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(71) Applicant: **NTN Corporation**
Osaka-shi, Osaka 550-0003 (JP)

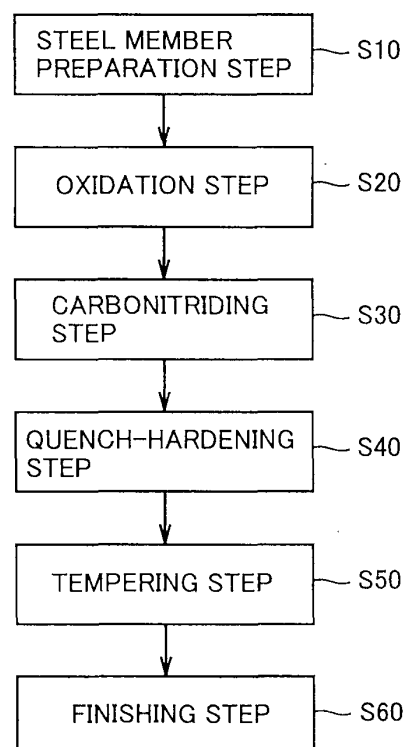
(72) Inventors:
• **FUJITA, Takumi**
Kuwana-shi
Mie 511-0867 (JP)
• **YAGITA, Kazuhiro**
Kuwana-shi
Mie 511-0867 (JP)

(74) Representative: **Bockhorni & Kollegen**
Elsenheimerstraße 49
80687 München (DE)

(54) **METHOD FOR PRODUCING MACHINE PART**

(57) A method of manufacturing a machine component includes the steps of preparing a member made of steel containing 0.1 mass % or more of vanadium (S10), forming a film containing vanadium at a surface of the member (S20), and forming a nitrogen-enriched layer by heating the member having the film formed in a heat treatment gas atmosphere containing nitrogen gas and absent of ammonia gas (S30). In the step of forming a film (S20), the member is heated to and oxidized in a temperature range not lower than 500°C and lower than A₁ transformation point of steel.

FIG.1



Description

TECHNICAL FIELD

[0001] The present invention relates to a method of manufacturing a machine component, more particularly, a method of manufacturing a machine component having a nitrogen-enriched layer at a surface layer.

BACKGROUND ART

[0002] For the purpose of improving the fatigue strength and/or wear resistance of a machine component, a nitrogen-enriched layer having a high nitrogen concentration as compared to the interior may be formed at the surface layer of the machine component by means of carbonitriding or the like. In a general carbonitriding process, atmosphere gas is often used, which is based on producing carrier gas by mixing propane, butane or city gas with air at a high temperature greater than or equal to 1000°C (endothermic converted gas; hereinafter, referred to RX gas), having a small amount of propane, butane, and ammonia added. By heating a workpiece in this atmosphere gas, a nitrogen-enriched layer is formed at the surface layer of the workpiece. During a carbonitriding process using RX gas as the carrier gas, a nitriding response occurs by undecomposed ammonia (for example, refer to "Improvement of Wear Resistance by Heat Treatment for Carburizing Steel" by Nobuyuki Mouri et al., NTN TECHNICAL REVIEW, 2008, No. 76, pp. 17-22 (NPD 1)).

CITATION LIST

NON PATENT DOCUMENT

[0003] NPD 1: "Improvement of Wear Resistance by Heat Treatment for Carburizing Steel" by Nobuyuki Mouri et al., NTN TECHNICAL REVIEW, 2008, No. 76, pp. 17-22

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0004] Decomposition of ammonia gas generally proceeds as the temperature becomes higher. Therefore, the nitriding process by undecomposed ammonia is not often executed at a temperature region not lower than 900°C. As a result, it was difficult to increase the treatment temperature to shorten the carbonitriding time even in the case of treating a product that requires a thick nitride layer. There was a problem that the processing time is lengthened. The carbonitriding process using ammonia gas also had the problem that the facility maintenance management cost is increased due to the requirement of installing a facility to introduce ammonia gas into the heat treatment furnace and rapid consumption of com-

ponents employed in the heat treatment furnace (for example, the basket for product transportation).

[0005] The present invention was made to solve the problems as described above, and an object thereof is to provide a machine component manufacturing method allowing a machine component having a nitrogen enriched layer at a surface layer to be manufactured by rapid heat treatment not using ammonia gas.

10 SOLUTION TO PROBLEM

[0006] A method of manufacturing a machine component according to the present invention includes the steps of preparing a member made of steel, forming a film containing vanadium at a surface of the member, and forming a nitrogen-enriched layer by heating the member having the film formed in an atmosphere of heat treatment gas containing nitrogen gas and absent of ammonia gas. In the step of preparing a member, a member made of steel containing 0.1 mass % or more of vanadium is prepared. In the step of forming a film, the member is heated to and oxidized in a temperature range not lower than 500°C and lower than A_1 transformation point of the steel.

[0007] During various studies in association with heat treatment of steel, the inventors found out that, by forming a film containing vanadium at the surface of a member made of steel, followed by heating in an atmosphere including nitrogen gas, a nitrogen-enriched layer is formed at the surface layer of the member even if the atmosphere is absent of ammonia gas, thus conceiving of the present invention. In the method of manufacturing a machine component in the present invention, a member made of steel, having a film containing vanadium formed at the surface, is heated in an atmosphere including nitrogen gas and absent of ammonia gas, leading to formation of a nitrogen-enriched layer at the surface layer of the machine component. Since the formation of a nitrogen-enriched layer is not advanced by undecomposed ammonia in the present manufacturing method, heat treatment at a higher temperature is allowed. Accordingly, the period of time for heat treatment can be shortened. Moreover, since ammonia is not used in the manufacturing method, consumption of the components employed in the heat treatment furnace can be suppressed to reduce the facility maintenance management cost. According to the machine component manufacturing method of the present invention, a machine component having a nitrogen-enriched layer at a surface layer can be manufactured by rapid heat treatment not using ammonia gas.

[0008] By adopting steel containing 0.1 mass % or more of vanadium as steel making up a machine component and subjecting the steel to oxidation, a film containing vanadium can readily be formed. Here, by performing oxidation in a temperature range lower than the A_1 transformation point of steel, phase transformation does not occur during oxidation and change in dimension or deformation due to heat treatment can be suppressed. In addition, by performing oxidation in a temperature

range lower than the A_1 transformation point of steel, a mother phase of steel is maintained in a ferrite state in which a solid solubility limit of carbon is low, and occurrence of decarburization can be suppressed.

[0009] Heat treatment gas absent of ammonia gas implies not including ammonia gas substantially, and does not exclude the mixture of ammonia gas at the impurity level.

[0010] In the step of forming a film in the method of manufacturing a machine component set forth above, the member may be forged.

[0011] When the manufacturing process of a machine component includes a forging step, a film containing vanadium can be formed efficiently by subjecting the machine component to oxidation in the forging step.

[0012] In the method of manufacturing a machine component set forth above, the heat treatment gas may include endothermic converted gas. Accordingly, formation of a nitrogen-enriched layer can be achieved while readily adjusting the carbon potential in the atmosphere.

[0013] In the method of manufacturing a machine component set forth above, the heat treatment gas may be a gas mixture of the nitrogen gas and reducing gas.

[0014] Thus, a nitrogen-enriched layer can be formed with reducing heat treatment gas containing nitrogen which is inexpensive and readily available as a nitrogen supply source. Consequently, cost for heat treatment can be reduced. For example, hydrogen gas, methane gas, propane gas, butane gas, or carbon monoxide gas can be adopted for the reducing gas.

[0015] In the method of manufacturing a machine component set forth above, the heat treatment gas may include the nitrogen gas and have an oxygen partial pressure less than or equal to 10^{-16} Pa.

[0016] Thus, heat treatment gas containing nitrogen which is inexpensive and readily available as a nitrogen supply source and having oxidizing capability suppressed to a low level can be employed. Consequently, cost for heat treatment can be reduced.

[0017] In the method of manufacturing a machine component set forth above, the heat treatment gas may include reducing gas so that it has the oxygen partial pressure less than or equal to 10^{-16} Pa. By adopting the heat treatment gas containing the reducing gas, the oxygen partial pressure can readily be lowered to 10^{-16} Pa or less.

[0018] In the method of manufacturing a machine component set forth above, the reducing gas may be hydrogen gas. The hydrogen gas which is readily available is suitable as the reducing gas.

[0019] The method of manufacturing a machine component set forth above may further include the step of quench-hardening the member by cooling the member having a nitrogen-enriched layer formed from a temperature greater than or equal to A_1 transformation point to a temperature less than or equal to M_S point. Accordingly, a machine component of high durability, having a nitrogen-enriched layer formed and quench-hardened, can be readily manufactured.

[0020] In the method of manufacturing a machine component set forth above, the step of forming a nitrogen-enriched layer may be performed such that the member heated to the temperature range is not cooled to a room temperature in the step of forming a film. By doing so, energy required for heat treatment can be lowered and a time period for heat treatment can be shortened.

[0021] In the method of manufacturing a machine component set forth above, in the step of forming a film, the member may be heated in a heat treatment chamber of an oxidative atmosphere, and in the step of forming a nitrogen-enriched layer, an atmosphere in the heat treatment chamber may be replaced with the heat treatment gas and then the member may be heated in the heat treatment chamber to thereby form the nitrogen-enriched layer. By doing so, a nitrogen-enriched layer can efficiently be formed on a machine component with the use of a batch furnace.

[0022] The method of manufacturing a machine component set forth above may further include the step of quench-hardening the member by cooling the member having a nitrogen-enriched layer formed from a temperature greater than or equal to the A_1 transformation point down to a temperature less than or equal to M_S point. In the step of forming a film, the film may be formed as the member is oxidized in an oxidation apparatus. In the step of forming a nitrogen-enriched layer, the member having the film formed may be conveyed by a conveyance apparatus into a nitrogen-enriched layer formation apparatus connected to the oxidation apparatus with the conveyance apparatus being interposed, and then the nitrogen-enriched layer may be formed in the nitrogen-enriched layer formation apparatus. In the step of quench-hardening the member, the member may be quench-hardened in a quenching apparatus connected to the nitrogen-enriched layer formation apparatus. By doing so, a nitrogen-enriched layer can efficiently be formed on a machine component with the use of a continuous furnace and the machine component can be quench-hardened.

[0023] In the method of manufacturing a machine component set forth above, the machine component may be a component constituting a rolling bearing.

[0024] A component such as a bearing ring and a rolling element constituting a rolling bearing is often required to have high fatigue strength and wear resistance. Therefore, the method of manufacturing a machine component of the present invention in which a nitrogen-enriched layer is formed is suitable for a method of manufacturing a component constituting a rolling bearing.

ADVANTAGEOUS EFFECTS OF INVENTION

[0025] As is clear from the description above, according to the method of manufacturing a machine component in the present invention, a machine component having a nitrogen-enriched layer at a surface layer can be manufactured by rapid heat treatment not using ammonia gas.

BRIEF DESCRIPTION OF DRAWINGS

[0026]

Fig. 1 is a flowchart showing overview of a method of manufacturing a machine component in a first embodiment.

Fig. 2 is a schematic diagram for illustrating one example of the method of manufacturing a machine component.

Fig. 3 is a schematic diagram for illustrating another example of the method of manufacturing a machine component.

Fig. 4 is a flowchart showing overview of a method of manufacturing a machine component in a second embodiment.

Fig. 5 represents concentration distribution of nitrogen in a nitrogen-enriched layer when a vanadium-containing film is formed at different oxidation temperatures.

Fig. 6 represents concentration distribution of nitrogen in a nitrogen-enriched layer formed without cooling to a room temperature after oxidation.

DESCRIPTION OF EMBODIMENTS

[0027] Embodiments of the present invention will be described hereinafter with reference to the drawings. In the drawings below, the same or corresponding elements have the same reference characters allotted, and description thereof will not be repeated.

(First Embodiment)

[0028] A first embodiment that is one embodiment of the present invention will initially be described. Referring to Fig. 1, in a method of manufacturing a machine component according to the first embodiment, a steel member preparation step is performed as a step (S10). At this step (S10), a steel member that is a member made of steel and formed in substantially the shape of a machine component is prepared. Specifically, for example, a steel material of AMS2315 that is steel containing vanadium greater than or equal to 0.1 mass % or a steel material having such composition that 0.1 mass % or more of vanadium has been added to SUJ2 complying with JIS is prepared and subjected to working such as forging, turning, and the like to produce a steel member.

[0029] Then, an oxidation step is performed as a step S20. At this step (S20), the steel member prepared at the step (S10) is subjected to oxidation. Specifically, the steel member is heated at a temperature range greater than or equal to 500°C and lower than A_1 transformation point of steel making up the steel member in an oxidative atmosphere such as in the air, whereby the surface layer of the steel member is oxidized. At this stage, the reaction of vanadium in the steel with carbon in the steel and nitrogen in the atmosphere causes a film containing vanadium to be formed at the surface of the steel member.

Specifically, this film is a V (vanadium)-N (nitrogen) film, a V-C (carbon) film, a V-C-N film, or the like.

[0030] Then, a carbonitriding step is performed as a step (S30). At this step (S30), the steel member subjected to oxidation at the step (S20) is subjected to carbonitriding. Specifically, in an atmosphere adjusted to the desired carbon potential by adding propane gas or the like as enrich gas into RX gas that is endothermic converted gas obtained by mixing propane gas and air in a reforming furnace and heating to a temperature greater than or equal to 1000°C under the presence of a catalyst, the steel member is heated at a temperature range greater than or equal to A_1 transformation point. At this stage, ammonia gas is not added to the atmosphere. Accordingly, an amount of carbon at the surface layer of the steel member attains to a value corresponding to carbon potential in the atmosphere. Since the surface of the steel member has a film containing vanadium formed at the step (S20) and the nitrogen gas in the air is included in the RX gas, nitrogen invades the surface layer of the steel member. As a result, the steel member is carbonitrided, forming a nitrogen-enriched layer at the surface layer of the steel member.

[0031] Then, a quench-hardening step is performed as a step (S40). At this step (S40), the steel member subjected to carbonitriding at the step (S30) is quench-hardened. Specifically, the steel member subjected to carbonitriding at the temperature range greater than or equal to A_1 transformation point at the step (S30) is quench-hardened by being cooled down to the temperature range less than or equal to M_S point from the temperature range greater than or equal to A_1 transformation point. Accordingly, the entire steel member including the nitrogen-enriched layer is quench-hardened, thus providing high fatigue strength and wear resistance to the steel member.

[0032] Then, a tempering step is performed as a step (S50). At this step (S50), the steel member subjected to quench-hardening at the step (S40) is tempered. Specifically, at the step (S50), the steel member subjected to quench-hardening at the step (S40) is heated to a temperature less than or equal to A_1 transformation point, and then cooled for the tempering process.

[0033] Then, a finishing step is performed as a step (S60). At this step (S60), the steel member obtained by performing the steps (S10) to (S50) is subjected to a finishing work to complete a machine component such as a bearing component. Specifically, at the step (S60), the tempered steel member is polished and the like for the completion of a machine component. By the process set forth above, the method of manufacturing a machine component of the present embodiment is completed to produce a completed machine component.

[0034] In the method of manufacturing a machine component of the present embodiment, a steel member having a film containing vanadium formed at the surface is heated in an atmosphere containing nitrogen gas and absent of ammonia gas to manufacture a machine com-

ponent having a nitrogen-enriched layer. In the method of manufacturing a machine component of the present embodiment, the formation of a nitrogen-enriched layer is not advanced by undecomposed ammonia. Therefore, heat treatment at high temperature is allowed without having to take into account the decomposition of ammonia. As a result, in the method of manufacturing a machine component of the present embodiment, the process of forming a nitrogen-enriched layer is performed at high temperature, allowing the period of time for the heat treatment to be shortened. Furthermore, since ammonia is not used in the manufacturing method, consumption of components employed in the heat treatment furnace is suppressed to allow the facility maintenance management cost to be reduced. Thus, according to the method of manufacturing a machine component of the present embodiment, a machine component having a nitrogen-enriched layer at the surface layer can be manufactured by rapid heat treatment not using ammonia gas.

[0035] By preparing a steel member made of steel containing 0.1 mass % or more of vanadium in the step (S10) and subjecting the steel member to oxidation in the step (S20), a film containing vanadium can readily be formed. Here, by performing oxidation in a temperature range lower than the A_1 transformation point, phase transformation does not occur during oxidation and change in dimension or deformation due to heat treatment can be suppressed. In addition, by performing oxidation in a temperature range lower than the A_1 transformation point of steel, a mother phase of steel is maintained in a ferrite state in which a solid solubility limit of carbon is low, and occurrence of decarburization can be suppressed. By performing oxidation at 500°C or higher, a film containing vanadium can efficiently be formed. In order to further efficiently form a film containing vanadium, a temperature for oxidation in the step (S20) may be set to 600°C or higher or to 650°C or higher.

[0036] Here, the heat treatment gas adopted in the step (S30) may be a gas mixture of nitrogen gas and reducing gas. Thus, a nitrogen-enriched layer can be formed with reducing heat treatment gas containing nitrogen which is inexpensive and readily available as a nitrogen supply source. Consequently, cost for heat treatment can be reduced.

[0037] The heat treatment gas adopted in the step (S30) may contain nitrogen gas and may have an oxygen partial pressure less than or equal to 10^{-16} Pa. The heat treatment gas may have an oxygen partial pressure less than or equal to 10^{-16} Pa by containing reducing gas. For example, hydrogen gas can be adopted as the reducing gas. Thus, heat treatment gas containing nitrogen which is inexpensive and readily available as a nitrogen supply source and having oxidizing capability suppressed to a low level can be employed. Consequently, cost for heat treatment can be reduced.

[0038] One example of a specific procedure for performing the steps (S20) to (S40) will now be described with reference to Fig. 2. Referring to Fig. 2, a batch fur-

nace 1 includes a heat treatment chamber 11, a carrier portion 12 installed on a bottom wall of heat treatment chamber 11, and an inlet port 13 and an exhaust port 14 disposed in a wall surface of the heat treatment chamber. Inlet port 13 can be connected to a gas supply source (not shown) and an atmosphere gas can be supplied into heat treatment chamber 11 through inlet port 13 as the inlet port is connected to a desired gas supply source. Exhaust port 14 can be connected to an exhaust apparatus (not shown) and the atmosphere gas in a heat treatment furnace can be exhausted through exhaust port 14. The steps (S20) to (S40) can be performed as below, with the use of this batch furnace 1.

[0039] Initially, at the step (S20), a steel member 90 prepared at the step (S10) is arranged on carrier portion 12 in heat treatment chamber 11. Then, the interior in heat treatment chamber 11 is adjusted to an oxidative atmosphere. Here, gas in heat treatment chamber 11 may be discharged through exhaust port 14 and then oxidative gas may be supplied through inlet port 13, so that the interior in heat treatment chamber 11 is adjusted to an oxidative atmosphere, or the interior in heat treatment chamber 11 may be adjusted to an oxidative atmosphere as inlet port 13 and exhaust port 14 are opened into the air. Then, in heat treatment chamber 11 adjusted to the oxidative atmosphere, steel member 90 is heated to and oxidized in a temperature range not lower than 500°C and lower than the A_1 transformation point of steel making up steel member 90. Thus, a film containing vanadium is formed in a region including a surface of steel member 90.

[0040] As the step (S20) is completed, the step (S30) is performed in succession. At the step (S30), initially, the atmosphere in heat treatment chamber 11 is replaced with heat treatment gas. Specifically, the atmosphere gas in heat treatment chamber 11 is exhausted through exhaust port 14 and heat treatment gas (for example, a gas mixture of nitrogen gas and reducing gas) is supplied through inlet port 13, so that the interior in heat treatment chamber 11 is replaced with the heat treatment gas. Then, steel member 90 is heated in heat treatment chamber 11, for example, to a temperature range not lower than 750°C and not higher than 1000°C and preferably to a temperature range not lower than 850°C and not higher than 950°C, which are temperature ranges not lower than the A_1 transformation point, so that a nitrogen-enriched layer is formed at the surface layer of steel member 90. Here, after the step (S20) is completed and before the step (S30) is performed, steel member 90 may be cooled to a room temperature. After the step (S20) is completed, however, the step (S30) is performed successively without cooling steel member 90 to a room temperature, so that energy required for heat treatment can be lowered and a time period for heat treatment can be shortened.

[0041] When the step (S30) is completed, the step (S40) is performed in succession. At the step (S40), steel member 90 having the nitrogen-enriched layer formed is

taken out of batch furnace 1 and quench-hardened, for example, by being immersed in an oil bath. Through the procedure above, the steps (S20) to (S40) can efficiently be performed with the use of batch furnace 1.

[0042] Alternatively, the steps (S20) to (S40) above may be performed with the use of a continuous furnace as below. Referring to Fig. 3, a continuous furnace 2 includes an oxidation furnace 21 serving as an oxidation apparatus, a nitriding furnace 22 serving as a nitrogen-enriched layer formation apparatus connected to oxidation furnace 21 with conveyors 24 and 25 serving as a conveyance apparatus being interposed, and a quenching oil bath 23 which serves as a quenching apparatus connected to nitriding furnace 22 and holds a quenching oil. In quenching oil bath 23, a conveyor 26 carrying out a workpiece in quenching oil bath 23 is disposed. The steps (S20) to (S40) can be performed as below, with the use of this continuous furnace 2.

[0043] Initially, at the step (S20), steel member 90 prepared at the step (S10) is placed on conveyor 24. Thus, steel member 90 is conveyed by conveyor 24 and enters oxidation furnace 21. Since the interior in oxidation furnace 21 opens, for example, into the air, it is set to an air atmosphere. In oxidation furnace 21, steel member 90 is heated to and oxidized in a temperature range not lower than 500°C and lower than the A_1 transformation point of steel making up steel member 90. Thus, a film containing vanadium is formed in a region including a surface of steel member 90.

[0044] Then, at the step (S30), steel member 90 is conveyed along an arrow α on conveyors 24 and 25 and enters nitriding furnace 22. Here, steel member 90 may enter nitriding furnace 22 without being cooled to a room temperature. The interior in nitriding furnace 22 is adjusted to an atmosphere of a gas mixture of nitrogen gas and reducing gas, such as an atmosphere of nitrogen gas and hydrogen gas as mixed. Then, steel member 90 is heated in nitriding furnace 22 to a temperature range not lower than the A_1 transformation point. Thus, a nitrogen-enriched layer is formed at the surface layer of steel member 90.

[0045] Then, steel member 90 having the nitrogen-enriched layer formed is conveyed on conveyor 25, so that it falls into quenching oil bath 23 along an arrow β . Thus, steel member 90 is rapidly cooled and quench-hardened. Then, quench-hardened steel member 90 is carried out of quenching oil bath 23 on conveyor 26. Through the procedure above, the steps (S20) to (S40) with the use of continuous furnace 2 are completed. By thus using continuous furnace 2, the steps (S20) to (S40) can efficiently be performed and efficiency in production of machine components can be improved.

(Second Embodiment)

[0046] A second embodiment that is another embodiment of the present invention will now be described with reference to Fig. 4. The method of manufacturing a machine component according to the second embodiment

is carried out in a manner basically similar to that of the first embodiment. However, the method of manufacturing a machine component of the second embodiment differs from that of the first embodiment in including a hot forging step.

[0047] In the method of manufacturing a machine component according to the second embodiment, steel containing vanadium greater than or equal to 0.1 mass % is prepared at the step (S10), likewise with the first embodiment. A steel member is produced by forming to a shape that allows hot forging in a step (S21) that will be described below.

[0048] Next, a hot forging step is performed as a step (S21). At this step (S21), the steel member is hot forged. Specifically, the steel member is shaped by hot forging in the air, for example. At this stage, the surface layer of the steel member is oxidized by the oxygen in the air. As a result, the reaction of vanadium in the steel with the carbon in the steel and nitrogen in the atmosphere causes formation of a film containing vanadium at the surface of the steel member, specifically a V-N film, a V-C film, a V-C-N film, or the like.

[0049] Then, the step (S20) is skipped, and steps (S30) to (S60) are performed, likewise with the first embodiment, to complete a machine component.

[0050] In the method of manufacturing a machine component of the present embodiment, oxidation of the steel member is performed taking advantage of the hot forging step in the manufacturing process. Therefore, the method of manufacturing a machine component of the present invention can be carried out while suppressing increase in the manufacturing steps.

EXAMPLES

(Example 1)

[0051] Experiments were carried out to confirm that, by forming a film containing vanadium through oxidation in a temperature range lower than A_1 transformation point, formation of a nitrogen-enriched layer is allowed by subsequent heating in a heat treatment gas atmosphere containing nitrogen gas and absent of ammonia gas. A procedure in the experiments is as follows.

[0052] Steel composed of 1.00 mass % of carbon, 0.31 mass % of silicon, 0.46 mass % of manganese, 1.51 mass % of chromium, and 1.02 mass % of vanadium as well as remainder iron and impurities (such steel that 1.02 mass % of vanadium had been added to SUJ2 complying with JIS) was prepared and worked to a prescribed shape. The obtained test piece was subjected to oxidation for 10 hours as being heated to 700°C in the air, which was a temperature lower than the A_1 transformation point. For comparison, a similar test piece was subjected to oxidation for 1.5 hour as being heated to 950°C in the air, which was a temperature not lower than the A_1 transformation point. These test pieces were heated to

950°C in a gas mixture containing 50 volume % of nitrogen gas and 50 volume % of hydrogen gas and held for 12 hours. Nitrogen concentration distribution at the surface layer of the obtained test pieces was analyzed with an electron probe micro analyser (EPMA). Fig. 5 shows results of analysis. In Fig. 5, the abscissa represents a depth (a distance) from a surface and the ordinate represents nitrogen concentration. In Fig. 5, a thin line corresponds to a sample subjected to oxidation at 950°C and a bold line corresponds to a sample subjected to oxidation at 700°C.

[0053] Referring to Fig. 5, even when oxidation is performed at 700°C which is a temperature lower than the A_1 transformation point, sufficient nitrogen concentration distribution comparable to that at the time when oxidation is performed at 950°C which is a temperature not lower than the A_1 transformation point is obtained. Thus, by performing oxidation at a temperature lower than the A_1 transformation point, change in dimension and deformation due to heat treatment of a machine component as well as occurrence of decarburization can be suppressed while a nitrogen-enriched layer having appropriate nitrogen concentration distribution is formed.

(Example 2)

[0054] An experiment for confirming whether or not cooling to a room temperature is necessary after a film containing vanadium was formed through oxidation and before nitriding was performed was conducted.

[0055] Initially, a test piece was produced from a steel material (such a steel material that 1.02 mass % of vanadium had been added to SUJ2 complying with JIS) similar to that in Example 1. This test piece was subjected to oxidation as being heated to 700°C in the air, which was a temperature lower than the A_1 transformation point, and thereafter, successively without cooling, the test piece was heated to 950°C and held for 6 hours in a gas mixture atmosphere containing 50 volume % of nitrogen gas and 50 volume % of hydrogen gas. Thereafter, nitrogen concentration distribution at the surface layer of the test piece was examined with the EPMA as in Example 1. Fig. 6 shows results of examination. In Fig. 6, the abscissa represents a depth (a distance) from a surface and the ordinate represents nitrogen concentration.

[0056] Referring to Fig. 6, even when nitriding is successively performed with a cooling step of cooling steel after oxidation being intentionally omitted, a nitrogen-enriched layer having sufficient nitrogen concentration distribution is obtained. Thus, by performing a nitriding step without performing the cooling step after oxidation, energy required for heat treatment can be lowered and a time period for heat treatment can be shortened. Such a heat treatment process can be performed, for example, with the use of the batch furnace or the continuous furnace described in the embodiments above.

[0057] It should be understood that the embodiments

and examples disclosed herein are illustrative and non-restrictive in every respect. The scope of the present invention is defined by the terms of the claims, rather than the description above, and is intended to include any modification within the scope and meaning equivalent to the terms of the claims.

INDUSTRIAL APPLICABILITY

[0058] The method of manufacturing a machine component of the present invention can particularly be applied advantageously to the method of manufacturing a machine component having a nitrogen-enriched layer at the surface layer.

REFERENCE SIGNS LIST

[0059] 1 batch furnace; 2 continuous furnace; 11 heat treatment chamber; 12 carrier portion; 13 inlet port; 14 exhaust port; 21 oxidation furnace; 22 nitriding furnace; 23 quenching oil bath; 24, 25, 26 conveyor; and 90 steel member.

Claims

1. A method of manufacturing a machine component comprising the steps of:

preparing a member made of steel;
forming a film containing vanadium at a surface of said member; and
forming a nitrogen-enriched layer by heating said member having said film formed in an atmosphere of heat treatment gas containing nitrogen gas and absent of ammonia gas,
in said step of preparing a member, a member made of steel containing 0.1 mass % or more of vanadium being prepared, and
in said step of forming a film, said member being heated to and oxidized in a temperature range not lower than 500°C and lower than A_1 transformation point of said steel.

2. The method of manufacturing a machine component according to claim 1, wherein said heat treatment gas includes endothermic converted gas.

3. The method of manufacturing a machine component according to claim 1, wherein said heat treatment gas is a gas mixture of the nitrogen gas and reducing gas.

4. The method of manufacturing a machine component according to claim 1, wherein said heat treatment gas includes the nitrogen gas and has an oxygen partial pressure less than or equal

to 10^{-16} Pa.

5. The method of manufacturing a machine component according to claim 4, wherein said heat treatment gas includes reducing gas so that it has the oxygen partial pressure less than or equal to 10^{-16} Pa. 5
6. The method of manufacturing a machine component according to claim 5, wherein said reducing gas is hydrogen gas. 10
7. The method of manufacturing a machine component according to any one of claims 1 to 6, wherein said step of forming a nitrogen-enriched layer is performed such that said member heated to said temperature range is not cooled to a room temperature in said step of forming a film. 15
8. The method of manufacturing a machine component according to any one of claims 1 to 7, wherein in said step of forming a film, said member is heated in a heat treatment chamber of an oxidative atmosphere, and in said step of forming a nitrogen-enriched layer, an atmosphere in said heat treatment chamber is replaced with said heat treatment gas and then said member is heated in said heat treatment chamber to thereby form the nitrogen-enriched layer. 20
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9. The method of manufacturing a machine component according to any one of claims 1 to 7, further comprising the step of quench-hardening said member by cooling said member having a nitrogen-enriched layer formed from a temperature greater than or equal to the A_1 transformation point down to a temperature less than or equal to M_S point, wherein in said step of forming a film, said film is formed as said member is oxidized in an oxidation apparatus, in said step of forming a nitrogen-enriched layer, said member having said film. formed is conveyed by a conveyance apparatus into a nitrogen-enriched layer formation apparatus connected to said oxidation apparatus with said conveyance apparatus being interposed and then said nitrogen-enriched layer is formed in said nitrogen-enriched layer formation apparatus, and in said step of quench-hardening said member, said member is quench-hardened in a quenching apparatus connected to said nitrogen-enriched layer formation apparatus. 35
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10. The method of manufacturing a machine component according to any one of claims 1 to 9, wherein said machine component is a component constituting a rolling bearing. 55

FIG.1

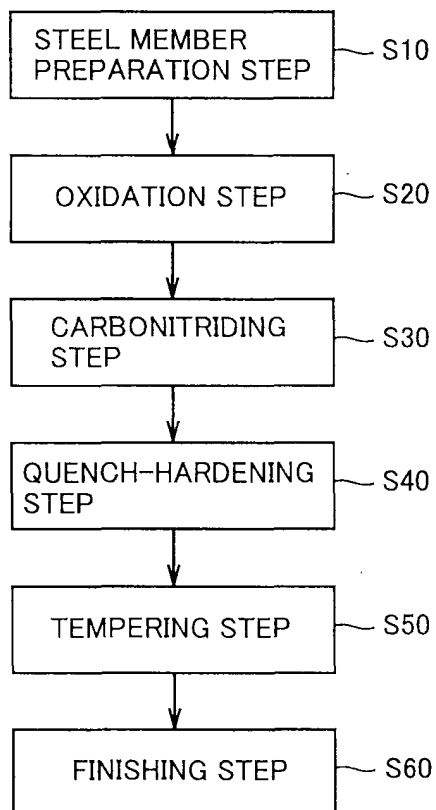


FIG.2

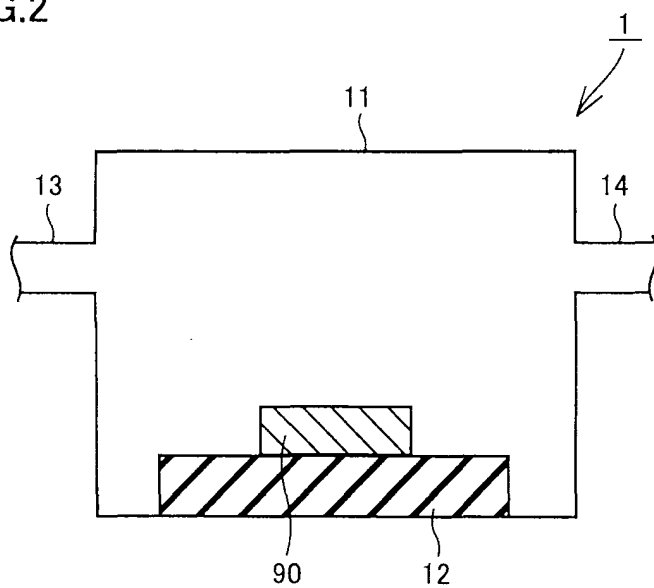


FIG.3

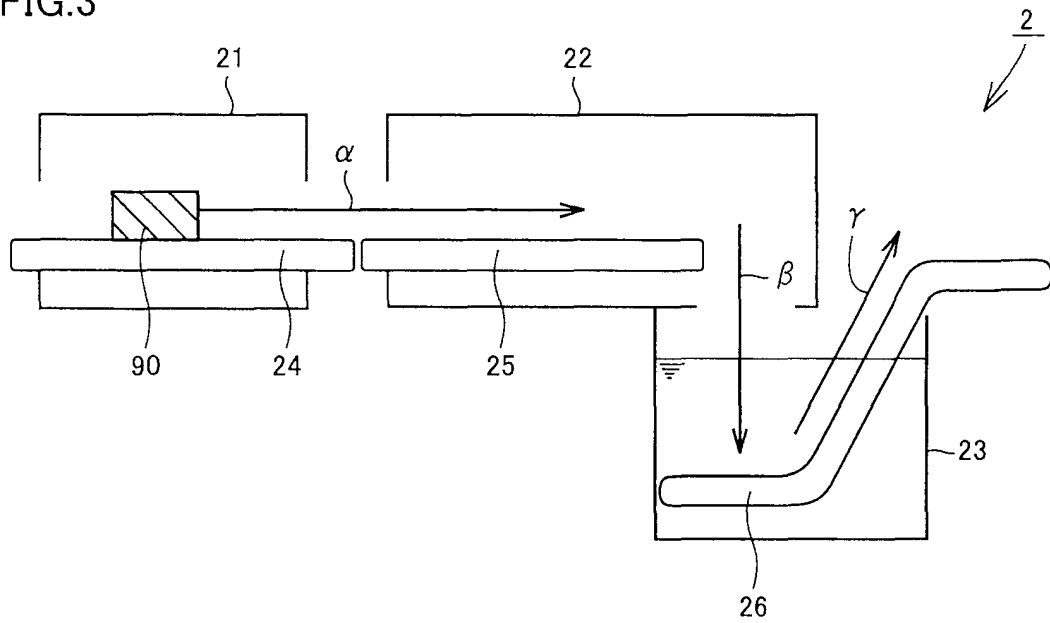


FIG.4

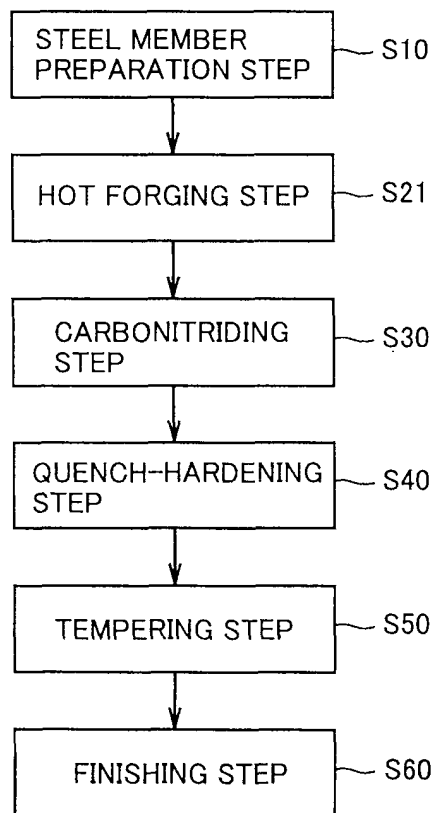


FIG.5

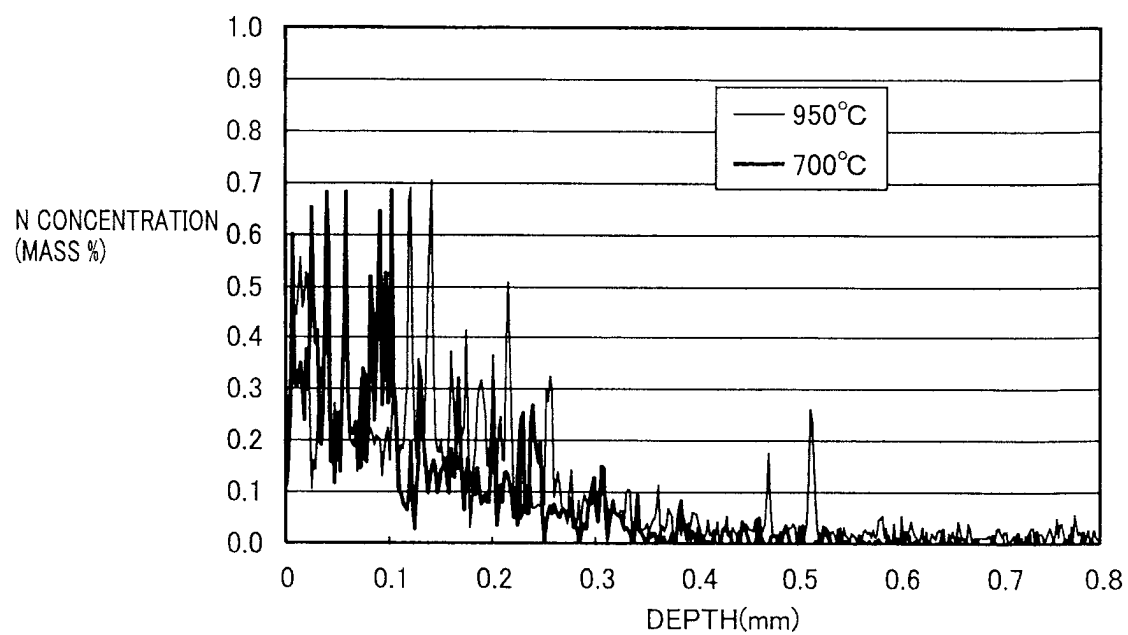
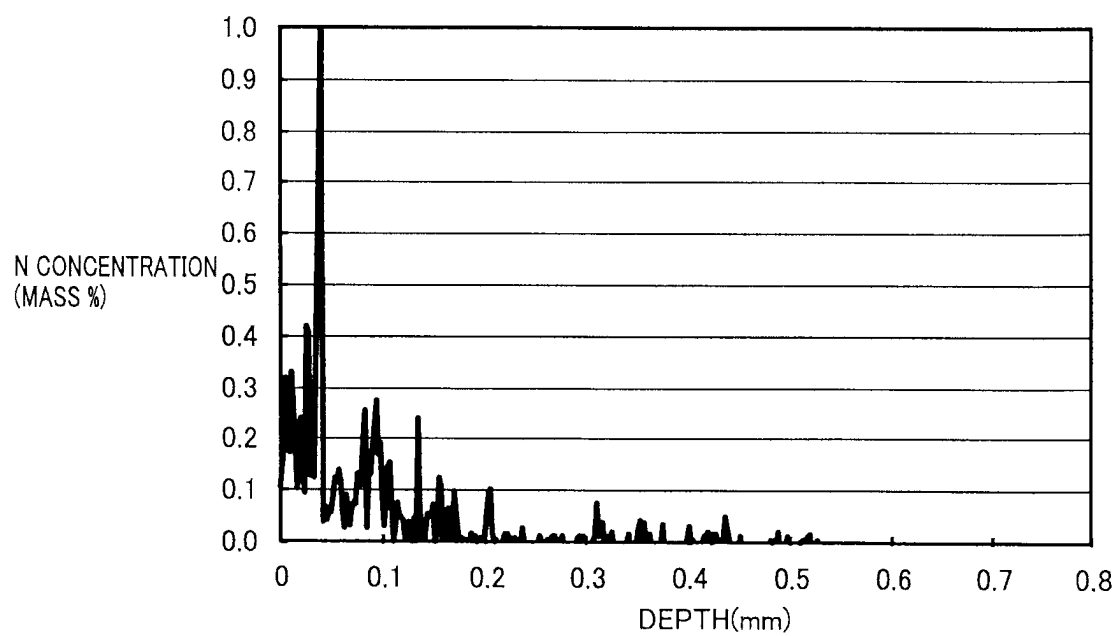


FIG.6



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2013/074671

A. CLASSIFICATION OF SUBJECT MATTER

C23C8/26(2006.01)i, C21D1/06(2006.01)i, C21D9/40(2006.01)i, C22C38/00
(2006.01)i, C22C38/12(2006.01)i, C23C8/14(2006.01)i, C23C8/34(2006.01)i,
C22C38/24(2006.01)n

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)

C23C8/26, C21D1/06, C21D9/40, C22C38/00, C22C38/12, C23C8/14, C23C8/34,
C22C38/24

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

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2013
Kokai Jitsuyo Shinan Koho 1971-2013 Toroku Jitsuyo Shinan Koho 1994-2013

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	JP 3128803 B2 (NSK Ltd.), 17 November 2000 (17.11.2000), claims; tables 1, 4 (examples 2, 3); tables 1, 4, 6 & US 5122000 A & GB 2243417 A & GB 9106203 A0	1-10
Y	JP 2008-231563 A (Honda Motor Co., Ltd.), 02 October 2008 (02.10.2008), claims; paragraphs [0029], [0038]; fig. 7 & US 2008/0230153 A1	1-10
Y	JP 09-324255 A (Koyo Seiko Co., Ltd.), 16 December 1997 (16.12.1997), claims; paragraphs [0007], [0012]; fig. 1 (Family: none)	1-10

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
22 November, 2013 (22.11.13)

Date of mailing of the international search report
03 December, 2013 (03.12.13)

Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2013/074671

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 61-060875 A (Hitachi, Ltd.), 28 March 1986 (28.03.1986), claims 1, 2; page 3, upper right column, line 6 to lower right column, line 4 (Family: none)	1, 4, 7-9
Y	JP 09-078223 A (Kagoshima-Ken), 25 March 1997 (25.03.1997), claims; paragraphs [0004] to [0007], [0010], [0013] to [0035]; fig. 5, 9 (Family: none)	1, 4, 7-9
Y	JP 60-165370 A (Ishikawajima-Harima Heavy Industries Co., Ltd.), 28 August 1985 (28.08.1985), pages 1 to 2; fig. 1 (Family: none)	1, 4, 7-9

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REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **NOBUYUKI MOURI et al.** Improvement of Wear Resistance by Heat Treatment for Carburizing Steel. *NTN TECHNICAL REVIEW*, 2008, vol. 76, 17-22
[0002] [0003]