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(71) Applicant: **Hitachi, Ltd.**
Tokyo 100-8280 (JP)

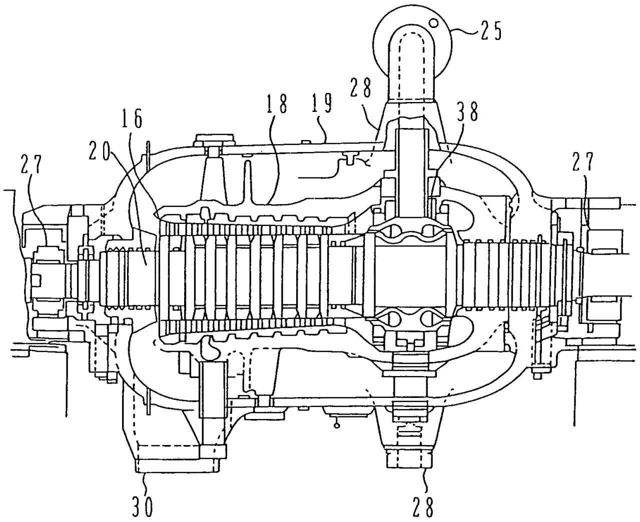
(72) Inventors:
- **Kawanaka Hirotsugu c/o Hitachi, Ltd.,I. P. Group Chiyoda-ku, Tokyo 100-8220 (JP)**
- **Arai Masahiko c/o Hitachi, Ltd.,I. P. Group Chiyoda-ku, Tokyo 100-8220 (JP)**
- **Yoda Hideo c/o Hitachi, Ltd.,I. P. Group Chiyoda-ku, Tokyo 100-8220 (JP)**

(74) Representative: **Beetz & Partner**
Steinsdorfstrasse 10
80538 München (DE)

(54) **High-strength martensite heat resisting cast steel and method of producing the steel**

(57) A high-strength martensite heat resisting steel which has long-time creep rupture strength required for steam temperature condition of 600 - 630°C and toughness at room temperature, and which is suitable for use as a material of a steam turbine rotor shaft and as large-sized forged steel with an improvement of hot forgeability. A method of producing the steel and applications of the steel are also provided. The high-strength martensite heat resisting steel contains 0.05 - 0.20% by mass of C, 0.1% or less of Si, 0.05 - 0.6% of Mn, 0.1 - 0.6% of Ni, 9.0 - 12.0% of Cr, 0.20 - 0.65% of Mo, 2.0 - 3.0% of W, 0.1 - 0.3% of V, 2.0% or less of Co, 0.02 - 0.20% of Nb, 0.015% or less of B, 0.01 - 0.10% of N, and 0.015% or less of Al, (W/Mo) being 4.0 - 10.0.

FIG.4



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a novel high-strength martensite heat resisting steel which has superior creep rupture strength at high temperatures of 600 - 630˚C and which is suitable for use as large-sized forged steel, and to a method of producing the novel steel. Also, the present invention relates to a rotor shaft of a steam turbine, a method of producing the rotor shaft, a rotor blade and a stator nozzle of the steam turbine, and a steam turbine power plant.

2. Description of the Related Art

[0002] Materials having superior high-temperature strength are required for various members of a steam turbine which are exposed to high temperatures. In reply to such requirement, a practically used material of a steam turbine rotor shaft has been changed from CrMoV steel to 12Cr steel, i.e., ferrite-base heat resisting steel having superior high-temperature strength. The steam turbine rotor shaft is required to have not only long-time creep rupture strength, but also toughness at room temperature to bear against stress abruptly applied when the steam turbine is started. If the toughness at room temperature is low, there is a risk that the rotor shaft may cause brittle rupture at the start of the steam turbine. For that reason, improvements of heat resisting steel have been progressed in recent years. In particular, ferrite-base 12Cr heat resisting steels having been developed for use at steam temperature of 600˚C or above are disclosed in Patent Document 1 (JP,A 62-103345), Patent Document 2 (JP,A 2-290950), Patent Document 3 (JP,A 4-147948), Patent Document 4 (JP,A 7-34202), and Patent Document 5 (JP,A 2000-54803).

[0003] Meanwhile, steam turbines have recently been improved with intent to realize higher efficiency and larger capacity, but a thermal power plant operating at steam temperature of 650˚C is not yet realized. The reasons reside in not only the state of the art that the high-temperature material technology for the entire plant is still insufficient, but also the problem of reduction in the material cost which is necessitated from a market trend toward a lower cost. The above-described materials of the turbine rotor shaft adapted for steam temperature of 600˚C or above are relatively high in cost. A primary one of factors pushing up the cost is poor productivity. Because the materials of the turbine rotor shaft are susceptible to strengthening of the grain boundary and enlargement and aggregation of $M_{23}C_6$ carbides, B is added to those materials to prevent aggregation into coarser grains. In producing a large-sized forged product, however, B noticeably reduces productivity because of increasing forging resistance and narrowing a forgeable temperature range. Thus, the production cost is increased.

SUMMARY OF THE INVENTION

[0004] An object of the present invention is to provide a high-strength martensite heat resisting steel which has long-time creep rupture strength required for steam temperature condition of 600 - 630˚C and toughness at room temperature, and which is suitable for use as a material of a steam turbine rotor shaft and as large-sized forged steel with an improvement of hot forgeability, and to a method of producing that steel. Another object of the present invention is to provide a steam turbine rotor shaft and a method of producing it, a steam turbine rotor blade and a method of producing it, a steam turbine stator nozzle and a method of producing it, as well as a steam turbine and a steam turbine power plant, including the method of producing the steam turbine, in which the turbine blade in a stage using steam to cool the rotor has a larger height by increasing the high-temperature tensile strength, and higher thermal efficiency is ensured.

[0005] First, by selecting 620˚C as the target temperature in use of heat resisting steel to be developed, the inventors studied influences of Ni, Mo, W and B upon creep rupture strength at 620˚C and toughness at room temperature. As a result, the inventors found respective composition ranges of added elements, which satisfied the required creep rupture strength at 620˚C and 10^5 hours and had superior toughness at room temperature, thereby accomplishing the steel according to one aspect of the present invention. Further, the inventors produced various kinds of steels while changing the Co content with respect to those composition ranges, and studied influences upon the creep rupture strength at 620˚C, the toughness, and the tensile strength, thereby accomplishing the steel according to another aspect of the present invention.

[0006] According to one aspect, the present invention resides in a high-strength martensite heat resisting steel containing 0.05 - 0.20% by mass of C, 0.1% or less of Si, 0.15 - 0.7% of Mn, 0.15 - 1.0% of Ni, 9.5 - 12.0% of Cr, 0.20 - 0.65% of Mo, 2.0 - 3.0% of W, 0.1 - 0.3% of V, 0.03 - 0.15% of Nb, and 0.01 - 0.10% of N, (W/Mo) being 4.0 - 10.0, the balance being Fe and unavoidable impurities, and also resides in a steam turbine rotor shaft, a rotor blade and a stator nozzle each using that steel.

[0007] According to another aspect, the present invention resides in a high-strength martensite heat resisting steel containing 0.05 - 0.20% by mass of C, 0.1% or less of Si, 0.15 - 0.7% of Mn, 0.15 - 1.0% of Ni, 9.5 - 12.0% of Cr, 0.20 - 0.65% of Mo, 0.1 - 2.0% of Co, 1.8 - 3.0% of W, 0.1 - 0.3% of V, 0.03 - 0.15% of Nb, and 0.01 - 0.10% of N, (W/Mo) being 4.0 - 10.0, the balance being Fe and unavoidable impurities, and also resides in a steam turbine rotor shaft, a rotor blade and a stator nozzle each using that steel.

[0008] Preferably, the high-strength martensite heat resisting steel of the present invention contains 0.09 - 0.16% by mass of C, 0.03 - 0.08% of Si, 0.3 - 0.55% of Mn, 0.2 - 0.7% of Ni, 10 - 11% of Cr, 0.3 - 0.55% of Mo, 2.0 - 2.5% of W, 0.1 - 0.3% of V, 0.04 - 0.10% of Nb, and 0.01 - 0.07% of N, (W/Mo) being 4.0 - 8.0.

[0009] More preferably, the high-strength martensite heat resisting steel of the present invention further contains at least one of 0.015% or less of B and 0.015% or less of Al. Also, (Mo + 0.5W) is 1.3 - 1.7 in order to stably ensure satisfactory creep rupture strength and toughness.

[0010] In particular, with intent to increase productivity and toughness, neither Co nor B is added. Even when those elements are added, it is preferable that the Co content is held 2.0% at maximum and the B content is held 0.015% at maximum. Further, the Al content is preferably held 0.005% or less to increase the long-time creep rupture strength.

[0011] Further, the present invention resides in a method of producing the high-strength martensite heat resisting steel having the above-described steel composition and a method of producing a rotor shaft of any of a high-, an intermediate- and a high- and intermediate-pressure integral steam turbine using that steel, wherein the method includes a series of steps of hot plastic working, quenching, primary tempering at desired temperature, and secondary tempering at higher temperature than that in the primary tempering.

[0012] The reasons why respective elements of the high-strength heat resisting cast steel according to the present invention, which can be used for the rotor shafts of the high-, the intermediate-, and the high- and intermediate-pressure integral steam turbine, are limited to the above ranges will be described below.

[0013] C is an element necessary for ensuring hardenability. In the tempering process, C binds with Cr, W, Mo, etc. to form $M_{23}C_6$- and M_6C-type carbides at the crystal grain boundary, and also binds with Nb, V, etc. to form MX-type carbo-nitrides within grains. To obtain those effects, C is required to be 0.05% at minimum. However, excessive addition of C causes excessive precipitation of the $M_{23}C_6$-type carbides and reduces strength of the matrix (base material); thus decreasing high-temperature strength. For that reason, an upper limit of the C content is set to 0.2%. In particular, a preferable range is 0.07 - 0.15% and a more preferable range is 0.09-0.16%.

[0014] Si is an element that effectively acts as a deoxidizer for molten steel. However, Si promotes precipitation of the Laves phase and reduces ductility due to segregation at the grain boundary, etc. For that reason, the Si content is limited to 0.10% or less. A preferable range is 0.03 - 0.08%.

[0015] Mn is an element that effectively serves as a deoxidizer and a desulfurizer. Also, Mn improves hardenability. Further, Mn suppresses precipitation of δ-ferrite while promoting precipitation of $M_{23}C_6$-type carbides. Therefore, Mn is required to be added 0.15% at minimum. However, excessive addition of Mn deteriorates oxidation resistance. For that reason, an upper limit of the Mn content is set to 0.7%. A preferable range is 0.3 - 0.55%.

[0016] Ni is an element that suppresses precipitation of δ-ferrite, thus providing toughness. However, excessive addition of Ni reduces the creep rupture strength. For that reason, the Ni content is limited to 0.15 - 1.0%. A preferable range is 0.2 - 0.7%.

[0017] Cr is an element that is effective in providing oxidation resistance and in precipitating $M_{23}C_6$-type carbides, to thereby increase the high-temperature strength. In order to obtain those effects, Cr is required to be 9% at minimum. However, excessive addition of Cr causes precipitation of δ-ferrite and reduces fatigue strength. For that reason, the Cr content is limited to 9.5 - 12.0%. A preferable range is 10 - 11%.

[0018] Mo improves hardenability and increases temper softening resistance. Also, Mo is also effective in increasing the high-temperature strength based on the action of promoting fine precipitation of $M_{23}C_6$-type carbides and preventing aggregation. Therefore, Mo is required to be 0.2% or more. In relation to the W content, however, the Mo content should be held 0.65% or less. A preferable range is 0.3 - 0.55%.

[0019] W has a more powerful action of suppressing aggregation of $M_{23}C_6$-type carbides into coarser grains in comparison with the Mo. Also, W strengthens the matrix with solid solution. In particular, W is effective in increasing the high-temperature strength by adding 2.0% or more when Co is not contained, and by adding 1.8% or more when Co is contained. In relation to the Mo content, however, the W content should be held 3.0% or less. A preferable range is 2.0 - 2.5%.

[0020] V is effective in precipitating a carbo-nitride of V, to thereby increase the high-temperature strength. However, if the V content exceeds 0.3%, carbon is excessively fixated and the amount of precipitated $M_{23}C_6$-type carbides is reduced, thus decreasing the high-temperature strength. For that reason, the V content is limited to 0.10 - 0.30%. A preferable range is 0.13 - 0.25%.

[0021] Co contributes to not only strengthening the matrix with solid solution, but also suppressing precipitation of δ-ferrite. Addition of 0.1% or more of Co noticeably increases the high-temperature strength, and one of the reasons why such effect is developed is presumably attributable to the interaction with W. In other words, that effect is a specific phenomenon occurred when W is contained 1.8% or more. In creep causing environment at high temperature and long time, however, excessive addition of Co causes aggregation of $M_{23}C_6$-type carbides into coarser grains at the crystal grain boundary, thus reducing the creep rupture strength and also reducing the ductility. This results in deteriorating productivity and increasing the cost. For that reason, an upper limit of the Co content is set to 2.0%. A preferable range is 0.5 - 1.9%.

[0022] Nb forms NbC and contributes to generating finer crystal grains. Also, a part of Nb is brought into the solid solution state in the quenching step and forms NbC in the tempering step, thus increasing the high-temperature strength. Therefore, Nb is required to be added 0.03% or more. As with V, however, if the Nb content exceeds 0.15%, carbon is excessively fixated and the amount of precipitated $M_{23}C_6$-type carbides is reduced, thus decreasing the high-temperature strength. For that reason, the Nb content is limited to 0.03 - 0.15%. A preferable range is 0.04 - 0.10%.

[0023] N has the actions of precipitating a nitride of V and increasing the high-temperature strength in the solid solution state based on the IS effect (interaction between an interstitial solid solution element and a substitutive solid solution element) in cooperation with Mo and W. Therefore, N is required to be added 0.02% at minimum. However, addition of N in excess of 0.1% reduces ductility. For that reason, the N content is limited to 0.02 - 0.1%. A preferable range is 0.04 - 0.07%.

[0024] B has the action of coming into the solid solution state in $M_{23}C_6$, thereby suppressing aggregation of $M_{23}C_6$-type carbides into coarser grains and increasing the high-temperature strength through strengthening of the grain boundary. However, addition of B in excess of 0.015% impairs weldability. Further, addition of B deteriorates productivity and increases the cost. For that reason, an upper limit of the B content is set to 0.015%. Further, in the heat resisting steel of the present invention having superior creep rupture strength in the temperature range of 600 - 630˚C, high toughness is obtaining by adding neither Co nor B. Thus, the electroslag remelting is not required and the production cost can be reduced. A preferable range is 0.008 - 0.015%.

[0025] Al is added as a deoxidizer and a crystal grain reducing agent (refiner). However, Al is a nitride-forming element and fixates N, which effectively acts to increase the creep rupture strength, thereby reducing the long-time creep rupture strength in a high temperature range. Also, Al promotes precipitation of the Laves phase in the form of a brittle intermetallic compound made of mainly W, and causes precipitation of the Laves phase at the crystal grain boundary, thus reducing the long-time creep rupture strength. In particular, when finer crystal grains are formed, the Laves phase is continuously precipitated along the crystal grain boundary. Accordingly, an upper limit of the Al content is set to 0.015%. A preferable range is 0.010% or less and a more preferable range is 0.0005 - 0.005%.

[0026] Mo and W have the similar effect in point of increasing the high-temperature strength and are added in a combined manner. With importance focused on the creep rupture strength in the high temperature range, however, the W content is relatively increased. In the combined addition of Mo and W, they are added such that (Mo + 0.5W) is preferably 1.3 - 1.7 and more preferably 1.5 $\pm$ 0.1 within the above-mentioned respective composition ranges of Mo and W. Here, (Mo + 0.5W) is defined as the Mo equivalent. Taking into account the correlation between W and Mo, it is possible to ensure the creep rupture strength and obtain the toughness by setting a (W/Mo) ratio to be 4.0 - 10.0 within the above-mentioned range of the Mo equivalent. Although those both characteristics are increased and decreased depending the added elements, satisfactory characteristics can be obtained when the (W/Mo) ratio is 4.0 - 8.0 in the same composition system.

[0027] The Cr equivalent expressed by the following formula is preferably 4 - 10.5 and more preferably 6.5 - 9.5:

$$\text{Cr equivalent} = -40\,\text{C\%} - 30\,\text{N\%} - 2\,\text{Mn\%} - 4\,\text{Ni\%} - 2\,\text{Co\%} + \text{Cr\%} + 6\,\text{Si\%} + 4\,\text{Mo\%} + 1.5\,\text{W\%} + 11\,\text{V\%} + 5\,\text{Nb\%} + 2\,\text{Ta\%}$$

[0028] Further, the present invention resides in a rotor shaft for use in a high-pressure steam turbine, an intermediate-pressure steam turbine, and a high- and intermediate-pressure integral steam turbine, wherein the rotor shaft is produced by preparing an ingot by vacuum melting, vacuum carbon deoxidation melting, or as required, electroslag remelting, and by performing successive steps of hot forging at 850 - 1150˚C, heating at 900 - 1150˚C, preferably 1000 - 1100˚C, after rough cutting of the ingot surface, quenching at a cooling rate of 50 - 150˚C/hour at a central hole by water spraying, primary tempering at 500 - 620˚C, preferably 550 - 650˚C, followed by subsequent furnace cooling, and secondary tempering at temperature of 630 - 750˚C, preferably 660 - 740˚C, higher than that in the primary tempering, followed by subsequent furnace cooling.

[0029] In the steam turbine rotor shaft made of the 12 mass%-Cr martensite steel according to the present invention, a buildup weld layer is preferably formed on the surface of a matrix (base material) in a journal portion of the rotor shaft by using a welding material made of Cr-Mo low-alloy steel that has a high bearing characteristic. It is preferable that the buildup weld layer is formed in 3 - 10 multi-layers. The Cr content of the welding material is gradually reduced from the first layer to any of the second to fourth layers. The fourth and subsequent layers are welded by using the welding material made of the steel having the same Cr content. Further, the Cr content of the welding material used for welding the first layer is reduced about 2 - 6% by mass from that of the base material, and the Cr content in the fourth and subsequent weld layers is set to 0.5 - 3% by mass (preferably 1 - 2.5% by mass).

[0030] The buildup welding is preferable to improve the bearing characteristic of the journal portion because of having the highest safety, but the journal portion may have a shrink-fitting or press-fitting structure of a sleeve made of low-alloy steel containing 1 - 3% of Cr. From the viewpoint of forming many weld layers and gradually reducing the Cr content in the weld layers, the number of the weld layers is preferably three or more. However, even if ten or more weld layers are formed, the effect cannot be obtained in excess of a saturated level. In order to form the weld layers having a required thickness, at least five buildup weld layers are preferably formed except for an allowance for final finish by cutting. In addition, preferably, the third and subsequent weld layers are made of the steel mainly having the tempered martensite structure, and the fourth and subsequent weld layers are made of the steel containing 0.03 - 0.1% by mass of C, 0.3 - 1% of Si, and 0.3 - 1.5% of Mn.

[0031] Still further, the present invention resides in a first-stage rotor blade and a first-stage stator nozzle of the high-pressure steam turbine, the intermediate-pressure steam turbine, and the high- and intermediate-pressure integral steam turbine, wherein the first-stage rotor blade and the first-stage stator nozzle are each produced by preparing an ingot by any of vacuum melting, vacuum carbon deoxidation melting, and electroslag remelting, and by performing successive steps of hot forging at 850 - 1150˚C, heating at 900 - 1150˚C, quenching at a cooling rate of 300 - 600˚C/hour by oil cooling, primary tempering at 500 - 620˚C, and secondary tempering at temperature of 630 - 750˚C higher than that in the primary tempering.

[0032] Still further, the present invention resides in a high-pressure steam turbine comprising a rotor shaft, rotor blades implanted to the rotor shaft, stator nozzles for guiding inflow of steam toward the rotor blades, and an inner casing for holding the stator nozzles, wherein the rotor blades are disposed in eight or more stages on one side with the first stage being of the double-flow type, and the rotor shaft alone or the rotor shaft and at least a first-stage rotor blade and stator nozzle of the rotor blades and the stator nozzles are made of the above-described martensite heat resisting steel.

[0033] Still further, the present invention resides in an intermediate-pressure steam turbine comprising a rotor shaft, rotor blades implanted to the rotor shaft, stator nozzles for guiding inflow of steam toward the rotor blades, and an inner casing for holding the stator nozzles, wherein the rotor blades are disposed in five or more stages on each of left and right sides in bilaterally symmetrical arrangement and have a double-flow structure with the first stage implanted to a central portion of the rotor shaft, and the rotor shaft alone or the rotor shaft and at least a first-stage rotor blade and stator nozzle of the rotor blades and the stator nozzles are made of the above-described martensite heat resisting steel.

[0034] Still further, the present invention resides in a high- and intermediate-pressure integral steam turbine comprising a rotor shaft, rotor blades implanted to the rotor shaft, stator nozzles for guiding inflow of steam toward the rotor blades, and an inner casing for holding the stator nozzles, wherein the rotor blades are disposed in seven or more stages on the high-pressure side and five or more stages on the intermediate-pressure side, and the rotor shaft alone or the rotor shaft and at least a first-stage rotor blade and stator nozzle of the rotor blades and the stator nozzles are made of the above-described martensite heat resisting steel.

[0035] Still further, the present invention resides in a steam turbine power plant including any of a set of a high-pressure steam turbine, an intermediate-pressure steam turbine, and two low-pressure steam turbines connected in tandem, and a set of a high- and intermediate-pressure integral steam turbine and a low-pressure steam turbine, wherein a rotor shaft alone or a rotor shaft and at least a first-stage rotor blade and stator nozzle of the rotor blades and the stator nozzles are made of the above-described martensite heat resisting steel.

[0036] In the steam turbine power plant according to the present invention, preferably, the low-pressure steam turbine includes the rotor blades disposed in eight or more stages on each of the left and right sides in bilaterally symmetrical arrangement and has the double-flow structure with the first stage implanted to the central portion of the rotor shaft. The last-stage one of the rotor blades is made of martensite steel containing 0.1 - 0.4% by mass of C, 0.25% or less of Si, 0.90% or less of Mn, 8.0 - 13.0% of Cr, 2 - 3% or less of Ni, 1.5 - 3.0% of Mo, 0.05 - 0.35% of V, 0.02 - 0.20% of one or more of Nb and Ta in total, and 0.02 - 0.10% of N, and it has tensile strength at room temperature of 120 kgf/mm^2 or more, preferably 128.5 kgf/mm^2 or more. Further, the blade height is 36 inches or more, and a value of [blade height (inch) x number of revolutions (rpm)] is 125,000 or more.

[0037] Such a long blade of the steam turbine must have high tensile strength and high cycle fatigue strength to be endurable against large centrifugal stress and vibration stress which are caused by high-speed rotation. To that end, the metal structure of a blade material is formed as the fully tempered martensite structure because the fatigue strength is reduced if the harmful δ ferrite structure is present. The material composition is adjusted so as to hold the Cr equivalent at 10 or less and to ensure that the metal structure of the blade material does not essentially contain the δ ferrite phase.

[0038] Further, in order to obtain the homogeneous and high-strength long blade of the steam turbine, thermal refining is conducted by performing, after smelting and forging steps, quenching (preferably oil cooling) through steps of heating to 1000 - 1100˚C, i.e., temperature sufficient for complete transform to the austenite structure, holding for preferably 0.5 - 3 hours and subsequent quick cooling to room temperature, and two or more stages of heat treatment, e.g., primary tempering through steps of heating to 550 - 570˚C, holding for preferably 1 - 6 hours and subsequent cooling to room temperature, and secondary tempering through steps of heating to 560 - 680˚C, holding for preferably 1 - 6 hours and subsequent cooling to room temperature.

[0039] In an inner casing of the steam turbine which is made of the high-strength heat resisting steel according to the present invention, preferably, the inner casing is made of high-strength martensite steel containing 0.06 - 0.16% by mass of C, 0.5% or less of Si, 1% or less of Mn, 0.2 - 1.0% of Ni, 8 - 12% of Cr, 0.05 - 0.35% of V, 0.01 - 0.15% of Nb, 2% or less of Co, 0.01 - 0.1% of N, 1.5% or less of Mo, 1 - 4% of W, and 0.0005 - 0.003% of B. Further, the element composition is adjusted to hold the Cr equivalent in the range of 4 - 10 such that 95% or more of the tempered martensite structure (i.e., 5% or less of the δ ferrite) is obtained.

[0040] Thus, according to the present invention, it is possible to provide the high-strength martensite heat resisting steel which has the long-time creep rupture strength required for the steam temperature condition of 600 - 630˚C and toughness at room temperature, and which is suitable for use as the material of the steam turbine rotor shaft and as large-sized forged steel with an improvement of hot forgeability, and to the method of producing the steel. Also, the present invention can provide the steam turbine rotor shaft and the method of producing it, the steam turbine rotor blade and the method of producing it, the steam turbine stator nozzle and the method of producing it, as well as the steam turbine and the steam turbine power plant, including the method of producing the steam turbine, in which the turbine blade in a stage using steam to cool the rotor has a larger height by increasing the high-temperature tensile strength, and higher thermal efficiency is ensured.

BRIEF DESCRIPTION OF THE DRAWINGS

[0041]

Fig. 1 is a graph showing the relationship between creep rupture strength at 620˚C and 10^5 hours and (W/Mo);
Fig. 2 is a graph showing the relationship between impact absorption energy at 25˚C and (W/Mo);
Fig. 3 is a graph showing the relationship between creep rupture strength and impact absorption energy;
Fig. 4 is a cross-sectional view of a high-pressure steam turbine according to the present invention;
Fig. 5 is a cross-sectional view of an intermediate-pressure steam turbine according to the present invention; and
Fig. 6 is a cross-sectional view of a high- and intermediate -pressure integral steam turbine according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0042] The best mode for carrying out the present invention will be described in detail below in connection with exemplary embodiments. It is to be noted that the present invention is not limited to those embodiments.

(First Embodiment)

[0043] Table 1, given below, shows chemical composition (% by mass) of the steel of the present invention and comparative steels which are used in this embodiment for comparative studies. In Table 1, samples No. 1-10 represent the steel of the present invention, samples No. 11-13 represent the comparative steels, and samples No. 14-19 represent the known steels (corresponding to Patent Documents 1 and 3). As seen from Table 1, in the samples No. 1-10 representing the steel of the present invention, the (W/Mo) ratio is 4.0 - 10.0.

[0044] Each of the steel samples shown in Table 1 was prepared by producing an ingot of 50 kg in a vacuum high-frequency induction melting furnace, and forming a plate of 30 mm (t) × 90 mm (w) × L by hot forging. The hot forging was performed under heating conditions of temperature 1150˚C × 3 hours and at the forging temperature of 1150 - 950˚C while the heating was repeated six times.

[0045] Simulating a central portion of a large-sized steam turbine rotor shaft, heat treatment was conducted by successively performing quenching of 1050˚C × 5 hours at a cooling rate of 100˚C/hour, primary tempering through heating and holding of 570˚C × 20 hours, and secondary tempering through heating and holding of 680˚C × 20 hours. For each of the steel samples thus prepared, creep rupture tests were made at various temperatures and the creep rupture strength at 620˚C and 10^5 hours was calculated from the test results by extrapolation. Also, V-notch Charpy impact tests at room temperature (20˚C) were made on each steel sample to obtain absorption energy.

Table 1

Sample	Chemical Composition (% by mass)														
	C	Si	Mn	Ni	Cr	Mo	W	V	Co	Nb	B	N	Al	Cr Equivalent	Mo Equivalent	W/Mo
1	0.12	0.06	0.50	0.25	10.16	0.45	2.05	0.16	1.85	0.06	0.011	0.021	0.001	6.3	1.48	4.6
2	0.13	0.06	0.50	0.24	10.12	0.46	2.07	0.16	1.00	0.06	0.011	0.020	0.001	7.7	1.50	4.5
3	0.12	0.06	0.52	0.27	10.16	0.44	2.08	0.16	1.00	0.06		0.053	0.001	7.0	1.48	4.7
4	0.12	0.07	0.51	0.24	10.13	0.45	2.06	0.16	0.54	0.06		0.051	0.001	8.1	1.48	4.6
5	0.13	0.06	0.53	0.25	10.22	0.47	2.04	0.16		0.06		0.048	0.001	8.9	1.49	4.3
6	0.13	0.06	0.51	0.50	10.23	0.46	2.06	0.17		0.06		0.049	0.001	8.0	1.49	4.5
7	0.12	0.06	0.51	0.51	10.27	0.43	2.20	0.17	1.82	0.05		0.051	0.002	4.7	1.53	5.1
8	0.12	0.06	0.52	0.50	10.41	0.35	2.31	0.17	1.83	0.05		0.048	0.002	4.8	1.51	6.6
9	0.12	0.06	0.50	0.49	10.41	0.25	2.50	0.17	1.81	0.05	0.012	0.020	0.002	5.7	1.50	10.0
10	0.12	0.07	0.52	0.50	10.43	0.31	2.39	0.17	1.81	0.05		0.049	0.002	4.9	1.51	7.7
11	0.12	0.06	0.49	0.50	10.17	0.80	1.41	0.17		0.06		0.048	0.001	8.8	1.51	1.8
12	0.12	0.07	0.51	0.24	10.40	0.22	2.56	0.17		0.05		0.050	0.002	9.4	1.50	11.6
13	0.12	0.07	0.06	0.20	10.00	0.60	1.80	0.20		0.06	0.012	0.022	0.010	11.6	1.50	3.0
14	0.12	0.06	0.04	0.05	10.20	0.70	1.70	0.20	3.30	0.06	0.002	0.022	0.010	6.1	1.55	2.4
15	0.12	0.05	0.50	0.50	10.38	0.41	1.82	0.17		0.05		0.050	0.004	7.9	1.32	4.4
16	0.11	0.06	0.46	0.25	10.20	0.20	2.60	0.20	2.54	0.07		0.016	0.002	5.9	1.50	13.0
17	0.11	0.06	0.46	0.25	10.20	0.20	2.60	0.20	2.52	0.07	0.013	0.017	0.002	5.9	1.50	13.0
18	0.14	0.28	0.52	0.60	11.09	1.24	0.42	0.19		0.09		0.035	0.004	10.8	1.45	0.3
19	0.12	0.08	0.06	0.20	10.00	0.60	1.80	0.20	3.02	0.06	0.012	0.021	0.010	5.7	1.50	3.0

[0046] Table 2, given below, shows the creep rupture strength at 620˚C and 10^5 hours and the absorption energy obtained from the results of the Charpy impact tests at 25˚C. As seen from Table 2, in the samples No. 1-10 representing the steel of the present invention, the creep rupture strength at 620˚C and 10^5 hours is relatively high in the range of 10.35 - 13.00 kgf/mm^2 as a whole. The samples No. 11-13 representing the comparative steels and the samples No. 14-19 representing the known steels have the creep rupture strengths varying in the range of 7.30 - 13.26 kgf/mm^2. In any type of the steels, steel characteristics are clarified by dividing them into systems containing Co and B, not containing Co and B, and not containing Co or B. It is apparent in each of those systems that the steel of the present invention having the (W/Mo) ratio of 4.0 - 10.0 has higher strength.

Table 2

	Creep Rupture Strength	Absorption Energy (20˚C)
	kgf/mm^2	J
1	11.72	55
2	11.79	58
3	11.26	130
4	10.46	155
5	11.03	119
6	11.85	139
7	11.40	137
8	12.00	132
9	13.00	42
10	11.70	128
11	10.17	145
12	12.70	110
13	10.71	60
14	12.03	58
15	11.62	135
16	11.22	85
17	13.26	10
18	7.30	45
19	11.34	60

[0047] Also, as seen from Table 2, in the samples No. 1-10 representing the steel of the present invention, the absorption energy obtained from the results of the Charpy impact tests at room temperature (20˚C) is relatively high in the range of 55 - 139 J as a whole. The samples No. 11-13 representing the comparative steels and the samples No. 14-19 representing the known steels have the absorption energy varying in the range of 10 - 145 J. In any type of the steels, steel characteristics are clarified by dividing them into systems containing Co and B, not containing Co and B, and not containing Co or B. It is apparent in each of those systems that the steel of the present invention having the (W/Mo) ratio of 4.0 - 10.0 has higher absorption energy.

[0048] Fig. 1 is a graph showing the relationship between the (W/Mo) ratio and the creep rupture strength at 620˚C and 10^5 hours. As seen from Fig. 1, in any type of the steels, the creep rupture strength at 620˚C and 10^5 hours is noticeably increased by increasing the (W/Mo) ratio in the steel and has a value higher than 10 kgf/mm^2. Thus, any type of the steels can be satisfactorily used as the material of the rotor shaft of the steam turbine operated at steam temperature of 600˚C or above from the viewpoint of the creep rupture strength.

[0049] Also, as seen from Fig. 1, in any type of the steels, the steel systems containing Co and B have higher strength than the steel systems not containing Co and B and not containing Co or B. Further, it is apparent that, in each of those steel systems, higher strength is obtained with an increase of the (W/Mo) ratio including the range of 4.0 - 10.0. In the steel system containing Co, however, the strength is reduced when the (W/Mo) ratio exceeds 10. Further, higher creep rupture strength is obtained as the Co content increases.

[0050] Fig. 2 is a graph showing the relationship between the (W/Mo) ratio and the absorption energy obtained from the results of the Charpy impact tests at room temperature (20˚C). As seen from Fig. 2, comparing all the types of the steels, the energy absorption is higher in the steel of the present invention in which the (W/Mo) ratio is 4.0 - 10.0, regardless of the steel systems containing Co and B, not containing Co and B, and not containing Co or B. Further, the absorption energy is at minimum in the steel system containing Co and B, and is abruptly reduced at the (W/Mo) ratio of 10 or above. Particularly, in the steel system containing Co, the absorption energy is abruptly reduced when the (W/Mo) ratio exceeds 10. Thus, it is apparent that, in each of the steel systems, the steel of the present invention having the (W/Mo) of 4.0 - 10.0 has higher absorption energy.

[0051] Fig. 3 is a graph showing the relationship between the creep rupture strength at 620˚C and 10^5 hours and the absorption energy obtained from the results of the Charpy impact tests at 20˚C. The relationship between the creep rupture strength and the absorption energy differs for each of the steel system not containing Co and B (indicated by marks ▲ and △), the steel system containing Co or B (indicated by marks ■ and □), and the steel system containing Co and B (indicated by marks ● and ○). As seen from Fig. 3, the higher the creep rupture strength, the lower is the absorption energy. Comparing the absorption energy at the same creep rupture strength, the absorption energy is reduced in the order of the steel system not containing Co and B, the steel system containing Co, the steel system containing B, and the steel system containing Co and B.

[0052] In other words, the comparative steels and the known steels are represented by the samples No. 11 and 15 (containing 0.5% of Ni) which belong to the steel system not containing Co and B (indicated by mark ▲), the sample No. 12 (containing 0.24% of Ni) which belongs to the steel system not containing Co and B (indicated by mark ▲), the samples No. 16 and 14 which belong to the steel system containing Co (indicated by mark ■), the sample No. 13 which belongs to the steel system containing B (indicated by mark ■), and the samples No. 19 and 17 which belong to the steel system containing Co and B (indicated by mark ●). From comparison at the same creep rupture strength, it is apparent that the samples No. 1-10 representing the steel of the present invention ((indicated by marks Δ, □ and ○) have higher absorption energy than the comparative steels and the known steels belonging to the respective same steel systems. Accordingly, the steel of the present invention has higher absorption energy than levels given by characteristic lines representing the comparative steels and the known steels. Comparing from another aspect, the steel of the present invention has higher creep rupture strength than the comparative steels and the known steels at the same absorption energy.

[0053] Thus, the steel of the present invention has the long-time creep rupture strength required for the steam temperature condition of 600 - 630˚C and toughness at room temperature, and it is suitable for use as the material of the steam turbine rotor shaft and as the large-sized forged steel with an improvement of hot forgeability.

(Second Embodiment)

[0054] Fig. 4 is a cross-sectional view.of a high-pressure steam turbine (HP) using the high-strength martensite heat resisting steel according to the present invention as a rotor shaft material. Fig. 5 is a cross-sectional view of an intermediate-pressure steam turbine (IP) using the high-strength martensite heat resisting steel according to the present invention as a rotor shaft material. In this second embodiment, the HP and the IP are connected in tandem to constitute a steam turbine power plant having steam temperature of 625˚C and output capacity of 1050 MW. A low-pressure steam turbine is of the cross-compound four-flow exhaust type, and the blade height in the last stage thereof is 43 inches. More specifically, the steam turbine power plant can be constituted by a set of (HP) - (IP) - generator and a set of two low-pressure steam turbines (LP) - generator, each set operating at the rotation speed of 3000 rpm, or by a set of (HP) - (LP) - generator and a set of (IP) - (LP) - generator, each set operating at the rotation speed of 3000 rpm. The steam temperature and pressure in the HP are 625˚C and 250 kgf/cm^2. In the IP, the steam temperature is heated to 625˚C by a reheater and operation is performed at pressure of 45 - 65 kgf/cm^2. Steam having temperature of 400˚C enters the LP and is sent to a condenser under vacuum of 722 mmHg at 100˚C or below.

[0055] The high-temperature and high-pressure steam turbine power plant according to this embodiment comprises mainly a coal firing boiler, one HP, one IP, two LPs, a condenser, a condensing pump, a low-pressure feedwater heater system, a deaerator, a booster pump, a feedwater pump, and a high-pressure feedwater heater system. More specifically, ultra high-temperature and high-pressure steam generated in the boiler enters the HP in which motive power is produced. Then, the steam is reheated by the boiler and enters the IP in which motive power is produced. The steam exhausted from the IP enters the LP in which motive power is produced, followed by being condensed in the condenser. The condensed water is sent to the low-pressure feedwater heater system and the deaerator by the condensing pump. The feedwater deaerated in the deaerator is sent to the high-pressure feedwater heater system by the booster pump and the condensing pump. After the water temperature is raised in the high-pressure feedwater heater system, the feedwater is returned to the boiler. In the boiler, the feedwater is converted to high-temperature and high-pressure steam through an economizer, an evaporator and a superheater.

[0056] The HP includes a high-pressure inner compartment (casing) 18, a high-pressure outer compartment (casing) 19 surrounding the inner compartment 18, and a high-pressure rotor shaft 20 provided with high-pressure rotor blades 16 implanted to it and disposed inside those casings. High-temperature and high-pressure steam obtained by a boiler passes through a main steam pipe and flows into a main steam inlet 28 through a flange and elbow 25 constituting a main steam section. The steam is then introduced to the rotor blade in the double-flow first stage through a nozzle box 38. The first stage has a double-flow structure, and the rotor blades are disposed in eight stages on one side. Stator nozzles are disposed corresponding to the rotor blades.

[0057] The IP is used to rotate the generator in cooperation with the HP by utilizing steam obtained by heating the steam, which is exhausted from the HP, to 625˚C again by a reheater. Similarly to the HP, the IP has an intermediate-pressure inner compartment (casing) 21 and an intermediate-pressure outer compartment (casing) 22, and further includes stator nozzle corresponding to the intermediate-pressure rotor blades 17. The intermediate-pressure rotor blades 17 are disposed six stages in each of the left and right sides in bilaterally symmetric arrangement with a double-flow structure in which the first-stage rotor blade is implanted to a central portion of the intermediate-pressure rotor shaft 24.

[0058] According to this embodiment, in each of the HP and IP, the rotor shaft, the first-stage rotor blade, and the first-stage stator nozzle are made of one sample steel of the present invention in Table 1 described above, i.e., the 12%-Cr steel containing Co and B. The rotor shafts of the HP and the IP have similar characteristics to those in the above-described first embodiment. The first-stage rotor blade and the first-stage stator nozzle are produced through the steps of quenching by oil cooling after heating to a temperature level similar to that in the case of the rotor shaft, and tempering at 650 - 750˚C. Thus, the first-stage rotor blade and the first-stage stator nozzle have slightly higher creep rupture strength and impact values than those of the rotor shaft.

[0059] The rotor shafts of the high-pressure steam turbine and the intermediate-pressure steam turbine were produced as follows. First, 30 tons of the heat resisting cast steel shown in Table 1 was smelted in an electric furnace, and after carbon vacuum deoxidation, the smelted steel was cast into a mold, followed by forming an electrode rod with elongation forging. Then, electroslag remelting was performed to smelt the cast steel from an upper portion toward a lower portion by using the electrode rod, followed by elongation forging into the rotor shape. The elongation forging was performed at temperature of 1150˚C or below in order to prevent forging cracks.

[0060] After annealing the forged steel, the steel was subjected to steps of heating and holding to 1050˚C while slowly rotating it at speed of 1 (rotation/minute), quenching (cooling rate of 100˚C/hour at a central portion) by water spraying while slowly rotating it at a similar speed, primary tempering at 570˚C, and secondary tempering at 690˚C. The rotor shafts were then obtained by cutting into the respective shapes shown in Figs. 4 and 5. In this embodiment, each rotor shaft was formed such that the upper side of the electroslag steel ingot becomes the first-stage blade side and the lower side becomes the last-stage blade side.

[0061] As a result of examining the central portion of each rotor shaft obtained according to this embodiment, it was proved that the rotor shaft sufficiently satisfied the characteristics (i.e., the creep rupture strength at 620˚C and 10^5 hours ≥ 10 kgf/mm^2 and the impact absorption energy at 20˚C ≥ 1.5 kgf-m) required for the high- and intermediate-pressure turbine rotors. Thus, it was proved that the steam turbine rotor capable of being used in steam at 600 - 630˚C could be produced.

[0062] Two LPs are connected in tandem and have substantially the same structure. In each LP, last-stage and other rotor blades are disposed in eight stages in each of the left and right sides and are arranged in substantially bilateral symmetry. Stator nozzles are disposed corresponding to the rotor blades. The last-stage rotor blade has an airfoil height of 43 inches and is produced through a series of steps of smelting by the electroslag remelting process, forging, and heat treatment. Such a long blade is made of martensite steel containing 0.08 - 0.18% by mass of C, 0.25% or less of Si, 0.90% or less of Mn, 8.0 - 13.0% of Cr, 2 - 3% of Ni, 1.5 - 3.0% of Mo, 0.05 - 0.35% of V, 0.02 - 0.20% of one or more of Nb and Ta in total, and 0.02 - 0.10% of N. Also, the long blade exhibits the tensile strength at room temperature of 120 kgf/mm^2 or more and has the fully tempered martensite structure. More preferably, the tensile strength is 128.5 kgf/mm^2 or more and the V-notch Charpy impact value at 20˚C is 4 kgf-m/cm^2 or more. An airfoil of the long blade having the airfoil height of 43 inches, against which high-speed steam impinges, is coated with an erosion shield formed by joining a stellite sheet made of a Co-base alloy by welding in order to prevent erosion caused by water droplets in the steam.

[0063] A low-pressure rotor shaft is made of forged steel having the fully tempered bainite structure of a super-clean material containing 3.75% of Ni, 1.75% of Cr, 0.4% of Mo, 0.15% of V, 0.25% of C, 0.05% of Si, and 0.10% of Mn, the balance being Fe. Each of the rotor blades and the stator nozzles in other stages than the last stage is made of the 12%-Cr steel containing 0.1% of Mo. Inner and outer casings are each made of 0.25%-C cast steel.

[0064] Further, in this embodiment, a shaft of a generator with output capacity of 1050-MW class is made of higher-strength steel having the fully tempered bainite structure and containing 0.15 - 0.30% of C, 0.1 - 0.3% of Si, 0.5% or less of Mn, 3.25 - 4.5% of Ni, 2.05 - 3.0% of Cr, 0.25 - 0.60% of Mo, and 0.05 - 0.20% of V. Further, the tensile strength at room temperature is 93 kgf/mm^2 or more, preferably 100 kgf/mm^2 or more, and 50%-FATT (Fracture Appearance

Transition Temperature) is 0˚C or below, preferably -20˚C or below.

[0065] A central hole is formed in the rotor shaft of each of the HP, IP and LP so that the presence or absence of defects can be checked through the central hole by ultrasonic inspection, visual inspection and/or fluorescence flaw detection. Alternatively, the central hole may be omitted because defects can also be detected by ultrasonic inspection from an outer surface of the rotor shaft.

[0066] Moreover, in this embodiment, the Cr-Mo low-alloy steel was buildup-welded on a journal portion of each rotor shaft of the HP and IP to improve bearing characteristics. A coated arc-welding electrode was used as a welding electrode for the buildup welding.

[0067] The buildup welding was performed to form eight layers. The thickness of each layer was 3 - 4 mm and the total thickness was about 28 mm with a weld surface cut about 5 mm by grinding. Welding conditions were set such that each of the preheating temperature, the inter-pass temperature, and the start temperature of stress removing annealing (SR) was 250 - 350˚C and the SR was performed under conditions of heating and holding of 630˚C $\times$ 36 hours. First to third layers were formed by using coated arc-welding electrodes made of 8%-Cr - 0.5%-Mo steel, 5%-Cr - 0.5%-Mo steel, and 2.3%-Cr - 1%-Mo steel, respectively, and fourth to eighth layers were each formed by using a coated arc-welding electrode made of 1.3%-Cr - 0.76%-Mo steel. Those welding materials contained 0.03 - 0.07% of C, 0.4 - 0.8% of Si, and 0.5 - 1.0% of Mn.

[0068] The first-stage rotor blade and the first-stage stator nozzle in each of the HP and IP were also produced by smelting, in a vacuum arc melting furnace, the heat resisting steel of the present invention containing Co and B, shown in Table 1 described above, and forming the steel into the blade and nozzle blank shape (with a width of 150 mm, a height of 50 mm, and a length of 1000 mm) by elongation forging. Further, the forged steel was subjected to heating to 1050˚C, oil quenching, and tempering at 690˚C. Thereafter, the forged steel was cut into the predetermined shape.

[0069] Also, it was confirmed that the first-stage rotor blade of each of the HP and IP sufficiently satisfied the required characteristics (i.e., the creep rupture strength at 625˚C and 10^5 hours ≥ 15 kgf/mm^2). Thus, it was proved that the steam turbine blade capable of being used in steam at 620˚C or above could be produced.

[0070] Inner casings of high- and intermediate-pressure sections, a casing of a main steam valve, and a casing of a steam control valve were each produced through the steps of smelting, in an electric furnace, heat-resisting cast steel of 0.12% C - 9% Cr - 0.6% Mo - 1.7% W - B, ladle refining, and casting into a sand mold. By sufficiently performing refining and deoxidation before the casting step, the cast steel could be obtained which contained no casting defects such as shrinkage.

[0071] Further, as a result of examining characteristics of the inner casings, the casing of the main steam valve, and the casing of the steam control valve, it was confirmed that each of those casings satisfied the required characteristics (i.e., the creep rupture strength at 625˚C and 10^5 hours ≥ 10 kgf/mm^2 and the impact absorption energy at 20˚C ≥ 1 kgf-m) and could be satisfactorily welded. Thus, it was proved that the steam turbine casing capable of being used in steam at 620˚C or above could be produced.

[0072] According to the second embodiment, it is possible to provide the steam turbine rotor shaft having the long-time creep rupture strength required for the steam temperature condition of 600 - 630˚C and toughness at room temperature, and the method of producing the rotor shaft, the steam turbine rotor blade having the required characteristics and the method of producing it, as well as the steam turbine stator nozzle having the required characteristics and the method of producing it. Further, it is possible to provide the steam turbine and the steam turbine power plant, including the method of producing the steam turbine, in which the turbine blade in the stage using steam to cool the rotor has a larger height by increasing the high-temperature tensile strength, and higher thermal efficiency is ensured.

(Third Embodiment)

[0073] Fig. 6 is a cross-sectional view of a high- and intermediate-pressure integral steam turbine. This third embodiment relates to a steam turbine power plant with steam temperature of 620˚C and output capacity of 600 MW. The power plant of this third embodiment is of the tandem compound double-flow type, and the last-stage blade height in the LP is 43 inches. A rotation speed of 3000 rpm is obtained by the high- and intermediate-pressure integral steam turbine (HP-IP) and one LP (C) or two LPs (D). The steam temperature and pressure in the high-pressure section (HP) are 600˚C and 250 kgf/cm^2. In the intermediate-pressure section (IP), the steam temperature is heated to 600˚C by a reheater and operation is performed at pressure of 45 - 65 kgf/cm^2. The steam temperature in the low-pressure section (LP) is 400˚C, and steam in the LP is sent to a condenser under vacuum of 722 mmHg at 100˚C or below.

[0074] The high-pressure side steam turbine (HP) includes an inner compartment (casing) 18 and an outer compartment (casing) 19 surrounding the inner casing 18. The intermediate-pressure steam turbine (IP) includes an inner compartment (casing) 21 and an outer compartment (casing) 22 surrounding the inner casing 21. A high- and intermediate-pressure integral rotor shaft 23 provided with high-pressure rotor blades 16 and intermediate-pressure rotor blades 17 both implanted to the rotor shaft is disposed inside those casings. The high-pressure and high-temperature steam obtained by the boiler passes through a main steam pipe and flows into a main steam inlet 28 through a flange and elbow 25 constituting a main steam section. The steam is then introduced to the high-pressure rotor blade 16 in the first stage of the high-pressure side steam turbine through a nozzle box 38. The rotor blades are disposed in eight stages in the HP on the left side in Fig. 6 and six stages in the IP on the right side in Fig. 6. Stator nozzles are disposed corresponding to the rotor blades.

[0075] In this third embodiment, each of the rotor shaft, the first-stage rotor blade, and the first-stage stator nozzle is made of the 12%-Cr steel containing Co and B among the steel samples of the present invention shown in Table 1 described above.

[0076] The rotor shaft of the high- and intermediate-pressure integral steam turbine was produced as follows. First, 30 tons of the 12%-Cr steel shown in Table 1 was smelted in an electric furnace, and after carbon vacuum deoxidation, the smelted steel was cast into a mold, followed by forming an electrode rod with elongation forging. Then, electroslag remelting was performed to smelt the cast steel from an upper portion toward a lower portion by using the electrode rod, followed by elongation forging into the rotor shape. The elongation forging was performed at temperature of 1150˚C or below in order to prevent forging cracks. After annealing the forged steel, the steel was subjected to steps of quenching by water spray cooling after heating to 1050˚C, two stages of tempering at 570˚C and 690˚C. The rotor shaft was then obtained by cutting into the shape shown in Fig. 5. Materials and production conditions for the other components were the same as those in the second embodiment. Further, buildup welding was also performed on a bearing journal portion in a similar manner. In addition, the rotor shaft had the same characteristics as those described above in the first embodiment.

[0077] The first-stage rotor blade and the first-stage stator nozzle were produced through the steps of quenching by oil cooling after heating to a temperature level similar to that in the case of the rotor shaft, and tempering at 650 - 750˚C. Thus, the first-stage rotor blade and the first-stage stator nozzle had slightly higher creep rupture strength and impact values than those of the rotor shaft.

[0078] The IP heats the steam discharged from the HP again to 600˚C by a reheater and rotates the generator in cooperation with the HP by using the heated steam.

[0079] One LP is connected to the HP-LP. Last-stage and other rotor blades are disposed in six stages in each of the left and right sides and are arranged in substantially bilateral symmetry. Stator nozzles are disposed corresponding to the rotor blades. The last-stage rotor blade has an airfoil height of 43 inches and is made of the 12%-Cr steel that is similar to that used in the second embodiment. Also, as in the second embodiment, the last-stage rotor blade in this third embodiment has erosion shields made of stellite steel, which are welded at two points in the front and rear sides of the rotor blade by electron beam welding or TIG welding.

[0080] Each of the rotor shaft of the low-pressure steam turbine and the rotor blades and the stator nozzles in other stages than the last stage is produced in the same manner as that described above in the second embodiment.

[0081] The concept of this third embodiment can be similarly applied to another type of power plant, e.g., a large-capacity power plant of 1000-MW class in which the steam inlet temperature of the high- and intermediate-pressure integral steam turbine is 610˚C or above and the steam inlet temperature and the steam outlet temperature of the low-pressure integral steam turbine are about 400˚C and about 60˚C, respectively.

[0082] While this third embodiment has been described in connection with the power plant of the tandem compound double-flow type, it can be modified based on the same concept to, e.g., a power plant with output capacity of 1050-MW class in which two low-pressure steam turbines are connected in tandem. In that case, a generator shaft is made of higher-strength steel having the fully tempered bainite structure, the tensile strength at room temperature of 93 kgf/mm^2 or more, preferably 100 kgf/mm^2 or more, and 50%-FATT (Fracture Appearance Transition Temperature) of 0˚C or below, preferably -20˚C or below, as in the second embodiment.

[0083] According to the third embodiment, it is possible to provide the steam turbine rotor shaft having the long-time creep rupture strength required for the steam temperature condition of 600 - 630˚C and toughness at room temperature, and the method of producing the rotor shaft, the steam turbine rotor blade having the required characteristics and the method of producing it, as well as the steam turbine stator nozzle having the required characteristics and the method of producing it. Further, it is possible to provide the steam turbine and the steam turbine power plant, including the method of producing the steam turbine, in which the turbine blade in the stage using steam to cool the rotor has a larger height by increasing the high-temperature tensile strength, and higher thermal efficiency is ensured. Features, components and specific details of the structures of the above-described embodiments may be exchanged or combined to form further embodiments optimized for the respective application. As far as those modifications are readily apparent for an expert skilled in the art they shall be disclosed implicitly by the above description without specifying explicitly every possible combination, for the sake of conciseness of the present description.

Claims

1. A high-strength martensite heat resisting steel containing 0.05 - 0.20% by mass of C, 0.1% or less of Si, 0.15 - 0.7%

of Mn, 0.15 - 1.0% of Ni, 9.5 - 12.0% of Cr, 0.20 - 0.65% of Mo, 2.0 - 3.0% of W, 0.1 - 0.3% of V, 0.03 - 0.15% of Nb, and 0.01 - 0.10% of N, (W/Mo) being 4.0 - 10.0, the balance being Fe and unavoidable impurities.

2. A high-strength martensite heat resisting steel containing 0.05 - 0.20% by mass of C, 0.1% or less of Si, 0.15 - 0.7% of Mn, 0.15 - 1.0% of Ni, 9.5 - 12.0% of Cr, 0.20 - 0.65% of Mo, 1.8 - 3.0% of W, 0.1 - 2.0% of Co, 0.1 - 0.3% of V, 0.03 - 0.15% of Nb, and 0.01 - 0.10% of N, (W/Mo) being 4.0 - 10.0, the balance being Fe and unavoidable impurities.

3. The high-strength martensite heat resisting steel according to Claim 1 or 2, wherein the steel contains 0.09 - 0.16% by mass of C, 0.03 - 0.08% of Si, 0.3 - 0.55% of Mn, 0.2 - 0.7% of Ni, 10 - 11% of Cr, 0.3 - 0.55% of Mo, 2.0 - 2.5% of W, 0.1 - 0.3% of V, 0.04 - 0.10% of Nb, and 0.01 - 0.07% of N, (W/Mo) being 4.0 - 8.0.

4. The high-strength martensite heat resisting steel according to any one of Claims 1 to 3, wherein the steel further contains at least one of 0.015% or less of B and 0.015% or less of Al.

5. The high-strength martensite heat resisting steel according to any one of Claims 1 to 4, wherein (Mo + 0.5W) is 1.3 - 1.7.

6. A method of producing a high-strength martensite heat resisting steel containing 0.05 - 0.20% by mass of C, 0.1% or less of Si, 0.15 - 0.7% of Mn, 0.15 - 1.0% of Ni, 9.5 - 12.0% of Cr, 0.20 - 0.65% of Mo, 2.0 - 3.0% of W, 0.1 - 0.3% of V, 0.03 - 0.15% of Nb, and 0.01 - 0.10% of N, (W/Mo) being 4.0 - 10.0, the balance being Fe and unavoidable impurities, wherein the method includes a series of steps of hot plastic working, quenching, primary tempering, and secondary tempering at higher temperature than that in the primary tempering.

7. A method of producing a high-strength martensite heat resisting steel containing 0.05 - 0.20% by mass of C, 0.1% or less of Si, 0.15 - 0.7% of Mn, 0.15 - 1.0% of Ni, 9.5 - 12.0% of Cr, 0.20 - 0.65% of Mo, 1.8 - 3.0% of W, 0.1 - 2.0% of Co, 0.1 - 0.3% of V, 0.03 - 0.15% of Nb, and 0.01 - 0.10% of N, (W/Mo) being 4.0 - 10.0, the balance being Fe and unavoidable impurities, wherein the method includes a series of steps of hot plastic working, quenching, primary tempering, and secondary tempering at higher temperature than that in the primary tempering.

8. The method of producing the high-strength martensite heat resisting steel according to Claim 6 or 7, wherein the steel contains 0.09 - 0.16% by mass of C, 0.03 - 0.08% of Si, 0.3 - 0.55% of Mn, 0.2 - 0.7% of Ni, 10 - 11% of Cr, 0.3 - 0.55% of Mo, 2.0 - 2.5% of W, 0.1 - 0.3% of V, 0.04 - 0.10% of Nb, and 0.01 - 0.07% of N, (W/Mo) being 4.0 - 8.0.

9. The method of producing the high-strength martensite heat resisting steel according to any one of Claims 6 to 8, wherein the steel further contains at least one of 0.015% or less of B and 0.015% or less of Al.

10. The method of producing the high-strength martensite heat resisting steel according to any one of Claims 6 to 9, wherein (Mo + 0.5W) is 1.3 - 1.7.

11. A steam turbine rotor shaft made of the high-strength martensite heat resisting steel according to any one of Claims 1 to 5.

12. A method of producing a steam turbine rotor shaft, wherein the method includes a step of obtaining a rotor shaft material by the method of producing the high-strength martensite heat resisting steel according to any one of Claims 6 to 10.

13. The method of producing the steam turbine rotor shaft according to Claim 12, wherein the method includes a step of producing an ingot of the martensite heat resisting steel by any of vacuum melting, vacuum carbon deoxidation melting and electroslag remelting, and performs successive steps of hot forging at 850 - 1150˚C, heating at 900 - 1150˚C, quenching at a cooling rate of 50 - 150˚C/hour at a central hole, primary tempering at 500 - 620˚C, and secondary tempering at temperature of 630 - 750˚C higher than that in the primary tempering.

14. A steam turbine rotor blade made of the high-strength martensite heat resisting steel according to any one of Claims 1 to 5.

15. A steam turbine stator nozzle made of the high-strength martensite heat resisting steel according to any one of Claims 1 to 5.

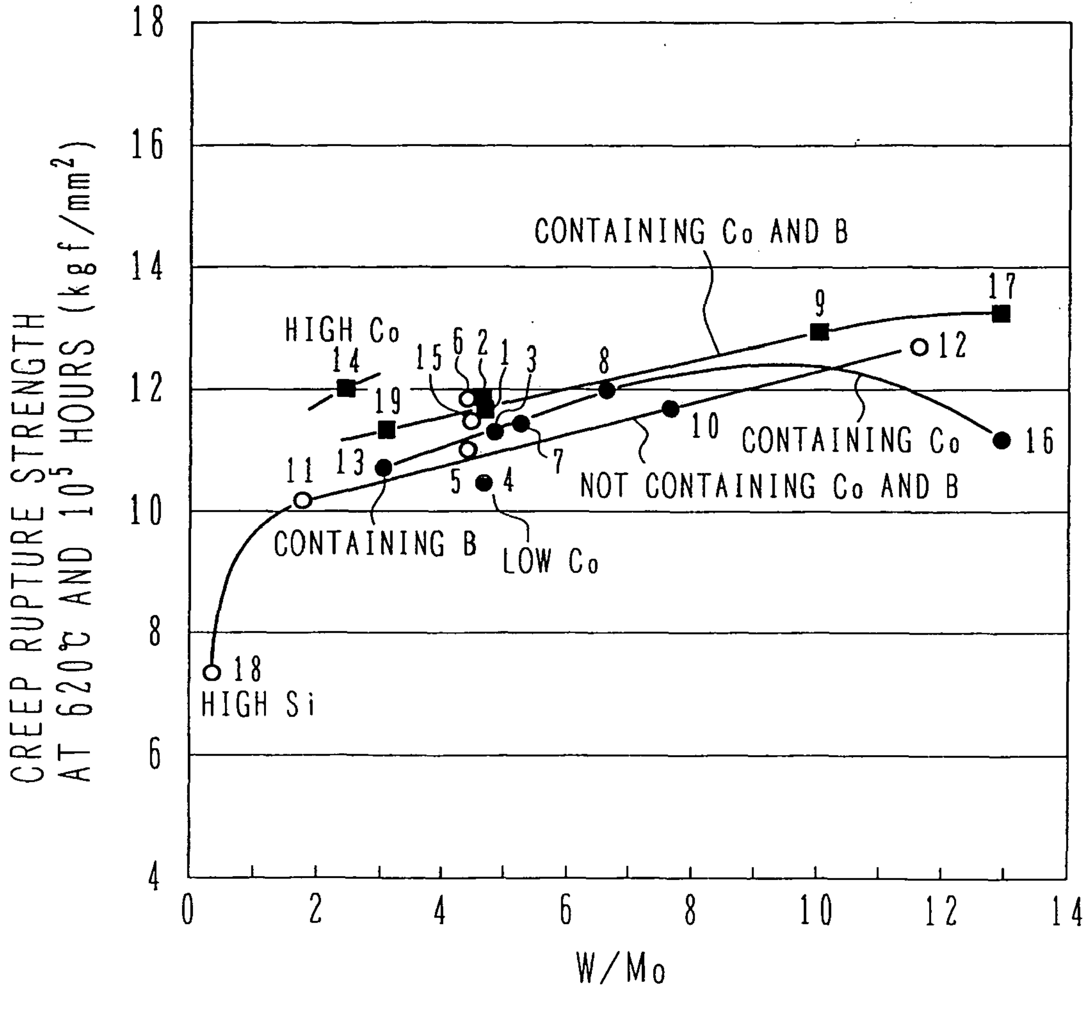
16. A steam turbine comprising a rotor shaft, rotor blades implanted to said rotor shaft, stator nozzles for guiding inflow of steam toward said rotor blades, and an inner casing for holding said stator nozzles, wherein said rotor blades are disposed in seven or more stages on the high pressure side and in five or more stages on the intermediate pressure side, and said rotor shaft alone or said rotor shaft and at least a first-stage rotor blade and stator nozzle of said rotor blades and said stator nozzles are constituted respectively by the rotor shaft according to Claim 11, the rotor blade according to Claim 14, and the stator nozzle according to Claim 15.

17. The steam turbine according to Claim 16, wherein said steam turbine is any of a high-pressure steam turbine, an intermediate-pressure steam turbine, and a high- and intermediate-pressure integral steam turbine.

18. A method of producing a steam turbine comprising a rotor shaft, rotor blades implanted to said rotor shaft, stator nozzles for guiding inflow of steam toward said rotor blades, and an inner casing for holding said stator nozzles, said rotor blades being disposed in seven or more stages on the high pressure side and in five or more stages on the intermediate pressure side, wherein the method includes a step of producing said rotor shaft by the method according to Claim 12 or 13.

19. A steam turbine power plant including any of a set of a high-pressure steam turbine, an intermediate-pressure steam turbine, and two low-pressure steam turbines connected in tandem, and a set of a high- and intermediate-pressure integral steam turbine and a low-pressure steam turbine, wherein at least one of said high-pressure steam turbine, said intermediate-pressure steam turbine, and said high- and intermediate-pressure integral steam turbine is constituted by the high-pressure steam turbine, the intermediate-pressure steam turbine, and the high- and intermediate-pressure integral steam turbine according to Claim 17.

FIG. 1


CREEP RUPTURE STRENGTH AT 620℃ AND 10^5 HOURS (kgf/mm^2)
W/Mo
CONTAINING Co AND B
HIGH Co
CONTAINING Co
NOT CONTAINING Co AND B
CONTAINING B
LOW Co
HIGH Si
18
16
14
12
10
8
6
4
0
2
4
6
8
10
12
14
1
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7
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16
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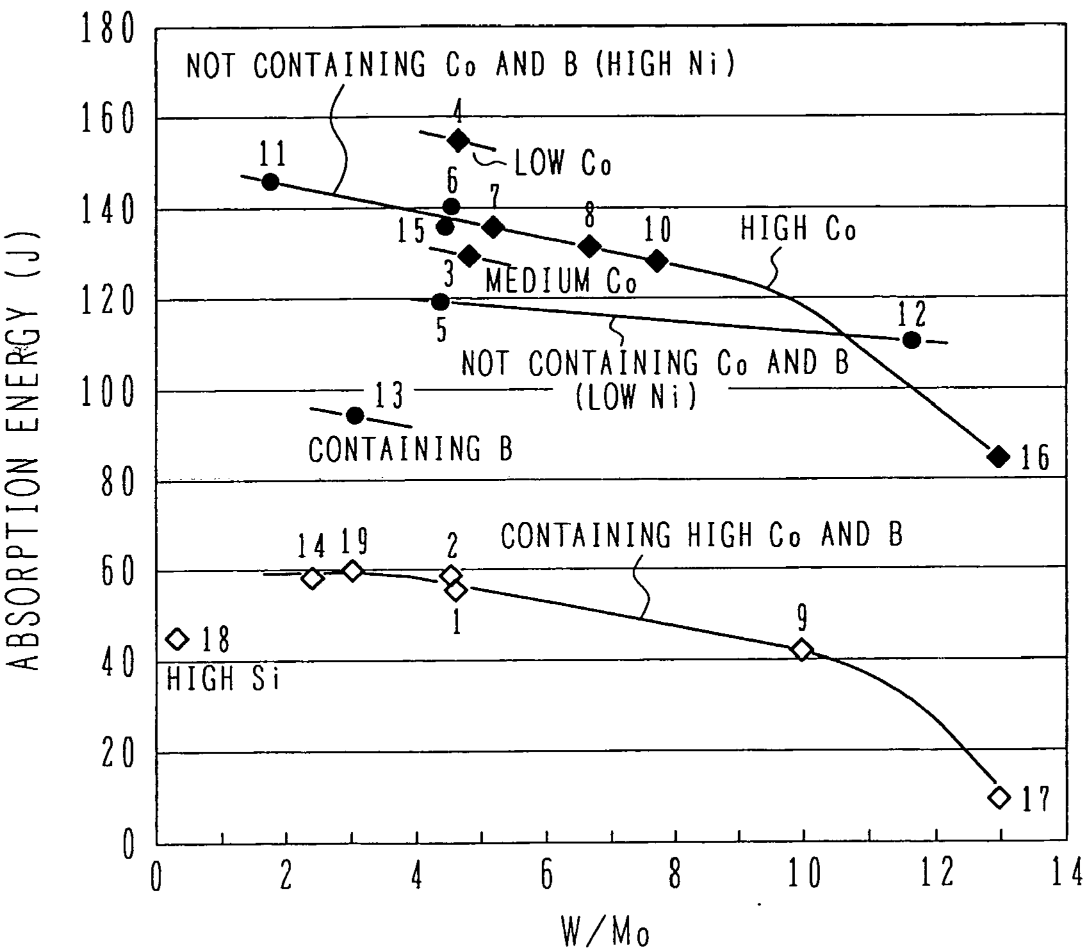
18
19

FIG. 2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140
120
100
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0
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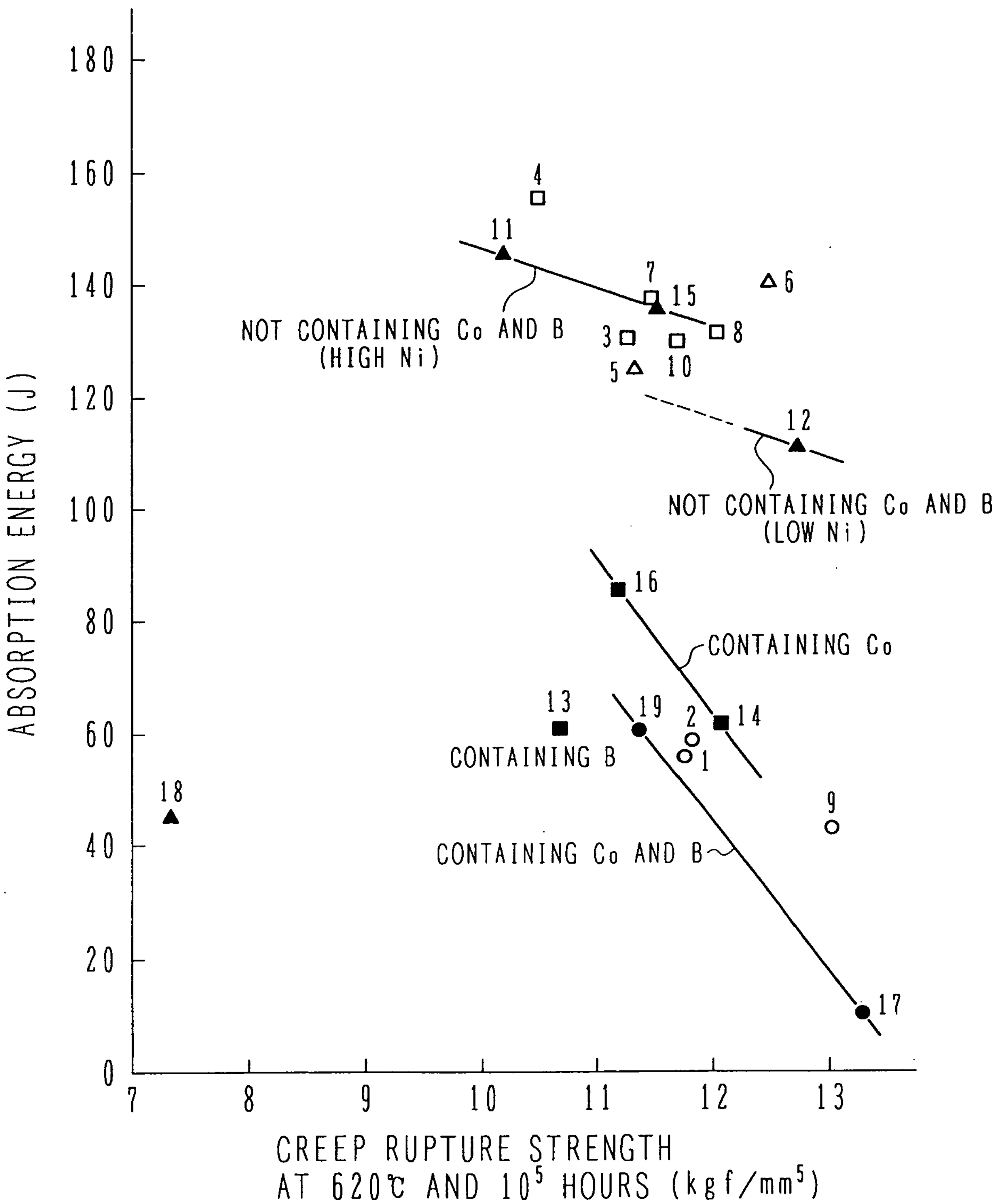
6
8
10
12
14
W/Mo
NOT CONTAINING Co AND B (HIGH Ni)
LOW Co
HIGH Co
MEDIUM Co
NOT CONTAINING Co AND B
(LOW Ni)
CONTAINING B
CONTAINING HIGH Co AND B
HIGH Si
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

FIG. 3


ABSORPTION ENERGY (J)
180
160
140
120
100
80
60
40
20
0
7
8
9
10
11
12
13
CREEP RUPTURE STRENGTH
AT 620℃ AND 10^5 HOURS (kgf/mm^5)
NOT CONTAINING Co AND B
(HIGH Ni)
NOT CONTAINING Co AND B
(LOW Ni)
CONTAINING Co
CONTAINING B
CONTAINING Co AND B
1
2
3
4
5
6
7
8
9
10
11
12
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18
19

FIG. 4

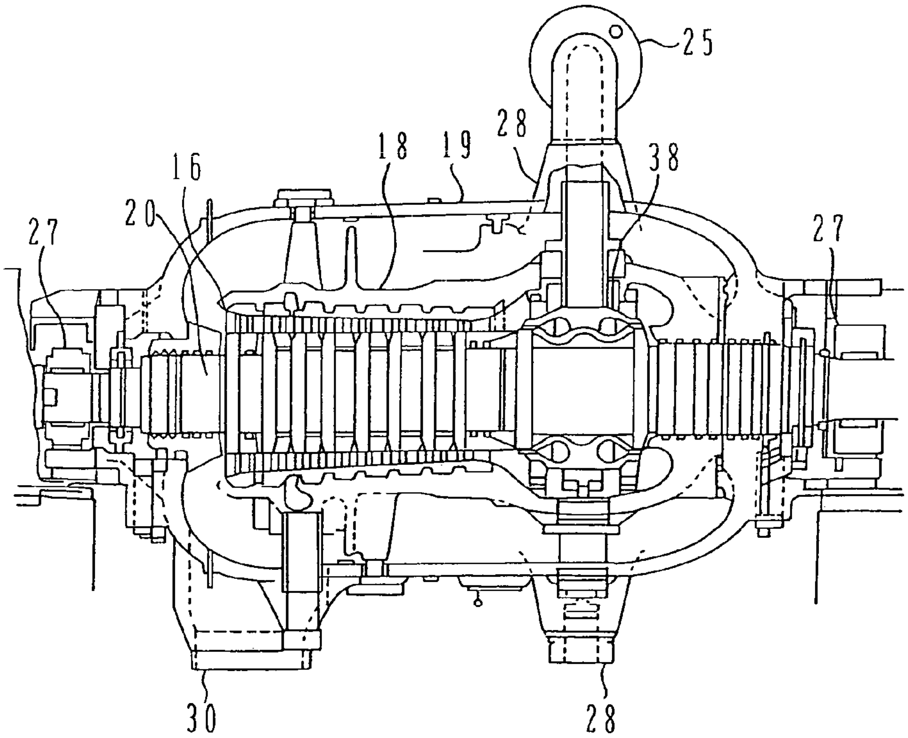


FIG. 5

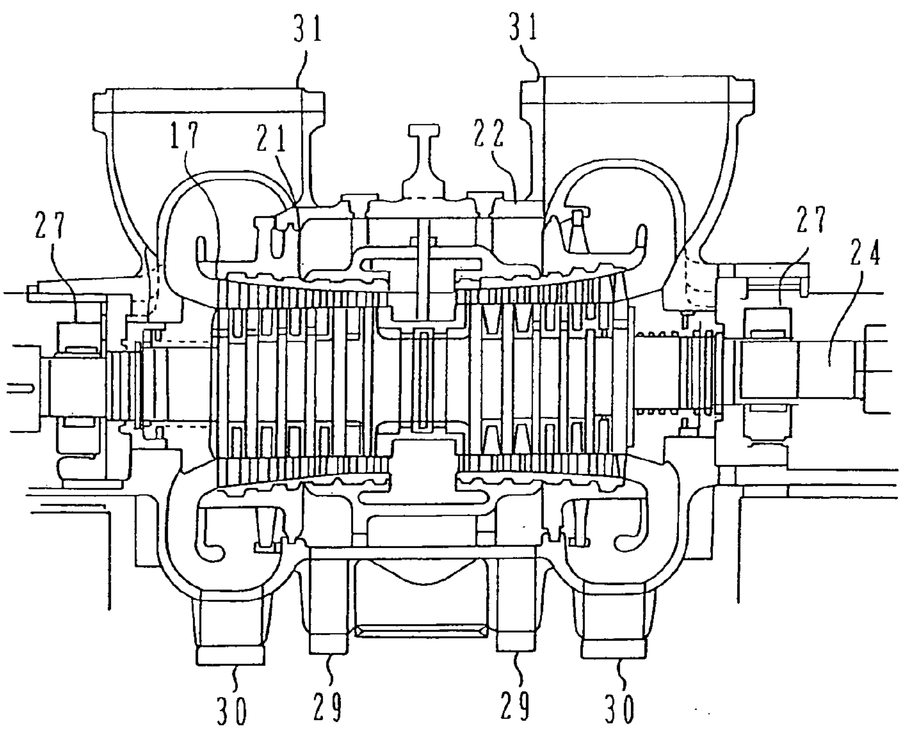
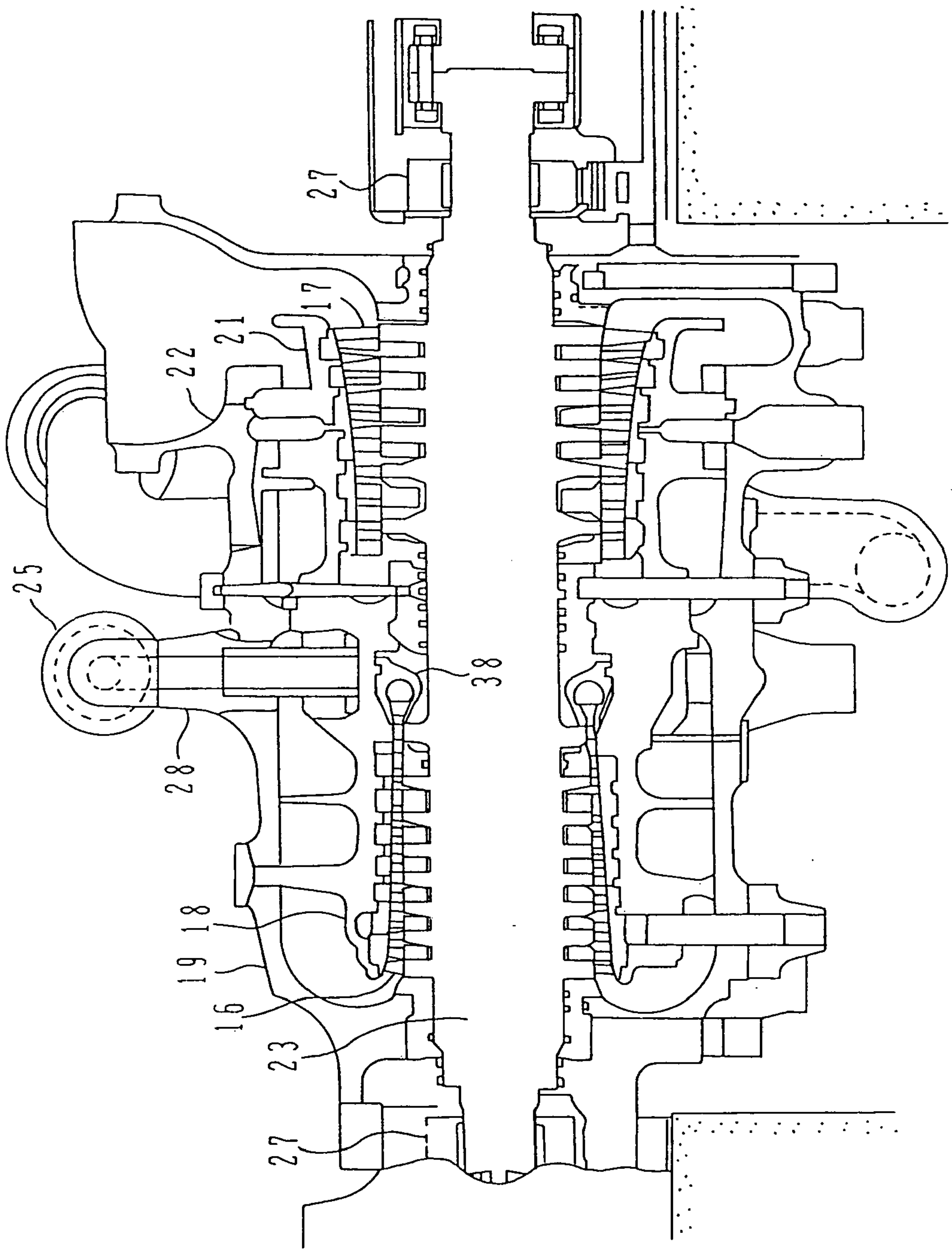


FIG. 6



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EUROPEAN SEARCH REPORT

Application Number
EP 06 02 0146

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	23 January 2007	Chebeleu, Alice

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