioxide gas constant.

[0123] 0115 However, in the above comparative examples, the nitriding potential could not be stably controlled.

[0124] 0116

(Comparison between Examples 1-1 to 1-3 and Comparative Examples)

[0125] A table of the above results is shown as Fig. 6.

[0126] 0117

(Structure of Second Embodiment)

[0127] As shown in Fig. 7, in a second embodiment, a third furnace introduction gas supplier 61' is formed by a tank filled with not a carbon dioxide gas but a carbon monoxide gas.

[0128] 0118 In the second embodiment, the introduction amount C1 of the carbon monoxide gas, which is a furnace introduction gas except for (other than) the ammonia gas and the ammonia decomposition gas, is controlled using a factor of proportionality c1 assigned to the carbon monoxide gas, such that $C1 = c1 \times (A + x \times B)$, wherein the introduction amount of the ammonia gas is represented by A, the introduction amount of the ammonia decomposition gas is represented by B, and a predetermined constant is represented by x.

[0129] 0119 The other structure of the second embodiment is substantially the same as that of the first embodiment explained with reference to Fig. 1. In Fig. 7, the same parts as those of the first embodiment are shown by the same reference numerals, and detailed explanation thereof is omitted.

[0130] 0120

(Operation: Example 2-1)

[0131] Next, a case is explained as an example 2-1, in which the surface hardening treatment device according to the second embodiment is used and the target nitriding potential is set to 0.6. In the example 2-1 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0132] 0121 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas and the carbon monoxide gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20 according to their respective initial introduction amounts. In this example, the initial introduction amount of the ammonia gas was set to 5.5 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 19 [l / min], the initial introduction amount of the carbon monoxide gas was set to 0.2 [l / min], x = 0.5 was set, and c1 = 0.01 was set. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0133] 0122 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0134] 0123 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0135] 0124 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (0.6 in this example) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0136] 0125 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (0.7 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0137] 0126 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0138] 0127 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas and the carbon monoxide gas among the three kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present

PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationship of $C1 = c1 \times (A + x \times B)$ is maintained, by changing the introduction amount of the ammonia gas and the introduction amount of the carbon monoxide gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0139] 0128 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas and the introduction amount of the carbon monoxide gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant) and the third supply amount controller 62 for the carbon monoxide gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0140] 0129 According to the control as described above, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (0.6) with extremely high precision since a timing of about 20 minutes after starting the treatment.

[0141] 0130

(Operation: Example 2-2)

[0142] Next, another case is explained as an example 2-2, in which the surface hardening treatment device according to the second embodiment is used and the target nitriding potential is set to 0.4. In the example 2-2 as well, a pit furnace having a size of $\varphi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0143] 0131 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas and the carbon monoxide gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20 according to their respective initial introduction amounts. In this example, as shown in Fig. 8, the initial introduction amount of the ammonia gas was set to 3 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 25 [l / min], the initial introduction amount of the carbon monoxide gas was set to 0.15 [l / min], $x = 0.5$ was set, and $c1 = 0.01$ was set. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0144] 0132 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0145] 0133 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0146] 0134 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (0.4 in this example) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0147] 0135 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (0.5 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0148] 0136 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0149] 0137 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas and the carbon monoxide gas among the three kinds of furnace

introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationship of $C1 = c1 \times (A + x \times B)$ is maintained, by changing the introduction amount of the ammonia gas and the introduction amount of the carbon monoxide gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0150] 0138 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas and the introduction amount of the carbon monoxide gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant) and the third supply amount controller 62 for the carbon monoxide gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0151] 0139 According to the control as described above, as shown in Fig. 9, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (0.4) with extremely high precision since a timing of about 20 minutes after starting the treatment.

[0152] 0140

(Operation: Example 2-3)

[0153] Next, another case is explained as an example 2-3, in which the surface hardening treatment device according to the second embodiment is used and the target nitriding potential is set to 0.2. In the example 2-3 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0154] 0141 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas and the carbon monoxide gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20 according to their respective initial introduction amounts. In this example, the initial introduction amount of the ammonia gas was set to 1 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 29 [l / min], the initial introduction amount of the carbon monoxide gas was set to 0.15 [l / min], $x = 0.5$ was set, and $c1 = 0.01$ was set. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0155] 0142 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0156] 0143 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0157] 0144 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (0.3 in this example) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0158] 0145 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (0.4 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0159] 0146 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0160] 0147 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the

respective gas introduction amounts of the ammonia gas and the carbon monoxide gas among the three kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationship of $C1 = c1 \times (A + x \times B)$ is maintained, by changing the introduction amount of the ammonia gas and the introduction amount of the carbon monoxide gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0161] 0148 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas and the introduction amount of the carbon monoxide gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant) and the third supply amount controller 62 for the carbon monoxide gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0162] 0149 According to the control as described above, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (0.2) with extremely high precision since a timing of about 30 minutes after starting the treatment.

[0163] 0150

(Explanation of Comparative Examples)

[0164] As comparative examples, controls of nitriding potential were performed. In each of them, the ammonia decomposition gas was not introduced, the ratio of the introduction amounts of the ammonia gas and the carbon monoxide gas was always maintained at 99 : 1, and the total introduction amount thereof was changed.

[0165] 0151 Specifically, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculated the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performed the PID control method in which the respective gas introduction amounts of the ammonia gas and the carbon monoxide gas were input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 was an output value, and the target nitriding potential (the set nitriding potential) was a target value. More specifically, in the present PID control method, the nitriding potential in the processing furnace 2 was brought close to the target nitriding potential, by changing the total introduction amount of the ammonia gas and the carbon monoxide gas while keeping the ratio of the introduction amounts of the ammonia gas and the carbon monoxide gas constant.

[0166] 0152 However, in the above comparative examples, the nitriding potential could not be stably controlled.

[0167] 0153

(Comparison between Examples 2-1 to 2-3 and Comparative Examples)

[0168] A table of the above results is shown as Fig. 10.

[0169] 0154

(Structure of Third Embodiment)

[0170] As shown in Fig. 11, a furnace introduction gas supplier 20' of a third embodiment further includes a fourth furnace introduction gas supplier 71 for nitrogen gas, a fourth supply amount controller 72, a fourth supply valve 73 and a fourth flow meter 74.

[0171] 0155 The fourth furnace introduction gas supplier 71 is formed by, for example, a tank filled with a fourth furnace introduction gas (in this example, nitrogen gas).

[0172] 0156 The fourth supply amount controller 72 is formed by a mass flow controller (which can finely change a flow rate within a short time period), and is interposed between the fourth furnace introduction gas supplier 71 and the fourth supply valve 73. An opening degree of the fourth supply amount controller 72 changes according to the control signal outputted from the gas introduction amount controller 14. In addition, the fourth supply amount controller 72 is configured to detect a supply amount from the fourth furnace introduction gas supplier 71 to the fourth supply valve 73, and output an information signal including the detected supply amount to the gas introduction amount controller 14 and

the recorder 6. This information signal can be used for correction or the like of the control performed by the gas introduction amount controller 14.

[0173] 0157 The fourth supply valve 73 is formed by an electromagnetic valve configured to switch between opened and closed states according to a control signal outputted from the gas introduction amount controller 14, and is interposed between the fourth supply amount controller 72 and the fourth flow meter 74.

[0174] 0158 The fourth flow meter 74 is formed by, for example, a mechanical flow meter such as a flow-type flow meter, and is interposed between the fourth supply valve 73 and the furnace introduction gas pipe 29. The fourth flow meter 74 detects a supply amount from the fourth supply valve 73 to the furnace introduction gas pipe 29. The supply amount detected by the fourth flow meter 74 can be provided for an operator's visual confirmation.

[0175] 0159 In the third embodiment, the introduction amount C1 of the carbon dioxide gas and the introduction amount C2 of the nitrogen gas, which are furnace introduction gases except for (other than) the ammonia gas and the ammonia decomposition gas, are controlled using a factor of proportionality c1 assigned to the carbon dioxide gas and a factor of proportionality c2 assigned to the nitrogen gas, such that $C1 = c1 \times (A + x \times B)$ and $C2 = c2 \times (A + x \times B)$, wherein the introduction amount of the ammonia gas is represented by A, the introduction amount of the ammonia decomposition gas is represented by B, and a predetermined constant is represented by x.

[0176] 0160 The other structure of the third embodiment is substantially the same as that of the first embodiment explained with reference to Fig. 1. In Fig. 11, the same parts as those of the first embodiment are shown by the same reference numerals, and detailed explanation thereof is omitted.

[0177] 0161

(Operation: Example 3-1)

[0178] Next, a case is explained as an example 3-1, in which the surface hardening treatment device according to the third embodiment is used and the target nitriding potential is set to 1.0. In the example 3-1 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0179] 0162 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas, the carbon dioxide gas and the nitrogen gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20' according to their respective initial introduction amounts. In this example, the initial introduction amount of the ammonia gas was set to 13 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 19 [l / min], the initial introduction amount of the carbon dioxide gas was set to 2.2 [l / min], the initial introduction amount of the nitrogen gas was set to 20 [l / min], x = 0.5 was set, c1 = 0.1 was set, and c2 = 0.9 was set. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0180] 0163 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0181] 0164 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0182] 0165 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (1.0 in this example) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0183] 0166 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (1.1 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0184] 0167 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0185] 0168 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas, the carbon dioxide gas and the nitrogen gas among the four

kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationships of $C1 = c1 \times (A + x \times B)$ and $C2 = c2 \times (A + x \times B)$ are maintained, by changing the introduction amount of the ammonia gas, the introduction amount of the carbon dioxide gas and the introduction amount of the nitrogen gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0186] 0169 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas, the introduction amount of the carbon dioxide gas and the introduction amount of the nitrogen gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant), the third supply amount controller 62 for the carbon dioxide gas and the fourth supply amount controller 72 for the nitrogen gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0187] 0170 According to the control as described above, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (1.0) with extremely high precision since a timing of about 20 minutes after starting the treatment.

[0188] 0171

(Operation: Example 3-2)

[0189] Next, another case is explained as an example 3-2, in which the surface hardening treatment device according to the third embodiment is used and the target nitriding potential is set to 0.6. In the example 3-2 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0190] 0172 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas, the carbon dioxide gas and the nitrogen gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20' according to their respective initial introduction amounts. In this example, as shown in Fig. 12, the initial introduction amount of the ammonia gas was set to 8 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 25 [l / min], the initial introduction amount of the carbon dioxide gas was set to 2 [l / min], the initial introduction amount of the nitrogen gas was set to 18.5 [l / min], $x = 0.5$ was set, $c1 = 0.1$ was set, and $c2 = 0.9$ was set. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0191] 0173 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0192] 0174 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0193] 0175 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (0.6 in this example) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0194] 0176 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (0.7 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0195] 0177 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0196] 0178 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted

oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas, the carbon dioxide gas and the nitrogen gas among the four kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationships of $C1 = c1 \times (A + x \times B)$ and $C2 = c2 \times (A + x \times B)$ are maintained, by changing the introduction amount of the ammonia gas, the introduction amount of the carbon dioxide gas and the introduction amount of the nitrogen gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0197] 0179 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas, the introduction amount of the carbon dioxide gas and the introduction amount of the nitrogen gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant), the third supply amount controller 62 for the carbon dioxide gas and the fourth supply amount controller 72 for the nitrogen gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0198] 0180 According to the control as described above, as shown in Fig. 13, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (0.6) with extremely high precision since a timing of about 30 minutes after starting the treatment.

[0199] 0181

(Operation: Example 3-3)

[0200] Next, another case is explained as an example 3-3, in which the surface hardening treatment device according to the third embodiment is used and the target nitriding potential is set to 0.2. In the example 3-3 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0201] 0182 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas, the carbon dioxide gas and the nitrogen gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20' according to their respective initial introduction amounts. In this example, the initial introduction amount of the ammonia gas was set to 3 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 29 [l / min], the initial introduction amount of the carbon dioxide gas was set to 1.8 [l / min], the initial introduction amount of the nitrogen gas was set to 15.8 [l / min], $x = 0.5$ was set, $c1 = 0.1$ was set, and $c2 = 0.9$ was set. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0202] 0183 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0203] 0184 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0204] 0185 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (0.2 in this example) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0205] 0186 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (0.3 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0206] 0187 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0207] 0188 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas, the carbon dioxide gas and the nitrogen gas among the four kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationships of $C1 = c1 \times (A + x \times B)$ and $C2 = c2 \times (A + x \times B)$ are maintained, by changing the introduction amount of the ammonia gas, the introduction amount of the carbon dioxide gas and the introduction amount of the nitrogen gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0208] 0189 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas, the introduction amount of the carbon dioxide gas and the introduction amount of the nitrogen gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant), the third supply amount controller 62 for the carbon dioxide gas and the fourth supply amount controller 72 for the nitrogen gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0209] 0190 According to the control as described above, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (0.2) with extremely high precision since a timing of about 40 minutes after starting the treatment.

[0210] 0191

(Explanation of Comparative Examples)

[0211] As comparative examples, controls of nitriding potential were performed. In each of them, the ammonia decomposition gas was not introduced, the ratio of the introduction amounts of the ammonia gas, the nitrogen gas and the carbon dioxide gas was always maintained at 50 : 45 : 5, and the total introduction amount thereof was changed.

[0212] 0192 Specifically, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculated the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performed the PID control method in which the respective gas introduction amounts of the ammonia gas, the nitrogen gas and the carbon dioxide gas were input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 was an output value, and the target nitriding potential (the set nitriding potential) was a target value. More specifically, in the present PID control method, the nitriding potential in the processing furnace 2 was brought close to the target nitriding potential, by changing the total introduction amount of the ammonia gas, the nitrogen gas and the carbon dioxide gas while keeping the ratio of the introduction amounts of the ammonia gas, the nitrogen gas and the carbon dioxide gas constant.

[0213] 0193 However, in the above comparative examples, the nitriding potential could not be stably controlled.

[0214] 0194

(Comparison between Examples 3-1 to 3-3 and Comparative Examples)

[0215] A table of the above results is shown as Fig. 14.

[0216] 0195

(Structure of Fourth Embodiment)

[0217] As shown in Fig. 15, in a fourth embodiment, a third furnace introduction gas supplier 61' is formed by a tank filled with not a carbon dioxide gas but a carbon monoxide gas.

[0218] 0196 In the fourth embodiment, the introduction amount C1 of the carbon monoxide gas and the introduction amount C2 of the nitrogen gas, which are furnace introduction gases except for (other than) the ammonia gas and the ammonia decomposition gas, are controlled using a factor of proportionality c1 assigned to the carbon monoxide gas and a factor of proportionality c2 assigned to the nitrogen gas, such that $C1 = c1 \times (A + x \times B)$ and $C2 = c2 \times (A + x \times B)$, wherein the introduction amount of the ammonia gas is represented by A, the introduction amount of the ammonia decomposition gas is represented by B, and a predetermined constant is represented by x.

[0219] 0197 The other structure of the fourth embodiment is substantially the same as that of the third embodiment explained with reference to Fig. 11. In Fig. 15, the same parts as those of the third embodiment are shown by the same reference numerals, and detailed explanation thereof is omitted.

[0220] 0198

(Operation: Example 4-1)

[0221] Next, a case is explained as an example 4-1, in which the surface hardening treatment device according to the fourth embodiment is used and the target nitriding potential is set to 1.0. In the example 4-1 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0222] 0199 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas, the carbon monoxide gas and the nitrogen gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20' according to their respective initial introduction amounts. In this example, the initial introduction amount of the ammonia gas was set to 13 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 19 [l / min], the initial introduction amount of the carbon monoxide gas was set to 0.9 [l / min], the initial introduction amount of the nitrogen gas was set to 20 [l / min], $x = 0.5$ was set, $c_1 = 0.04$ was set, and $c_2 = 0.96$ was set. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0223] 0200 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0224] 0201 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0225] 0202 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (1.0 in this example) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0226] 0203 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (1.1 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0227] 0204 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0228] 0205 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas, the carbon monoxide gas and the nitrogen gas among the four kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationships of $C_1 = c_1 \times (A + x \times B)$ and $C_2 = c_2 \times (A + x \times B)$ are maintained, by changing the introduction amount of the ammonia gas, the introduction amount of the carbon monoxide gas and the introduction amount of the nitrogen gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0229] 0206 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas, the introduction amount of the carbon monoxide gas and the introduction amount of the nitrogen gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant), the third supply amount controller 62 for the carbon monoxide gas and the fourth supply amount controller 72 for the nitrogen gas, in order to realize the respective determined introduction amounts of the furnace

introduction gases.

[0230] 0207 According to the control as described above, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (1.0) with extremely high precision since a timing of about 30 minutes after starting the treatment.

[0231] 0208

(Operation: Example 4-2)

[0232] Next, another case is explained as an example 4-2, in which the surface hardening treatment device according to the fourth embodiment is used and the target nitriding potential is set to 0.6. In the example 4-2 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0233] 0209 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas, the carbon monoxide gas and the nitrogen gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20' according to their respective initial introduction amounts. In this example, the initial introduction amount of the ammonia gas was set to 8 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 25 [l / min], the initial introduction amount of the carbon monoxide gas was set to 0.8 [l / min], the initial introduction amount of the nitrogen gas was set to 19.7 [l / min], $x = 0.5$ was set, $c1 = 0.04$ was set, and $c2 = 0.96$ was set. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0234] 0210 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0235] 0211 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0236] 0212 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (0.6 in this example) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0237] 0213 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (0.7 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0238] 0214 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0239] 0215 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas, the carbon monoxide gas and the nitrogen gas among the four kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationships of $C1 = c1 \times (A + x \times B)$ and $C2 = c2 \times (A + x \times B)$ are maintained, by changing the introduction amount of the ammonia gas, the introduction amount of the carbon monoxide gas and the introduction amount of the nitrogen gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0240] 0216 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas, the introduction amount of the carbon monoxide gas and the introduction amount of the nitrogen gas as a result of the

PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant), the third supply amount controller 62 for the carbon monoxide gas and the fourth supply amount controller 72 for the nitrogen gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0241] 0217 According to the control as described above, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (0.6) with extremely high precision since a timing of about 40 minutes after starting the treatment.

[0242] 0218

(Operation: Example 4-3)

[0243] Next, another case is explained as an example 4-3, in which the surface hardening treatment device according to the fourth embodiment is used and the target nitriding potential is set to 0.2. In the example 4-3 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0244] 0219 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas, the carbon monoxide gas and the nitrogen gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20' according to their respective initial introduction amounts. In this example, the initial introduction amount of the ammonia gas was set to 3 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 29 [l / min], the initial introduction amount of the carbon monoxide gas was set to 0.7 [l / min], the initial introduction amount of the nitrogen gas was set to 16 [l / min], $x = 0.5$ was set, $c1 = 0.04$ was set, and $c2 = 0.96$ was set. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0245] 0220 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0246] 0221 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0247] 0222 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (0.2 in this example) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0248] 0223 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (0.3 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0249] 0224 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0250] 0225 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas, the carbon monoxide gas and the nitrogen gas among the four kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationships of $C1 = c1 \times (A + x \times B)$ and $C2 = c2 \times (A + x \times B)$ are maintained, by changing the introduction amount of the ammonia gas, the introduction amount of the carbon monoxide gas and the introduction amount of the nitrogen gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the

parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0251] 0226 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas, the introduction amount of the carbon monoxide gas and the introduction amount of the nitrogen gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant), the third supply amount controller 62 for the carbon monoxide gas and the fourth supply amount controller 72 for the nitrogen gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0252] 0227 According to the control as described above, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (0.2) with extremely high precision since a timing of about 40 minutes after starting the treatment.

[0253] 0228

(Explanation of Comparative Examples)

[0254] As comparative examples, controls of nitriding potential were performed. In each of them, the ammonia decomposition gas was not introduced, the ratio of the introduction amounts of the ammonia gas, the nitrogen gas and the carbon monoxide gas was always maintained at 50 : 48 : 2, and the total introduction amount thereof was changed.

[0255] 0229 Specifically, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculated the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performed the PID control method in which the respective gas introduction amounts of the ammonia gas, the nitrogen gas and the carbon monoxide gas were input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 was an output value, and the target nitriding potential (the set nitriding potential) was a target value. More specifically, in the present PID control method, the nitriding potential in the processing furnace 2 was brought close to the target nitriding potential, by changing the total introduction amount of the ammonia gas, the nitrogen gas and the carbon monoxide gas while keeping the ratio of the introduction amounts of the ammonia gas, the nitrogen gas and the carbon monoxide gas constant.

[0256] 0230 However, in the above comparative examples, the nitriding potential could not be stably controlled.

[0257] 0231

(Comparison between Examples 4-1 to 4-3 and Comparative Examples)

[0258] A table of the above results is shown as Fig. 16.

[0259] 0232

(Structure of Fifth Embodiment)

[0260] As shown in Fig. 17, a furnace introduction gas supplier 20' of a fifth embodiment further includes a fifth furnace introduction gas supplier 81 for carbon dioxide gas, a fifth supply amount controller 82, a fifth supply valve 83 and a fifth flow meter 84, in addition to the furnace introduction gas supplier 20' of the fourth embodiment.

[0261] 0233 The fifth furnace introduction gas supplier 81 is formed by, for example, a tank filled with a fifth furnace introduction gas (in this example, carbon dioxide gas).

[0262] 0234 The fifth supply amount controller 82 is formed by a mass flow controller (which can finely change a flow rate within a short time period), and is interposed between the fifth furnace introduction gas supplier 81 and the fifth supply valve 83. An opening degree of the fifth supply amount controller 82 changes according to the control signal outputted from the gas introduction amount controller 14. In addition, the fifth supply amount controller 82 is configured to detect a supply amount from the fifth furnace introduction gas supplier 81 to the fifth supply valve 83, and output an information signal including the detected supply amount to the gas introduction amount controller 14 and the recorder 6. This information signal can be used for correction or the like of the control performed by the gas introduction amount controller 14.

[0263] 0235 The fifth supply valve 83 is formed by an electromagnetic valve configured to switch between opened and closed states according to a control signal outputted from the gas introduction amount controller 14, and is interposed between the fifth supply amount controller 82 and the fifth flow meter 84.

[0264] 0236 The fifth flow meter 84 is formed by, for example, a mechanical flow meter such as a flow-type flow meter,

and is interposed between the fifth supply valve 83 and the furnace introduction gas pipe 29. The fifth flow meter 84 detects a supply amount from the fifth supply valve 83 to the furnace introduction gas pipe 29. The supply amount detected by the fifth flow meter 84 can be provided for an operator's visual confirmation.

[0265] 0237 In the fifth embodiment, the introduction amount C1 of the carbon monoxide gas, the introduction amount C2 of the nitrogen gas and the introduction amount C3 of the carbon dioxide gas, which are furnace introduction gases except for (other than) the ammonia gas and the ammonia decomposition gas, are controlled using a factor of proportionality c1 assigned to the carbon monoxide gas, a factor of proportionality c2 assigned to the nitrogen gas and a factor of proportionality c3 assigned to the carbon dioxide gas, such that $C1 = c1 \times (A + x \times B)$, $C2 = c2 \times (A + x \times B)$ and $C3 = c3 \times (A + x \times B)$, wherein the introduction amount of the ammonia gas is represented by A, the introduction amount of the ammonia decomposition gas is represented by B, and a predetermined constant is represented by x.

[0266] 0238 The other structure of the fifth embodiment is substantially the same as that of the fourth embodiment explained with reference to Fig. 15. In Fig. 17, the same parts as those of the fourth embodiment are shown by the same reference numerals, and detailed explanation thereof is omitted.

[0267] 0239

(Operation: Example 5-1)

[0268] Next, a case is explained as an example 5-1, in which the surface hardening treatment device according to the fifth embodiment is used and the target nitriding potential is set to 1.0. In the example 5-1 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0269] 0240 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas, the carbon monoxide gas, the nitrogen gas and the carbon dioxide gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20" according to their respective initial introduction amounts. In this example, the initial introduction amount of the ammonia gas was set to 13 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 19 [l / min], the initial introduction amount of the carbon monoxide gas was set to 0.45 [l / min], the initial introduction amount of the nitrogen gas was set to 21 [l / min], the initial introduction amount of the carbon dioxide gas was set to 0.9 [l / min], $x = 0.5$ was set, $c1 = 0.02$ was set, $c2 = 0.94$ was set, and $c3 = 0.04$. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0270] 0241 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0271] 0242 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0272] 0243 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (1.0 in this example) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0273] 0244 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (1.1 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0274] 0245 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0275] 0246 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas, the carbon monoxide gas, the nitrogen gas and the carbon dioxide gas among the five kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationships of $C1 = c1 \times (A + x \times B)$, $C2 = c2 \times (A + x \times B)$

and $C3 = c3 \times (A + x \times B)$ are maintained, by changing the introduction amount of the ammonia gas, the introduction amount of the carbon monoxide gas, the introduction amount of the nitrogen gas and the introduction amount of the carbon dioxide gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0276] 0247 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas, the introduction amount of the carbon monoxide gas, the introduction amount of the nitrogen gas and the introduction amount of the carbon dioxide gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant), the third supply amount controller 62 for the carbon monoxide gas, the fourth supply amount controller 72 for the nitrogen gas and the fifth supply amount controller 82 for the carbon dioxide gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0277] 0248 According to the control as described above, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (1.0) with extremely high precision since a timing of about 30 minutes after starting the treatment.

[0278] 0249

(Operation: Example 5-2)

[0279] Next, another case is explained as an example 5-2, in which the surface hardening treatment device according to the fifth embodiment is used and the target nitriding potential is set to 0.6. In the example 5-2 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0280] 0250 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas, the carbon monoxide gas, the nitrogen gas and the carbon dioxide gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20 according to their respective initial introduction amounts. In this example, the initial introduction amount of the ammonia gas was set to 12 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 25 [l / min], the initial introduction amount of the carbon monoxide gas was set to 0.5 [l / min], the initial introduction amount of the nitrogen gas was set to 23 [l / min], the initial introduction amount of the carbon dioxide gas was set to 1.0 [l / min], $x = 0.5$ was set, $c1 = 0.02$ was set, $c2 = 0.94$ was set, and $c3 = 0.04$. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0281] 0251 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0282] 0252 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0283] 0253 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (1.0 in this example) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0284] 0254 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (0.7 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0285] 0255 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0286] 0256 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted

oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas, the carbon monoxide gas, the nitrogen gas and the carbon dioxide gas among the five kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationships of $C1 = c1 \times (A + x \times B)$, $C2 = c2 \times (A + x \times B)$ and $C3 = c3 \times (A + x \times B)$ are maintained, by changing the introduction amount of the ammonia gas, the introduction amount of the carbon monoxide gas, the introduction amount of the nitrogen gas and the introduction amount of the carbon dioxide gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0287] 0257 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas, the introduction amount of the carbon monoxide gas, the introduction amount of the nitrogen gas and the introduction amount of the carbon dioxide gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant), the third supply amount controller 62 for the carbon monoxide gas, the fourth supply amount controller 72 for the nitrogen gas and the fifth supply amount controller 82 for the carbon dioxide gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0288] 0258 According to the control as described above, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (0.6) with extremely high precision since a timing of about 40 minutes after starting the treatment.

[0289] 0259

(Operation: Example 5-3)

[0290] Next, another case is explained as an example 5-3, in which the surface hardening treatment device according to the fifth embodiment is used and the target nitriding potential is set to 0.2. In the example 5-3 as well, a pit furnace having a size of $\phi 700 \times 1000$ was used as the processing furnace 2, 570 °C was adopted as the temperature to be heated, and a steel material having a surface area of 4 m² was used as the work S.

[0291] 0260 While the processing furnace 2 is heated, the ammonia gas, the ammonia decomposition gas, the carbon monoxide gas, the nitrogen gas and the carbon dioxide gas are introduced into the processing furnace 2 from the furnace introduction gas supplier 20 according to their respective initial introduction amounts. In this example, the initial introduction amount of the ammonia gas was set to 3 [l / min], the initial introduction amount of the ammonia decomposition gas was set to 29 [l / min], the initial introduction amount of the carbon monoxide gas was set to 0.3 [l / min], the initial introduction amount of the nitrogen gas was set to 16 [l / min], the initial introduction amount of the carbon dioxide gas was set to 0.6 [l / min], $x = 0.5$ was set, $c1 = 0.02$ was set, $c2 = 0.94$ was set, and $c3 = 0.04$. These initial introduction amounts can be set and inputted by the parameter setting device 15. Furthermore, the stirring fan drive motor 9 is driven and thus the stirring fan 8 rotates to stir the atmospheric gases in the processing furnace 2.

[0292] 0261 In the initial state, the on-off valve controller 16 closes the on-off valve 17.

[0293] 0262 In addition, the in-furnace temperature measurement device 10 measures a temperature of the in-furnace gases, and outputs an information signal including the measured temperature to the nitriding potential adjustor 4 and the recorder 6. The nitriding potential adjustor 4 judges whether the state in the processing furnace 2 is still during the temperature rising step or already after the temperature rising step has been completed (a stable state).

[0294] 0263 In addition, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates an in-furnace nitriding potential (which is initially an extremely high value (since no hydrogen gas exists in the furnace), but decreases as decomposition of the ammonia gas (generation of the hydrogen gas) proceeds) and judges whether the calculated value has dropped lower than the sum of the target nitriding potential (1.0 in this example) and a standard margin. This standard margin can also be set and inputted by the parameter setting device 15, and is for example 0.1.

[0295] 0264 When it is determined that the temperature rising step has been completed and also it is determined that the calculated value of the in-furnace nitriding potential has dropped lower than the sum (0.3 in this example) of the target nitriding potential and the standard margin, the nitriding potential adjustor 4 starts to control an introduction amount of each of the furnace introduction gases via the gas introduction amount controller 14. Herein, the on-off valve controller 16 opens the on-off valve 17.

[0296] 0265 When the on-off valve 17 is opened, the processing furnace 2 and the atmospheric gas concentration

detector 3 communicate with each other, and then the atmospheric gas concentration detector 3 detects an in-furnace hydrogen concentration or an in-furnace ammonia concentration, and detects an in-furnace oxygen concentration. The detected hydrogen concentration signal or ammonia concentration signal and the detected oxygen concentration signal are outputted to the nitriding potential adjustor 4 and the recorder 6.

[0297] 0266 The in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculates the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performs the PID control method in which the respective gas introduction amounts of the ammonia gas, the carbon monoxide gas, the nitrogen gas and the carbon dioxide gas among the five kinds of furnace introduction gases are input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 is an output value, and the target nitriding potential (the set nitriding potential) is a target value. Specifically, in the present PID control method, the nitriding potential in the processing furnace 2 is brought close to the target nitriding potential while the relationships of $C1 = c1 \times (A + x \times B)$, $C2 = c2 \times (A + x \times B)$ and $C3 = c3 \times (A + x \times B)$ are maintained, by changing the introduction amount of the ammonia gas, the introduction amount of the carbon monoxide gas, the introduction amount of the nitrogen gas and the introduction amount of the carbon dioxide gas while keeping the introduction amount of the ammonia decomposition gas constant. In the present PID control method, the setting parameter values that have been set and inputted by the parameter setting device 15 are used. The setting parameter values may be different depending on values of the target nitriding potential.

[0298] 0267 Then, the gas introduction amount controller 14 controls the introduction amount of the ammonia gas, the introduction amount of the carbon monoxide gas, the introduction amount of the nitrogen gas and the introduction amount of the carbon dioxide gas as a result of the PID control method. The gas introduction amount controller 14 transmits control signals to the first supply amount controller 22 for the ammonia gas, the second supply amount controller 26 for the ammonia decomposition gas (whose flow rate is constant), the third supply amount controller 62 for the carbon monoxide gas, the fourth supply amount controller 72 for the nitrogen gas and the fifth supply amount controller 82 for the carbon dioxide gas, in order to realize the respective determined introduction amounts of the furnace introduction gases.

[0299] 0268 According to the control as described above, the in-furnace nitriding potential can be stably controlled in the vicinity of the target nitriding potential. Thereby, the surface hardening treatment of the work S can be performed with extremely high quality. Specifically, a feedback control is performed with a sampling rate of about several hundred milliseconds, and the introduction amount of the ammonia gas is increased and decreased within a range of about 3 ml (± 1.5 ml), so that the nitriding potential can be controlled to the target nitriding potential (0.2) with extremely high precision since a timing of about 40 minutes after starting the treatment.

[0300] 0269

(Explanation of Comparative Examples)

[0301] As comparative examples, controls of nitriding potential were performed. In each of them, the ammonia decomposition gas was not introduced, the ratio of the introduction amounts of the ammonia gas, the nitrogen gas, the carbon monoxide gas and the carbon dioxide gas was always maintained at 50 : 47: 1 : 2, and the total introduction amount thereof was changed.

[0302] 0270 Specifically, the in-furnace nitriding potential calculator 13 of the nitriding potential adjustor 4 calculated the in-furnace nitriding potential based on the inputted hydrogen concentration signal or ammonia concentration signal and the inputted oxygen concentration signal. Then, the gas flow rate output adjustor 30 performed the PID control method in which the respective gas introduction amounts of the ammonia gas, the nitrogen gas, the carbon monoxide gas and the carbon dioxide gas were input values, the nitriding potential calculated by the in-furnace nitriding potential calculator 13 was an output value, and the target nitriding potential (the set nitriding potential) was a target value. More specifically, in the present PID control method, the nitriding potential in the processing furnace 2 was brought close to the target nitriding potential, by changing the total introduction amount of the ammonia gas, the nitrogen gas, the carbon monoxide gas and the carbon dioxide gas while keeping the ratio of the introduction amounts of the ammonia gas, the nitrogen gas, the carbon monoxide gas and the carbon dioxide gas constant.

[0303] 0271 However, in the above comparative examples, the nitriding potential could not be stably controlled.

[0304] 0272

(Comparison between Examples 5-1 to 5-3 and Comparative Examples)

[0305] A table of the above results is shown as Fig. 18.

Description of Reference Signs

[0306] 0273

5	1	Surface hardening treatment device
	2	Processing furnace
	3	Atmospheric gas concentration detector
	4	Nitriding potential adjustor
	5	Temperature adjustor
10	6	Recorder
	8	Stirring fan
	9	Stirring-fan drive motor
	10	In-furnace temperature measuring device
	11	Furnace body heater
15	13	In-furnace nitriding potential calculator
	14	Gas introduction controller
	15	Parameter setting device (touch panel)
	16	On-off valve controller
	17	On-off valve
20	20, 20', 20"	Furnace introduction gas supplier
	21	First furnace introduction gas supplier
	22	First supply amount controller
	23	First supply valve
	24	First flow meter
25	25	Second furnace introduction gas supplier
	26	Second supply amount controller
	27	Second supply valve
	28	Second flow meter
	29	Furnace introduction gas pipe
30	30	Gas flow rate output adjustor
	31	Programmable logic controller
	40	Exhaust gas pipe
	41	Exhaust gas combustion decomposition apparatus
	61, 61'	Third furnace introduction gas supplier
35	62	Third supply amount controller
	63	Third supply valve
	64	Third flow meter
	71	Fourth furnace introduction gas supplier
	72	Fourth supply amount controller
40	73	Fourth supply valve
	74	Fourth flow meter
	81	Fifth furnace introduction gas supplier
	82	Fifth supply amount controller
	83	Fifth supply valve
45	84	Fifth flow meter

Claims

- 50 1. A surface hardening treatment device for performing a gas nitrocarburizing treatment as a surface hardening treatment for a work arranged in a processing furnace by introducing a plurality of furnace introduction gases including an ammonia gas and an ammonia decomposition gas, the surface hardening treatment device comprising
- 55 an in-furnace atmospheric gas concentration detector configured to detect a hydrogen concentration or an ammonia concentration in the processing furnace,
an in-furnace nitriding potential calculator configured to calculate a nitriding potential in the processing furnace based on the hydrogen concentration or the ammonia concentration detected by the in-furnace atmospheric gas concentration detector, and

a gas-introduction-amount controller configured to change an introduction amount of each of the plurality of furnace introduction gases except for the ammonia decomposition gas while keeping an introduction amount of the ammonia decomposition gas constant, based on the nitriding potential in the processing furnace calculated by the in-furnace nitriding potential calculator and a target nitriding potential, such that the nitriding potential in the processing furnace is brought close to the target nitriding potential.

2. The surface hardening treatment device according to claim 1, further comprising

an in-furnace oxygen concentration detector configured to detect an oxygen concentration in the processing furnace,
wherein
the in-furnace nitriding potential calculator is configured to calculate the nitriding potential in the processing furnace based on the hydrogen concentration or the ammonia concentration detected by the in-furnace atmospheric gas concentration detector and the oxygen concentration detected by the in-furnace oxygen concentration detector.

3. The surface hardening treatment device according to claim 1 or 2, wherein the gas-introduction-amount controller is configured to control the introduction amount $C_1, \dots, C_N$ (N is an integer of one or more) of each of the plurality of furnace introduction gases except for the ammonia gas and the ammonia decomposition gas, using a factor of proportionality $c_1, \dots, c_N$ assigned to each of the plurality of furnace introduction gases except for the ammonia gas and the ammonia decomposition gas, such that

$$C_1 = c_1 \times (A + x \times B), \dots, C_N = c_N \times (A + x \times B)$$

wherein the introduction amount of the ammonia gas is represented by A , the introduction amount of the ammonia decomposition gas is represented by B , and a predetermined constant is represented by x .

4. The surface hardening treatment device according to claim 3, wherein the predetermined constant x is within 0.4 to 0.6.

5. The surface hardening treatment device according to claim 4, wherein the predetermined constant x is 0.5.

6. The surface hardening treatment device according to any of claims 1 to 5, wherein the plurality of furnace introduction gases includes a carbon dioxide gas.

7. The surface hardening treatment device according to any of claims 1 to 5, wherein the plurality of furnace introduction gases includes a carbon monoxide gas.

8. The surface hardening treatment device according to any of claims 1 to 5, wherein the plurality of furnace introduction gases includes a carbon dioxide gas and a nitrogen gas.

9. The surface hardening treatment device according to any of claims 1 to 5, wherein the plurality of furnace introduction gases includes a carbon monoxide gas and a nitrogen gas.

10. A surface hardening treatment method of performing a gas nitrocarburizing treatment as a surface hardening treatment for a work arranged in a processing furnace by introducing a plurality of furnace introduction gases including an ammonia gas and an ammonia decomposition gas, the surface hardening treatment method comprising

an in-furnace atmospheric gas concentration detecting step of detecting a hydrogen concentration or an ammonia concentration in the processing furnace,
an in-furnace nitriding potential calculating step of calculating a nitriding potential in the processing furnace based on the hydrogen concentration or the ammonia concentration detected at the in-furnace atmospheric gas concentration detecting step, and
a gas-introduction-amount controlling step of changing an introduction amount of each of the plurality of furnace introduction gases except for the ammonia decomposition gas while keeping an introduction amount of the ammonia decomposition gas constant, based on the nitriding potential in the processing furnace calculated at

the in-furnace nitriding potential calculating step and a target nitriding potential, such that the nitriding potential in the processing furnace is brought close to the target nitriding potential.

- 5 11. A surface hardening treatment device for performing a gas nitrocarburizing treatment as a surface hardening treatment for a work arranged in a processing furnace by introducing a plurality of furnace introduction gases including an ammonia gas, an ammonia decomposition gas and a carburizing gas, the surface hardening treatment device comprising

10 an in-furnace atmospheric gas concentration detector configured to detect a hydrogen concentration or an ammonia concentration in the processing furnace,
an in-furnace nitriding potential calculator configured to calculate a nitriding potential in the processing furnace based on the hydrogen concentration or the ammonia concentration detected by the in-furnace atmospheric gas concentration detector, and
15 a gas-introduction-amount controller configured to change an introduction amount of each of the ammonia gas and the carburizing gas while keeping an introduction amount of the ammonia decomposition gas constant, based on the nitriding potential in the processing furnace calculated by the in-furnace nitriding potential calculator and a target nitriding potential, such that the nitriding potential in the processing furnace is brought close to the target nitriding potential.

- 20 12. The surface hardening treatment device according to claim 11, wherein the gas-introduction-amount controller is configured to control the introduction amount C1 of the carburizing gas, using a factor of proportionality c1 assigned to the carburizing gas, such that

$$25 \quad C1 = c1 \times (A + x \times B)$$

wherein the introduction amount of the ammonia gas is represented by A, the introduction amount of the ammonia decomposition gas is represented by B, and a predetermined constant is represented by x.

- 30 13. A surface hardening treatment device for performing a gas nitrocarburizing treatment as a surface hardening treatment for a work arranged in a processing furnace by introducing a plurality of furnace introduction gases including an ammonia gas, an ammonia decomposition gas, a carburizing gas and a nitrogen gas, the surface hardening treatment device comprising

35 an in-furnace atmospheric gas concentration detector configured to detect a hydrogen concentration or an ammonia concentration in the processing furnace,
an in-furnace nitriding potential calculator configured to calculate a nitriding potential in the processing furnace based on the hydrogen concentration or the ammonia concentration detected by the in-furnace atmospheric gas concentration detector, and
40 a gas-introduction-amount controller configured to change an introduction amount of each of the ammonia gas, the carburizing gas and the nitrogen gas while keeping an introduction amount of the ammonia decomposition gas constant, based on the nitriding potential in the processing furnace calculated by the in-furnace nitriding potential calculator and a target nitriding potential, such that the nitriding potential in the processing furnace is brought close to the target nitriding potential.

- 45 14. The surface hardening treatment device according to claim 13, wherein the gas-introduction-amount controller is configured to control the introduction amount C1 of the carburizing gas and the introduction amount C2 of the nitrogen gas, using a factor of proportionality c1 assigned to the carburizing gas and a factor of proportionality c2 assigned to the nitrogen gas, such that

$$50 \quad C1 = c1 \times (A + x \times B) \text{ and } C2 = c2 \times (A + x \times B)$$

55 wherein the introduction amount of the ammonia gas is represented by A, the introduction amount of the ammonia decomposition gas is represented by B, and a predetermined constant is represented by x.

FIG.1

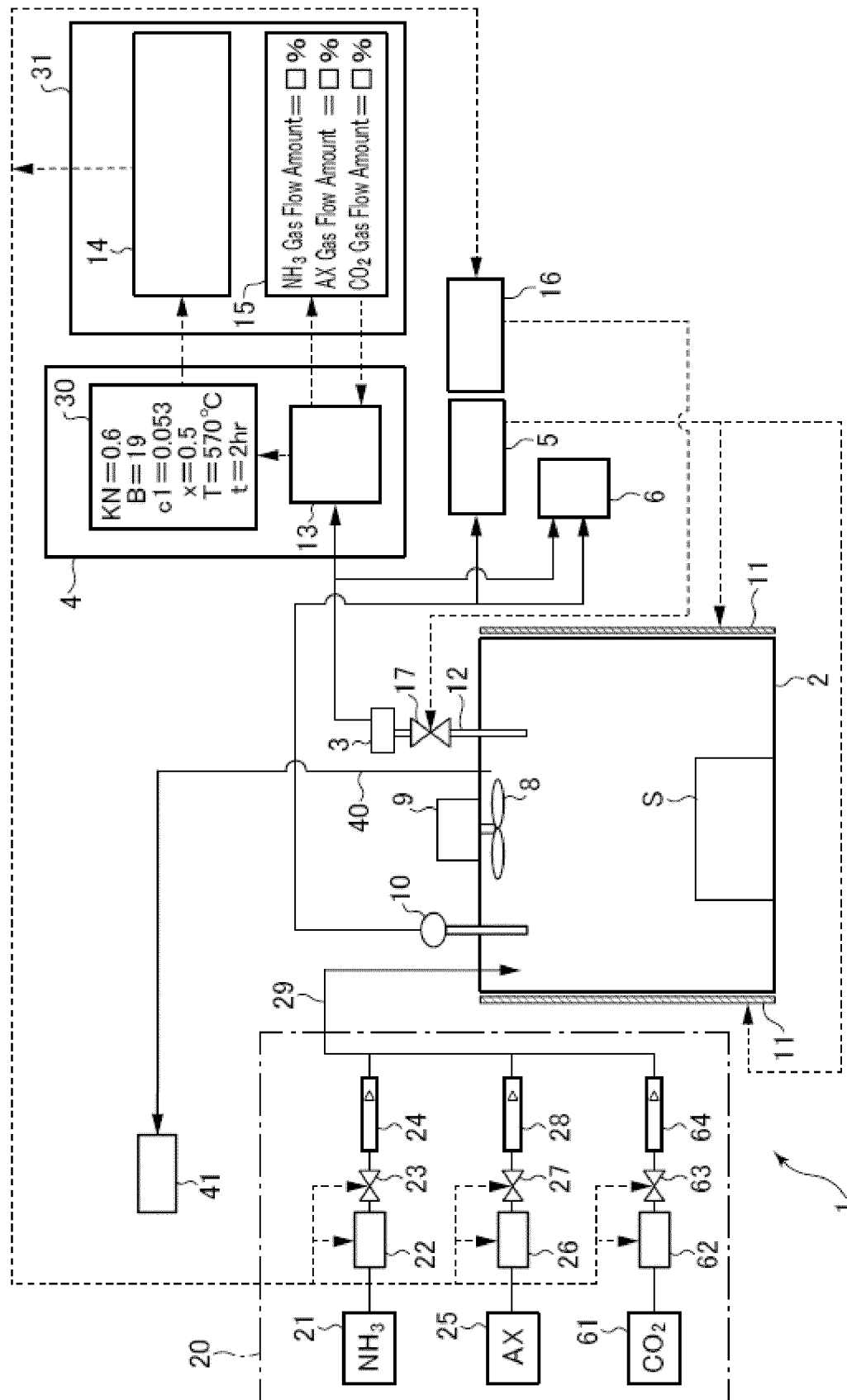


FIG.2

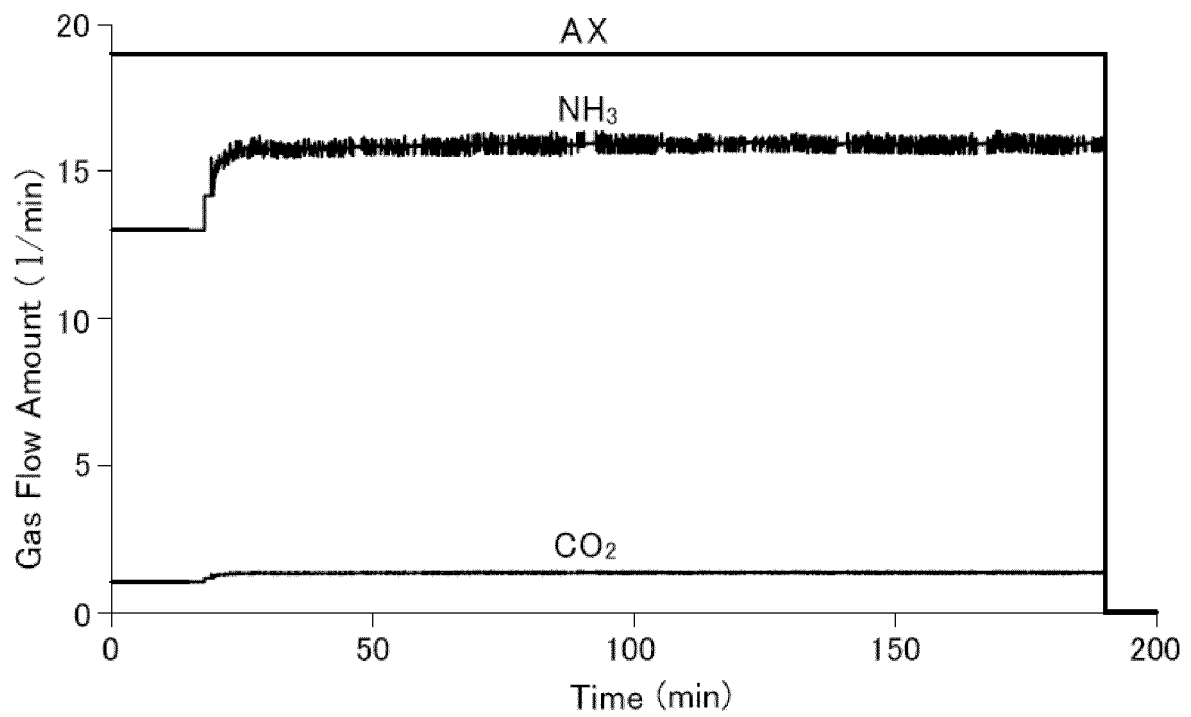


FIG.3

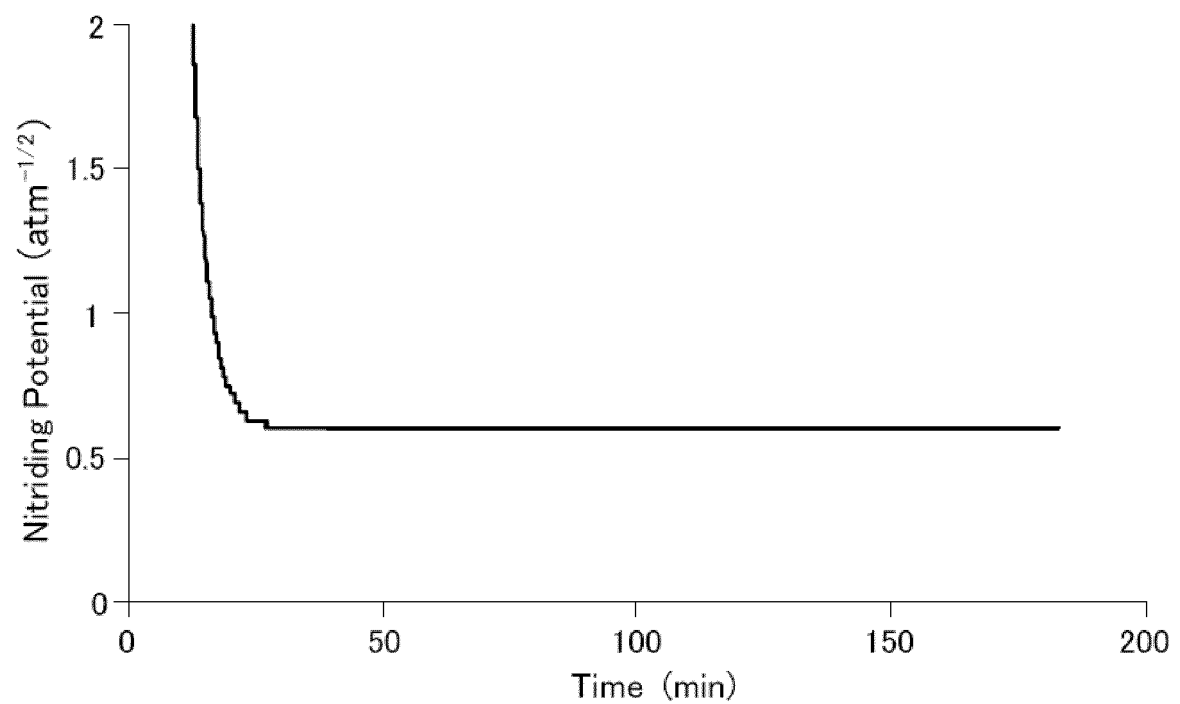


FIG.4

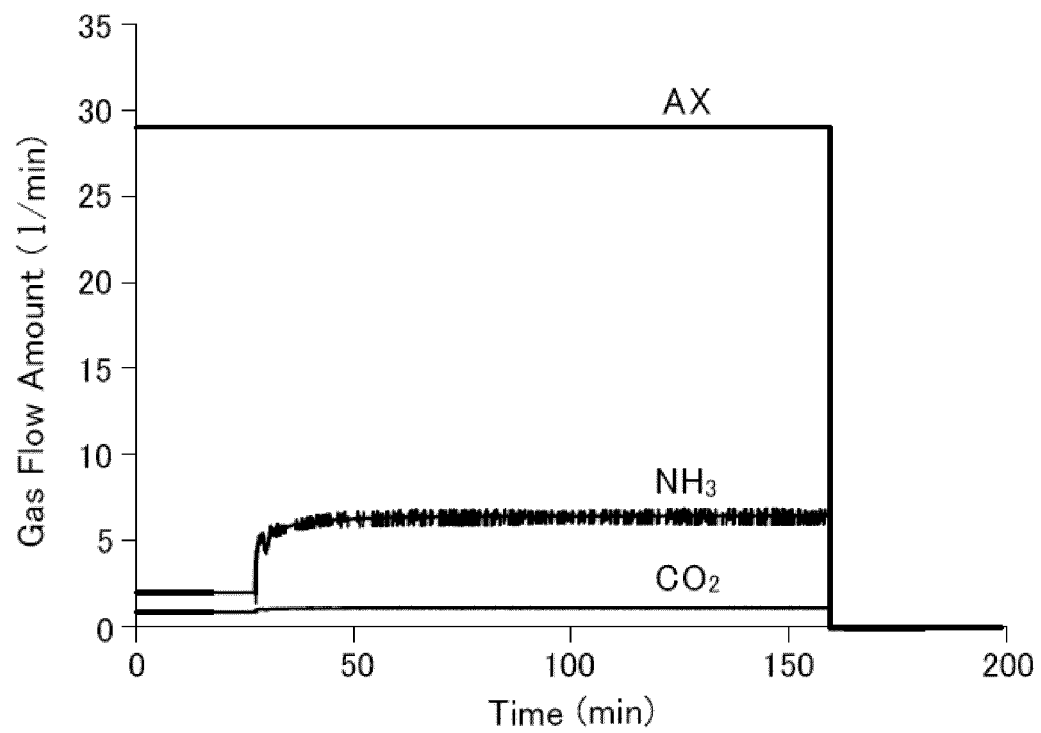


FIG.5

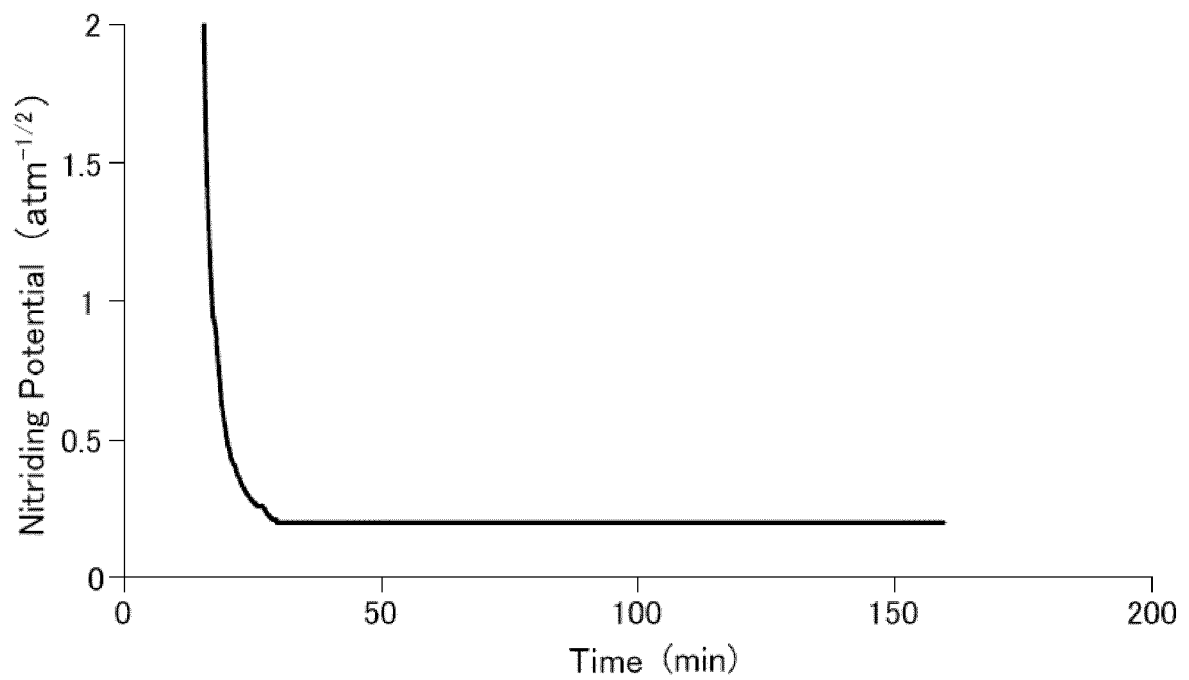


FIG. 6

Set Values				Measured Values				
	Set Nitriding Potential	Temperature	Other Parameters	Nitriding Potential	NH ₃ Gas	AX Gas	CO ₂ Gas	Total Gas
Example 1-1	0.6	570°C	AX Gas Flow Amount = 19 (l/min) Set Values of Parameters: x=0.5, C=0.053	0.6	Variable	19	Variable	About 36
Comparative Example			NH ₃ :CO ₂ =95:5	Uncontrollable	Variable	—	Variable	<10 ※Suspended
Example 1-2	0.4	570°C	AX Gas Flow Amount = 25 (l/min) Set Values of Parameters: x=0.5, C=0.053	0.4	Variable	25	Variable	About 37
Comparative Example			NH ₃ :CO ₂ =95:5	Uncontrollable	Variable	—	Variable	<10 ※Suspended
Example 1-3	0.2	570°C	AX Gas Flow Amount = 29 (l/min) Set Values of Parameters: x=0.5, C=0.053	0.2	Variable	29	Variable	About 36
Comparative Example			NH ₃ :CO ₂ =95:5	Uncontrollable	Variable	—	Variable	<10 ※Suspended

FIG.7

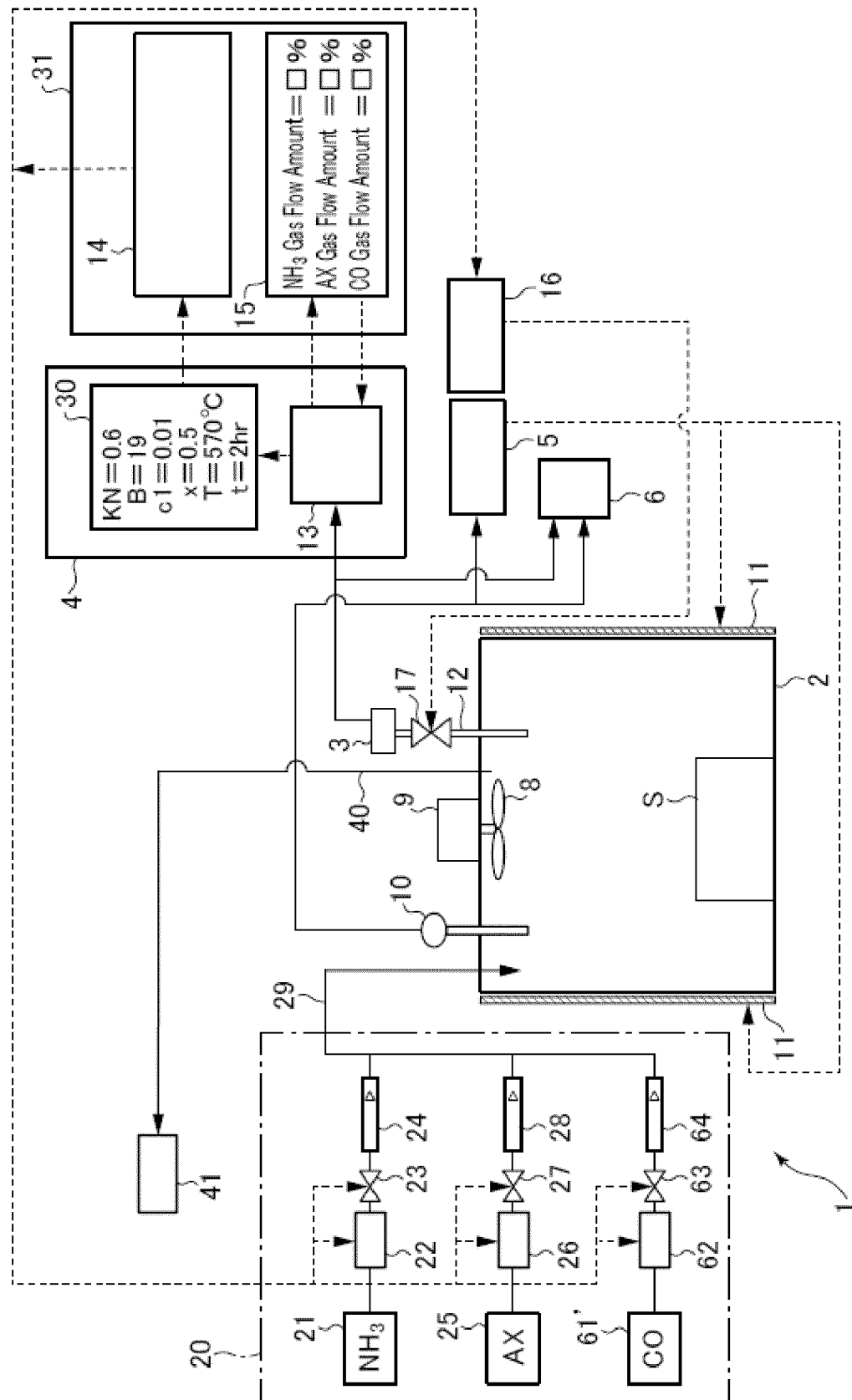


FIG.8

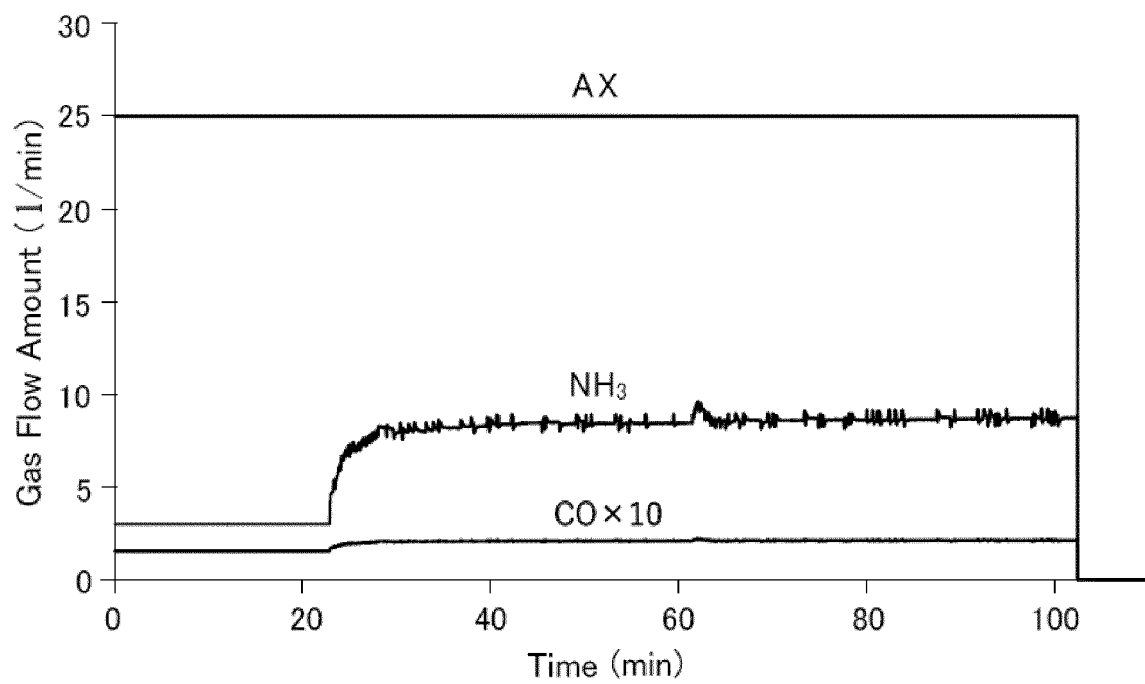


FIG.9

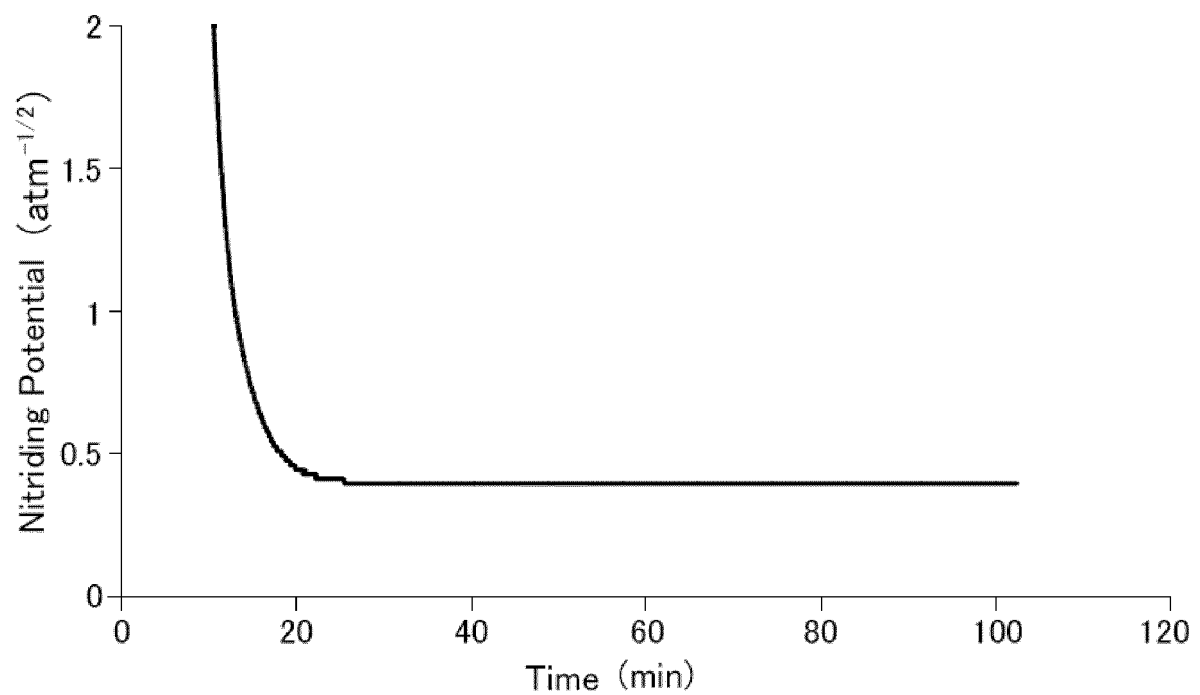


FIG.10

Set Values			Measured Values					
	Set Nitriding Potential	Temperature	Other Parameters	Nitriding Potential	NH ₃ Gas	AX Gas	CO Gas	Total Gas
Example 2-1	0.6	570°C	AX Gas Flow Amount =19 (l/min) Set Values of Parameters : x=0.5, C=0.01	0.6	Variable	19	Variable	About 34
Comparative Example			NH ₃ :CO=99:1	Uncontrollable	Variable	—	Variable	<10 ✖Suspended
Example 2-2	0.4	570°C	AX Gas Flow Amount =25 (l/min) Set Values of Parameters : x=0.5, C=0.01	0.4	Variable	25	Variable	About 33
Comparative Example			NH ₃ :CO=99:1	Uncontrollable	Variable	—	Variable	<10 ✖Suspended
Example 2-3	0.2	570°C	AX Gas Flow Amount =29 (l/min) Set Values of Parameters : x=0.5, C=0.01	0.2	Variable	29	Variable	About 33
Comparative Example			NH ₃ :CO=99:1	Uncontrollable	Variable	—	Variable	<10 ✖Suspended

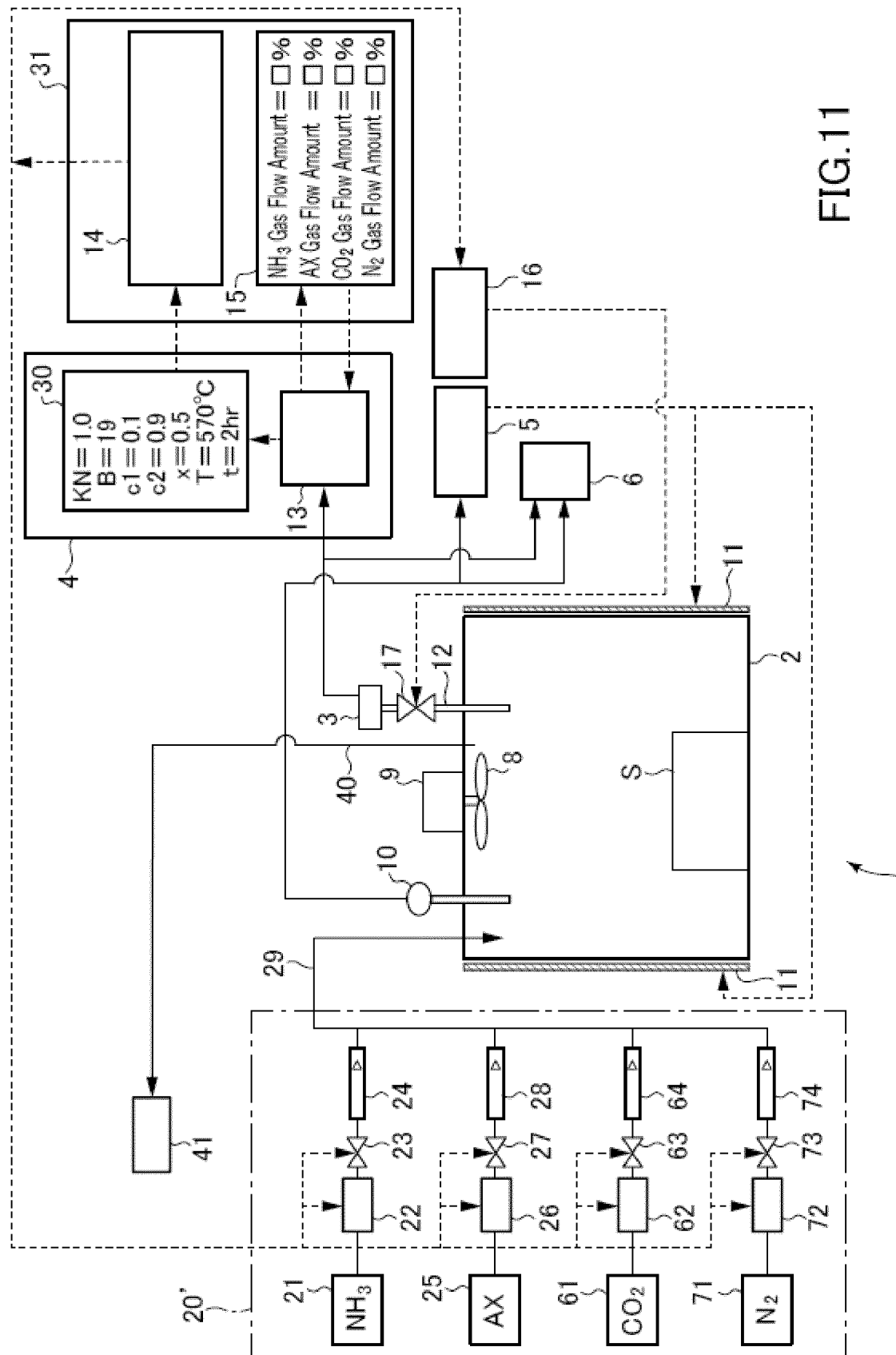


FIG.11

FIG.12

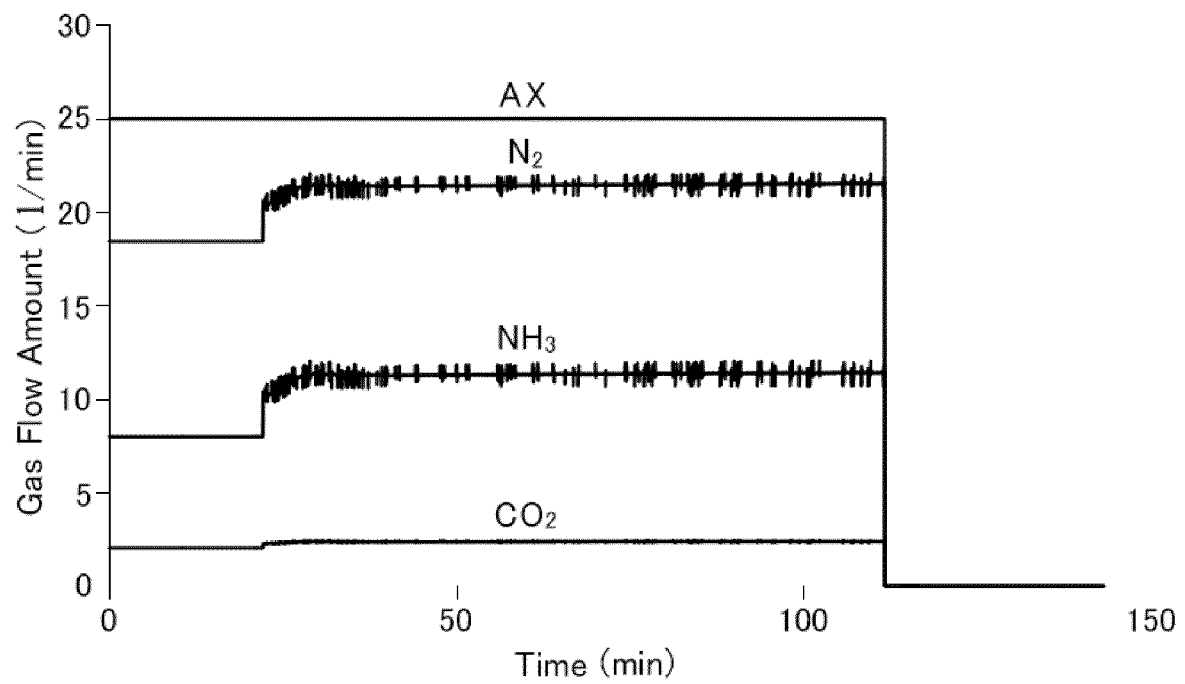


FIG.13

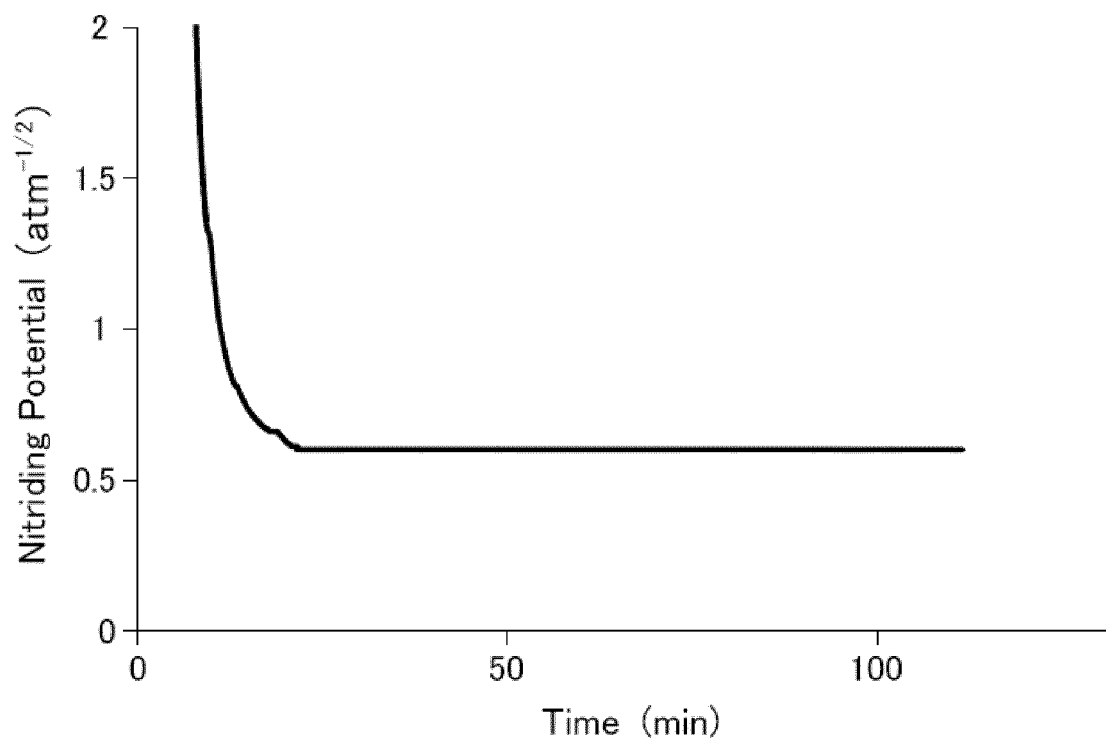


FIG. 14

Set Values				Measured Values					
	Set Nitriding Potential	Temperature	Other Parameters	Nitriding Potential	NH ₃ Gas	AX Gas	CO ₂ Gas	N ₂ Gas	Total Gas
Example 3-1	1	570°C	AX Gas Flow Amount =19 (l/min) Set Values of Parameters : x=0.5, C=0.1, D=0.9	1	Variable	19	Variable	Variable	About 60
Comparative Example			NH ₃ :N ₂ :CO ₂ =50:45:5	Uncontrollable	Variable	—	Variable	Variable	Variable
Example 3-2	0.6	570°C	AX Gas Flow Amount =25 (l/mln) Set Values of Parameters : x=0.5, C=0.1, D=0.9	0.6	Variable	25	Variable	Variable	About 59
Comparative Example			NH ₃ :N ₂ :CO ₂ =50:45:5	Uncontrollable	Variable	—	Variable	Variable	Variable
Example 3-3	0.2	570°C	AX Gas Flow Amount =29 (l/mln) Set Values of Parameters : x=0.5, C=0.1, D=0.9	0.2	Variable	29	Variable	Variable	About 53
Comparative Example			NH ₃ :N ₂ :CO ₂ =50:45:5	Uncontrollable	Variable	—	Variable	Variable	Variable

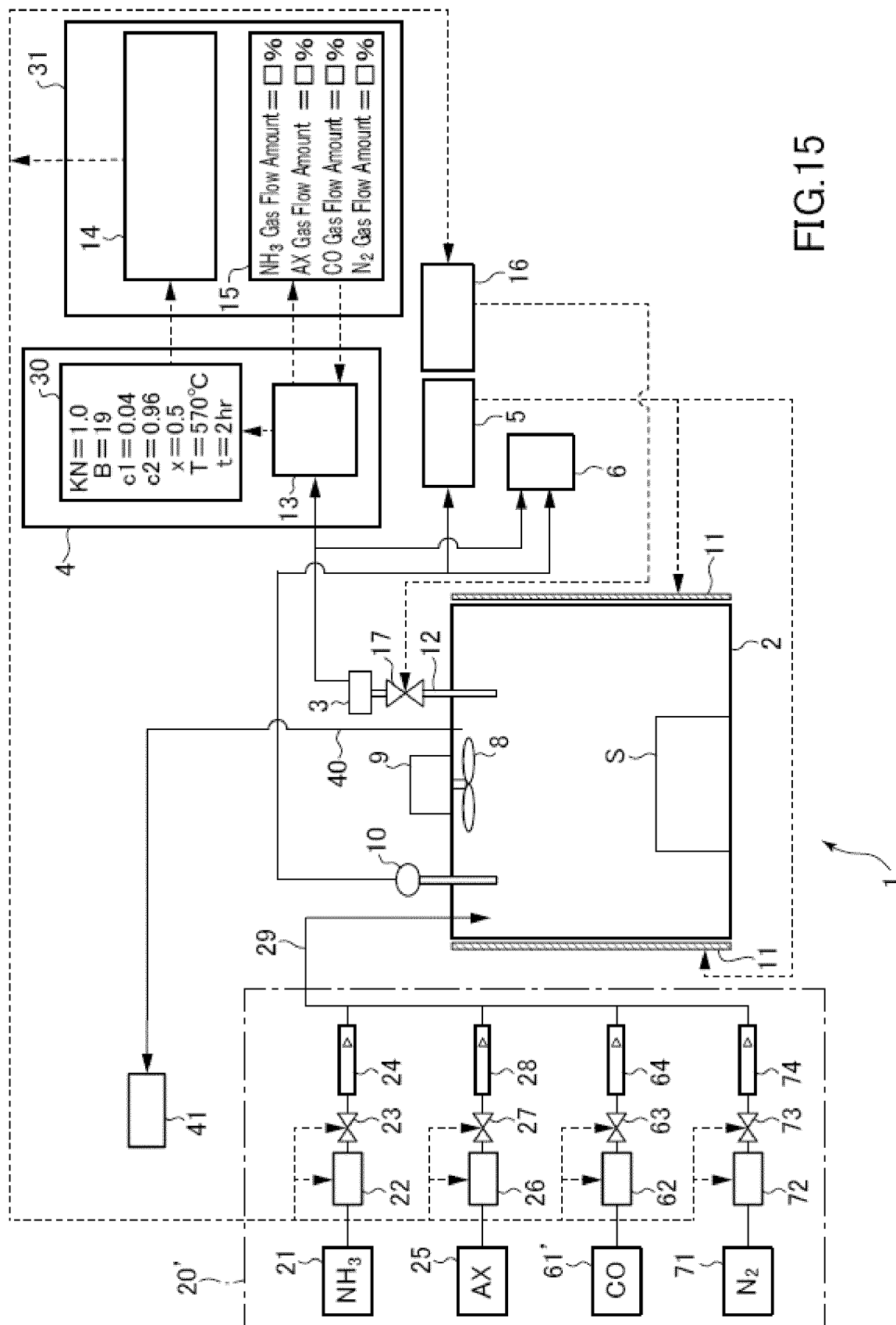


FIG. 16

Set Values				Measured Values					
	Set Nitriding Potential	Temperature	Other Parameters	Nitriding Potential	Gas Flow Amounts (l/min)				
					NH ₃ Gas	AX Gas	CO Gas	N ₂ Gas	Total Gas
Example 4-1	1	570°C	AX Gas Flow Amount =19 (l/min) Set Values of Parameters: x=0.5, C=0.04, D=0.96	1	Variable	19	Variable	Variable	About 57
Comparative Example			NH ₃ :N ₂ :CO =50:48:2	Uncontrollable	Variable	—	Variable	Variable	Variable
Example 4-2	0.6	570°C	AX Gas Flow Amount =25 (l/min) Set Values of Parameters: x=0.5, C=0.04, D=0.96	0.6	Variable	25	Variable	Variable	About 53
Comparative Example			NH ₃ :N ₂ :CO =50:48:2	Uncontrollable	Variable	—	Variable	Variable	Variable
Example 4-3	0.2	570°C	AX Gas Flow Amount =29 (l/min) Set Values of Parameters: x=0.5, C=0.04, D=0.96	0.2	Variable	29	Variable	Variable	About 49
Comparative Example			NH ₃ :N ₂ :CO =50:48:2	Uncontrollable	Variable	—	Variable	Variable	Variable

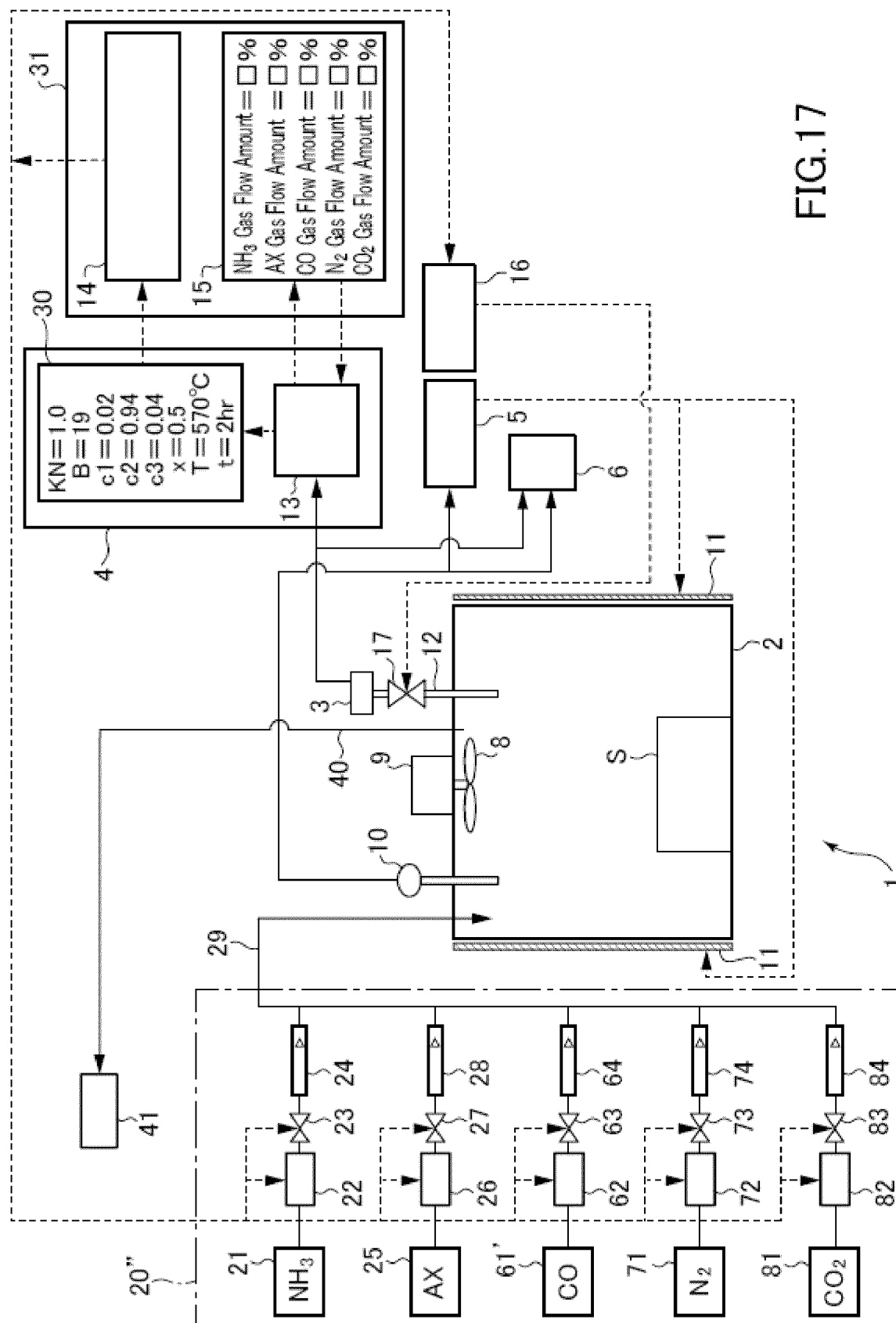


FIG. 17

FIG.18

Set Values				Measured Values						
Set Nitriding Potential		Temperature	Other Parameters	Nitriding Potential	NH ₃ Gas	AX Gas	CO Gas	N ₂ Gas	CO ₂ Gas	Total Gas
Example 5-1	1	570°C	AX Gas Flow Amount =19 (l/min) Set Values of Parameters : x=0.5, C=0.02, D=0.94, E=0.04	1	Variable	19	Variable	Variable	Variable	About 57
Comparative Example			NH₃:N₂:CO:CO₂=50:47:1:2	Uncontrollable	Variable	—	Variable	Variable	Variable	<10 ✖ Suspended
Example 5-2	0.6	570°C	AX Gas Flow Amount =25 (l/min) Set Values of Parameters : x=0.5, C=0.02, D=0.94, E=0.04	0.6	Variable	25	Variable	Variable	Variable	About 54
Comparative Example			NH₃:N₂:CO:CO₂=50:47:1:2	Uncontrollable	Variable	—	Variable	Variable	Variable	<10 ✖ Suspended
Example 5-3	0.2	570°C	AX Gas Flow Amount =29 (l/min) Set Values of Parameters : x=0.5, C=0.02, D=0.94, E=0.04	0.2	Variable	29	Variable	Variable	Variable	About 49
Comparative Example			NH₃:N₂:CO:CO₂=50:47:1:2	Uncontrollable	Variable	—	Variable	Variable	Variable	<10 ✖ Suspended

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2020/038315

A. CLASSIFICATION OF SUBJECT MATTER

C23C 8/30 (2006.01) i

FI: C23C8/30

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C23C8/30

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996

Published unexamined utility model applications of Japan 1971-2020

Registered utility model specifications of Japan 1996-2020

Published registered utility model applications of Japan 1994-2020

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 6345320 B1 (PERKER NETSUSHORI KOGYO CO., LTD.) 20 June 2018 (2018-06-20) paragraphs [0040]-[0065], fig. 1	1, 3-14 2
Y A	WO 2016/129333 A1 (SUNCALL CORPORATION) 18 August 2016 (2016-08-18) paragraphs [0043], [0062]-[0064]	1, 3-14 2
Y A	JP 2013-249524 A (NIPPON TECHNO KK) 12 December 2013 (2013-12-12) claims, paragraphs [0018]-[0066]	1, 3-14 2



Further documents are listed in the continuation of Box C.



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"&" document member of the same patent family

Date of the actual completion of the international search
02 December 2020 (02.12.2020)Date of mailing of the international search report
15 December 2020 (15.12.2020)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application no.
PCT/JP2020/038315

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REFERENCES CITED IN THE DESCRIPTION

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- Nitriding and Nitrocarburizing on Iron Materials. **DIETER LIEDTKE et al.** Agune Technical Center. 2013, 158-163 [0008] [0030]
- **Y. HIRAOKA ; A. ISHIDA.** Effect of Compound Layer Thickness Composed of γ' -Fe₄N on Rotated-Bending Fatigue Strength in Gas-Nitrided JIS-SCM435 Steel. *Materials Transactions*, 2017, vol. 58 (7), 993-999 [0030]
- **HITOSHI KABASAWA.** *The Special Steel*, vol. 61 (3), 17-19 [0030]