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(54) Steam-turbine power plant and steam turbine

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Installation de turbines à vapeur et turbine à vapeur

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- **PATENT ABSTRACTS OF JAPAN vol. 95, no. 009 & JP-A-07 233704 (HITACHI LTD), 5 September 1995,**
- **Toshio Fujita: 'Current progress in 9-12% Cr ferritic heat restant steels', Third International Charles Parson Turbine Conference, Materials Engineering in Trurbines and compressors, 25-28 April 1995; Civic Centre, Newcastle Upon Tyne, UK, Conference Proc eedings, Volume Two, pages 493-516**

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Description

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

[0001] The present invention relates to a novel steam turbine of high efficiency and high temperature, and more particularly to a steam turbine in which a main steam temperature and/or a reheat steam temperature are/is 620 (°C) or above. It also relates to a steam-turbine power plant which employs such steam turbines.

2. DESCRIPTION OF THE RELATED ART:

[0002] Conventional steam turbines have had a steam temperature of 566 (°C) at maximum and a steam pressure of 246 (atg).

[0003] It is desired, however, to heighten the efficiencies of thermal power plants from the viewpoints of the exhaustion of fossil fuel such as petroleum and coal, the saving of energy, and the prevention of environmental pollution. For enhancing the power generation efficiencies, it is the most effective expedient to raise the steam temperatures of the steam turbines. Regarding materials for such high-efficiency turbines, 1Cr-1 Mo-1/4V ferritic low-alloy forged steel and 11 Cr-1 Mo-V-Nb-N forged steel are known as rotor materials, while 1 Cr-1 Mo-1/4V ferritic low-alloy cast steel and 11 Cr-1 Mo-V-Nb-N cast steel are known as casing materials. Among these materials, austenitic alloys disclosed in the official gazette of Japanese Patent Applications Laid-open No. 180044/1987 and No. 23749/1986, and martensitic steel disclosed in the official gazette of Japanese Patent Applications, Laid-open No. 147948/1992, No. 290950/1990 and No. 371551/1992 are especially known as materials whose high-temperature strengths are superior.

[0004] Although, in the laid-open applications mentioned above, the rotor materials, the casing materials, etc. are disclosed, almost no consideration is given to the steam turbines and the thermal power plants which are accompanied by the higher steam temperatures as stated above.

[0005] Further, a supercritical steam turbine is known from the official gazette of Japanese Patent Applications, Laid-open No. 248806/1987, but a plant system as a whole is not considered at all.

[0006] Toshio Fujita: "Current progress in 9 to 12 % Cr ferritic heat resistant steels", Third International Charles Parson Turbine Conference, Materials Engineering in Turbines and Compressors, 25 to 28 April, 1995, Newcastle upon Tyne, UK, Conference proceedings, vol. 2, pages 493 to 516 mentions the need for new rotor steels for temperatures of 593°C to 650°C for advanced power plants. This prior art discloses a steel for a steam turbine rotor containing 11.0% Cr, 0.11% C, 0.05% Si, 0.50% Mn, 0.5% Ni, 0.15% Mo, 2.6% W, 0.20% V, 0.080% Nb, 0,015% B and 0.025% N, the percentages being given in terms of mass.

SUMMARY OF THE INVENTION

[0007] An object of the present invention is to provide a steam turbine which permits a heightened steam temperature of 610 - 660 (°C) by heat-resisting ferritic steel and which exhibits a high thermal efficiency, and a steam-turbine power plant which employs the steam turbine.

[0008] Another object of the present invention is to provide steam turbines whose running temperatures are 610 - 660 (°C) and whose basic designs are substantially the same, and a steam-turbine power plant which employs the steam turbines. The above objects are solved by a steam turbine according to claim 1, a steam turbine power plant according to claim 16 and a coal-fired steam turbine power plant according to claim 18. The dependent claims relate to preferred embodiments of the invention.

[0009] An embodiment of the present invention consists in a steam-turbine power plant having a high-pressure turbine and an intermediate-pressure turbine which are joined to each other, and low-pressure turbines which are connected in tandem. The improvement comprises that steam inlet of each of the high-pressure and intermediate-pressure turbines which leads to moving blades of a first-stage included in each of the high-pressure and intermediate-pressure turbines being at a temperature of 610 - 660 (°C) (preferably 615 - 640 (°C), and more preferably 620 - 630 (°C)). Further, that steam Inlet of each of the low-pressure turbines which leads to moving blades of a first stage included in each of the low-pressure turbines is at a temperature of 380 - 475 (°C) (preferably 400 - 430 (°C)), and a rotor shaft, at least first stage ones of each of the moving blades and the fixed blades, and a casing, which are included in each of the high-pressure and intermediate-pressure turbines and which are exposed to the temperature of the steam Inlet of each of the high-pressure and intermediate-pressure turbines, are made of high-strength martensitic steel which contains 8-13 (weight-%) of Cr.

[0010] Further, an embodiment of the present invention consists in a steam turbine comprising a rotor shaft, moving blades which are assembled on the rotor shaft, fixed blades which guide Inflow of steam to the moving blades, and an inner casing which holds the fixed blades. The steam flows Into a first stage of the moving blades at a temperature of 610 - 660 (°C) and under a pressure of at least 250 (kg/cm^2) (preferably 246-316 (kg/cm^2)) or 170 - 200 (kg/cm^2). The rotor shaft and, at least, first-stage ones of the moving blades and the fixed blades are made of high-strength martensitic steel of fully-tempered martensitic structure which exhibits a 10^5-hour creep rupture strength of at least 15 (kg/mm^2) (preferably 17 (kg/mm^2)) at a temperature corresponding to the respective steam temperatures (preferably 610 (°C), 625 (°C), 640 (°C), 650 (°C) and 660 (°C)), and which contains 8 - 13 (weight-%), preferably 9.5 - 13 (weight-%) (more preferably 10.5 - 11.5 (weight%)) of Cr, and the inner casing is made of martensitic cast steel which exhibits a 10^5-hour creep rupture strength of at least 10 (kg/mm^2) (preferably 10.5 (kg/mm^2)) at the temperature corresponding to the respective steam temperatures, and which contains 8 - 13, preferably 8-12, and more preferably 8 - 9.5 (weight -%) of Cr. Here the first stage of the moving blades may be made of Ni-based alloy which exhibits tensile strength of at least 90 (kg/mm^2), preferably of at least 100 (kg/mm^2) at a room temperature.

[0011] Further, an embodiment of the present invention consists in a steam turbine having a rotor shaft, moving blades which are assembled on the rotor shaft, fixed blades which guide inflow of steam to the moving blades, and an inner casing which holds the fixed blades. In the improvement, the rotor shaft and, at least, first-stage ones of the moving blades and the fixed blades are made of high-strength martensitic steel which contains 0.05 - 0.20 (%) of C, at most 0.15 (%) of Si, 0.03 - 1.5 (%) of Mn, 9.5 13 (%) of Cr, 0.05 - 1.0 (%) of Ni, 0.05 - 0.35 (%) of V, 0.01 - 0.20 (%) of Nb, 0.01 - 0.06 (%) of N, 0.05 - 0.5 (%) of Mo, 1.0 - 4.0 (%) of W, 2 - 10 (%) of Co and 0.0005 - 0.03 (%) of B, and which has at least 78 (%) of Fe, the percentages being given in terms of weight, and the inner casing is made of high-strength martensitic steel which contains 0.06 - 0.16 (%) of C, at most 0.5 (%) of Si, at most 1 (%) of Mn, 0.2 - 1.0 (%) of Ni, 8 -12 (%) of Cr, 0.05 - 0.35 (%) of V, 0.01 - 0.15 (%) of Nb, 0.01 - 0.8 (%) of N, at most 1 (%) of Mo, 1 - 4 (%) of W and 0.0005 - 0.03 (%) of B, and which has at least 85 (%) of Fe, the percentages being given in terms of weight. The moving blades, at least first stage one thereof, may be made of Ni-based alloy which contains 0.03 - 0.20(%) of C, at most 0.3 (%) of Si, at most 0.2 (%) of Mn, 12 - 20 (%) of Cr, 9 - 20 (%) of Mo, 0.5 - 1.5 (%) of Al, 2 - 3 (%) of Ti, at most 5 (%) of Fe, 0.003 - 0.015 (%) of B.

[0012] Further, an embodiment of the present invention consists in high-pressure steam turbine having a rotor shaft, moving blades which are assembled on the rotor shaft, fixed blades which guide inflow of steam to the moving blades, and an inner casing which holds the fixed blades, wherein the moving blades are arranged including at least 7 stages on each side in a lengthwise direction of the rotor shaft, except a first stage which is of double flow, and the rotor shaft has a distance (L) of at least 5000 (mm) (preferably 5200 - 5500 (mm)) between centers of bearings in which it is journaled, and a minimum diameter (D) of at least 600 (mm) (preferably 620 - 700 (mm)) at its parts which correspond to the fixed blades, a ratio (L/D) between the distance (L) and the diameter (D) being 8.0 - 9.0 (preferably 8.3 - 8.7), and it is made of high-strength martensitic steel which contains 9 - 13 (weight-%) of Cr.

[0013] Further, an embodiment of the present invention consists in the an intermediate-pressure steam turbine having a rotor shaft, moving blades which are assembled on the rotor shaft, fixed blades which guide inflow of steam to the moving blades, and an inner casing which holds the fixed blades, wherein the moving blades have a double-flow construction in which at least 6 stages are included on each side in a lengthwise direction of the rotorshaft, In a bilaterally symmetric arrangement on both sides, and in which the first stages of the arrangement are assembled on a central part of the rotor shaft in the lengthwise direction, and the rotor shaft has a distance (L) of at least 5000 (mm), preferably 5200 (mm) (more preferably 5300 - 5800 (mm)) between centers of bearings in which it is journaled, and a minimum diameter (D) of at least 600 (mm), preferably 620 (mm) (more preferably 620 - 680 (mm)) at its parts which correspond to the fixed blades, a ratio (UD) between the distance (L) and the diameter (D) being 8.2 - 9.2 (preferably 8.5 - 9.0), and it is made of high-strength martensitic steel which contains 9 - 13 (weight-%) of Cr.

[0014] Further, an embodiment of the present invention consists in a low-pressure steam turbine having a rotor shaft, moving blades which are assembled on the rotor shaft, fixed blades which guide inflow of steam to the moving blades, and an inner casing which holds the fixed blades, wherein the moving blades have a double-flow construction in which at least 8 stages are included on each side in a lengthwise direction of the rotor shaft, in a bilaterally symmetric arrangement on both sides, and in which the first stages of the arrangement are assembled on a central part of the rotor shaft in the lengthwise direction, the rotor shaft has a distance (L) of at least 7200 (mm) (preferably 7400 - 7600 (mm)) between centers of bearings In which it is journaled, and a minimum diameter (D) of at least 1150 (mm) (preferably 1200 - 1350 (mm)) at its parts which correspond to the fixed blades, a ratio (L/D) between the distance (L) and the diameter (D) being 5.4 - 6.3 (preferably 5.7 - 6.1), and it Is made of Ni-Cr-Mo-V low-alloy steel which contains 3.25 -4.25 (weight-%) of Ni, and each of the final-stage moving blades of the arrangement has a length of at least 40 (inches) and is made of a Ti-based alloy.

[0015] Further, an embodiment of the present invention consists in a steam-turbine power plant having a high-pressure turbine and an intermediate-pressure turbine which are joined to each other, and two low-pressure turbines which are connected in tandem, wherein that steam inlet of each of the high-pressure and intermediate-pressure turbines which leads to moving blades of a first stage included in each of the high-pressure and intermediate-pressure turbines is at a temperature of 610 - 660 (°C), that steam inlet of the low-pressure turbine which leads to moving blades of a first stage included in the low-pressure turbine is at a temperature of 380 - 475 (°C), the first-stage moving blade of the high-pressure turbine, and that part of a rotor shaft of the high-pressure turbine on which the first-stage moving blade is assembled are held at metal temperatures which are not, at least, 40 (°C) lowerthan the temperature of the steam inlet of the high-pressure turbine leading to the first-stage moving blade (preferably, the metal temperatures are 20 - 35 (°C) lower than the steam temperature), the first-stage moving blade of the intermediate-pressure turbine, and that part of a rotor shaft of the intermediate-pressure turbine on which the first-stage moving blades are assembled are held at metal temperatures which are not, at least, 75 (°C) lower than the temperature of the steam inlet of the intermediate-pressure turbine leading to the first-stage moving blade (preferably, the metal temperatures are 50 - 70 (°C) lower than the steam temperature), and the rotor shaft of each of the high-pressure and intermediate-pressure turbines and, at least, the first-stage one of the moving blades of each of the high-pressure and intermediate-pressure turbines are made of martensitic steel which contains 9.5 - 13 (weight-%) of Cr.

[0016] Further, an embodiment of the present invention consists in a coal-fired power plant having a coal-fired boiler, steam turbines which are driven by steam developed by the boiler, and one or more, preferably two, generators which are driven by the steam turbines and which can generate an output of at least 1000 (MW), wherein the steam turbines include a high-pressure turbine, an intermediate-pressure turbine which is joined to the high-pressure turbine, and two low-pressure turbines, that steam inlet of each of the high-pressure and intermediate-pressure turbines which leads to moving blades of a first stage included in each of the high-pressure and intermediate-pressure turbines is at a temperature of 610 - 660 (°C), that steam inlet of the low-pressure turbine which leads to moving blades of af first stage included in the low-pressure turbine is at a temperature of 380 - 475 (°C), the steam heated by a superheater of the boiler to a temperature which is at least 3 (°C) (preferably 3 -10 (°C), more preferably 3 - 7 (°C)) higherthan the temperature of the steam inlet of the high-pressure turbine leading to the first-stage moving blade thereof is caused to flow into the first-stage moving blade of the high-pressure turbine, the steam having come out of the high-pressure turbine is heated by a reheater of the boiler to a temperature which is at least 2 (°C) (preferably 2-10 (°C), more preferably 2 - 5 (°C)) higher than the temperature of the steam inlet of the intermediate-pressure turbine leading to the first-stage moving blade thereof, whereupon the heated steam is caused to flow into the first-stage moving blade of the Intermediate-pressure turbine, and the steam having come out of the intermediate-pressure turbine is heated by an economizer of the boiler to a temperature which is at least 3 (°C) (preferably 3-10 (°C), more preferably 3 - 6 (°C)) higherthan the temperature of the steam inlet of the low-pressure turbine leading to the first-stage moving blade thereof, whereupon the heated steam is caused to flow into the first-stage moving blade of the low-pressure turbine.

[0017] Further, an embodiment of the present invention consists in the low-pressure steam turbine stated before; wherein that steam inlet of the low-pressure turbine which leads to a first-stage one of the moving blades is at a temperature of 380 - 475 (°C) (preferably 400 - 450 (°C)), and the rotor shaft is made of low-alloy steel which contains 0.2 - 0.3 (%) of C, at most 0.05 (%) of Si, at most 0.1 (%) of Mn, 3.25 - 4.25 (%) of Ni, 1.25 - 2.25 (%) of Cr, 0.07 - 0.20 (%) of Mo, 0.07 - 0.2 (%) of V and at least 92.5 (%) of Fe, the percentages being given in terms of weight.

[0018] Also, an embodiment of the present invention consists in the high-pressure steam turbine stated before; wherein the moving blades are arranged including at least 7 stages (preferably 9-12 stages), and they have lengths of 35 - 210 (mm) in a region from an upstream side of the steam flow to a downstream side thereof, diameters of those parts of the rotor shaft on which the moving blades are assembled are larger than diameters of those parts of the rotor shaft which correspond to the fixed blades; and widths of the moving-blade assembling parts of the rotor shaft in an axial direction of the rotor shaft being stepwise larger on the downstream side than on the upstream side at, at least, 3 stages (preferably 4 - 7 stages), and the ratios of these widths to the lengths of the moving blades decrease from the upstream side toward the downstream side within a range of 0.6 - 1.0 (preferably 0.65 - 0.95).

[0019] Further, in the high-pressure steam turbine stated before, an embodiment of the present invention consists in the improvement wherein the moving blades are arranged in at least 7 stages, and they have lengths of 35 - 210 (mm) In a region from an upstream side of the steam flow to a downstream side thereof, ratios between the lengths of the moving blades of the respectively adjacent stages are at most 1.2 (preferably 1.10-1.15), and they increase gradually toward the downstream side, and the lengths of the moving blades are larger on the downstream side than on the upstream side.

[0020] Further, in the high-pressure steam turbine stated before, an embodiment of the present invention consists in the improvement wherein the moving blades are arranged in at least 7 stages, and they have lengths of 35 - 210 (mm) in a region from an upstream side of the steam flow to a downstream side thereof, and widths of those parts of the rotor shaft which correspond to the fixed blades, the widths being taken in an axial direction of the rotor shaft, are stepwise smaller on the downstream side than on the upstream side at, at least, 2 stages (preferably 2-4 stages), and the ratios of these widths to the lengths of the downstream-side moving blades decrease stepwise toward the downstream side within a range of 0.65 - 1.8 (preferably 0.7 - 1.7).

[0021] Also, an embodiment of the present invention consists in the intermediate-pressure steam turbine stated before, wherein the moving blades have a double-flow construction in which at least 6 stages (preferably 6 - 9 stages) are included on each side in a lengthwise direction of the rotorshaft, in a bilaterally symmetric arrangement on both sides, and they have lengths of 100 - 300 (mm) in a region from an upstream side of the steam flow to a downstream side thereof, diameters of those parts of the rotor shaft on which the moving blades being assembled are larger than diameters of those parts of the rotor shaft which correspond to the fixed blades, and widths of the moving-blade assembling parts of the rotor shaft in an axial direction of the rotor shaft being stepwise larger on the downstream side than on the upstream side at, at least, 2 stages (preferably 3 - 6 stages), and the ratios of these widths to the lengths of the moving blades decrease from the upstream side toward the downstream side within a range of 0.45 - 0.75 (preferably 0.5 - 0.7).

[0022] Further, in the intermediate-pressure steam turbine stated before, an embodiment of the present invention consists in the improvement wherein the moving blades have a double-flow construction in which at least 6 stages are included on each side in a lengthwise direction of the rotor shaft, in a bilaterally symmetric arrangement on both sides, and they have lengths of 100 - 300 (mm) in a region from an upstream side of the steam flow to a downstream side thereof, and the lengths of the respectively adjacent moving blades are larger on the downstream side than on the upstream side, and their ratios are at most 1.3 (preferably 1.1 -1.2) and increase gradually toward the downstream side.

[0023] Further, in the intermediate-pressure steam turbine stated before, an embodiment of the present invention consists in the improvement wherein the moving blades have a double-flow construction in which at least 6 stages are included on each side in a lengthwise direction of the rotor shaft, in a bilaterally symmetric arrangement on both the sides, and they have lengths of 100 - 300 (mm) in a region from an upstream side of the steam flow to a downstream side thereof, and widths of those parts of the rotor shaft which correspond to the fixed blades, the widths being taken in an axial direction of the rotor shaft, are stepwise smaller on the downstream side than on the upstream side at, at least, 2 stages (preferably 3 - 6 stages), and the ratios of these widths to the lengths of the downstream-side moving blades decrease stepwise toward the downstream side within a range of 0.45 -1.60 (preferabl 0.5-1.5).

[0024] Also, an embodiment of the present invention consists in the low-pressure steam turbine stated before; wherein the moving blades have a double-flow construction in which at least 8 stages (preferably 8 - 10 stages) are included on each side in a lengthwise direction of the rotor shaft, in a bilaterally symmetric arrangement on both sides, and they have lengths of 90 - 1300 (mm) in a region from an upstream side of the steam flow to a downstream side thereof; diameters of those parts of the rotor shaft on which the moving blades are assembled are larger than diameters of those parts of the rotor shaft which correspond to the fixed blades; and widths of the moving-blade assembling parts of the rotor shaft in an axial direction of the rotor shaft are stepwise larger on the downstream side than on the upstream side at, at least, 3 stages (preferably 4 - 7 stages), and the ratios of these widths to the lengths of the moving blades decrease from the upstream side toward the downstream side within a range of 0.15 -1.0 (preferably 0.15 - 0.91).

[0025] Further, In the low-pressure steam turbine stated before, an embodiment of the present invention consists in the improvement wherein the moving blades have a double-flow construction in which at least 8 stages are included on each side in a lengthwise direction of the rotor shaft, in a bilaterally symmetric arrangement on both sides, and they have lengths of 90 - 1300 (mm) in a region from an upstream side of the steam flow to a downstream side thereof; and the lengths of the moving blades of the respectively adjacent stages are larger on the downstream side than on the upstream side, and their ratios increase gradually toward the downstream side within a range of 1.2 - 1.7 (preferably 1.3 - 1.6).

[0026] Further, in the low-pressure steam turbine stated before, an embodiment of the present invention consists in the improvement wherein the moving blades have a double-flow construction in which at least 8 stages are included on each side in a lengthwise direction of the rotor shaft, in a bilaterally symmetric arrangement on both sides, and they have lengths of 90 - 1300 (mm) in a region from an upstream side of the steam flow to a downstream side thereof; and widths of those parts of the rotor shaft which correspond to the fixed blades, the widths being taken in an axial direction of the rotor shaft, are stepwise larger on the downstream side than on the upstream side at, at least, 3 stages (preferably 4 - 7 stages), and the ratios of these widths to the lengths of the respectively adjacent moving blades on the downstream side decrease stepwise toward the downstream side within a range of 0.2- 1.4 (preferably 0.25 - 1.25).

[0027] Also, an embodiment of the present invention consists in a high-pressure steam turbine having a rotor shaft, moving blades which are assembled on the rotor shaft, fixed blades which guide inflow of steam to the moving blades, and an inner casing which holds the fixed blades; wherein the moving blades are arranged including at least 7 stages; diameters of those parts of the rotor shaft which correspond to the fixed blades are smaller than diameters of those parts of the rotor shaft which correspond to the assembled moving blades; widths of the rotor shaft parts corresponding to the fixed blades, in an axial direction of the rotor shaft are stepwise larger on an upstream side of the steam flow than on a downstream side thereof at, at least, 2 of the stages (preferably 2-4 stages), and the width between the final stage of the moving blades and the stage thereof directly preceding the final stage is 0.75 - 0.95 (preferably 0.8 - 0.9, more preferably 0.84 - 0.88) times as large as the width between the second stage and the third stage of the moving blades; and widths of the rotor shaft parts corresponding to the assembled moving blades, in the axial direction of the rotor shaft are stepwise larger on the downstream side of the steam flow than on the upstream side thereof at, at least, 3 of the stages (preferably 4 - 7 stages), and the axial width of the final stage of the moving blades is 1 - 2 (preferably 1.4 -1.7) times as large as the axial width of the second stage of the moving blades.

[0028] Also, an embodiment of the present invention consists in an intermediate-pressure steam turbine having a rotor shaft, moving blades which are assembled on the rotor shaft, fixed blades which guide inflow of steam to the moving blades, and an inner casing which holds the fixed blades; wherein the moving blades are arranged including at least 6 stages; diameters of those parts of the rotor shaft which correspond to the fixed blades are smaller than diameters of those parts of the rotor shaft which correspond to the assembled moving blades; widths of the rotor shaft parts corresponding to the fixed blades, in an axial direction of the rotor shaft are stepwise larger on an upstream side of the steam flow than on a downstream side thereof at, at least, 2 of the stages (preferably 3 - 6 stages), and the width between the final stage of the moving blades and the stage thereof directly preceding the final stage is 0.55 - 0.8 (preferably 0.6 - 0.7) times as large as the width between the first stage and the second stage of the moving blades; and widths of the rotor shaft parts corresponding to the assembled moving blades, in the axial direction of the rotor shaft are stepwise larger on the downstream side of the steam flow than on the upstream side thereof at, at least, 2 of the stages (preferably 3 - 6 stages), and the axial width of the final stage of the moving blades is 0.8 - 2 (preferably 1 - 1.5) times as large as the axial width of the first stage of the moving blades.

[0029] Also, an embodiment of the present invention consists in a low-pressure steam turbine having a rotor shaft, moving blades which are assembled on the rotor shaft, fixed blades which guide inflow of steam to the moving blades, and an inner casing which holds the fixed blades; wherein the moving blades have a double-flow construction in which at least 8 stages are included on each side in an axial direction of the rotor shaft, in a bilaterally symmetric arrangement on both sides; diameters of those parts of the rotor shaft which correspond to the fixed blades are smaller than diameters of those parts of the rotor shaft which correspond to the assembled moving blades; widths of the rotor shaft parts corresponding to the fixed blades, in the axial direction of the rotor shaft are stepwise larger on an upstream side of the steam flow than on a downstream side thereof at, at least, 3 of the stages (preferably 4-7 stages), and the width between the final stage of the moving blades and the stage thereof directly preceding the final stage is 1.5 - 2.5 (preferably 1.7 - 2.2) times as large as the width between the first stage and the second stage of the moving blades; and widths of the rotor shaft parts corresponding to the assembled moving blades, in the axial direction of the rotor shaft, are stepwise larger on the downstream side of the steam flow than on the upstream side thereof at, at least, 3 of the stages (preferably 4 - 7 stages), and the axial width of the final stage of the moving blades is 2 - 3 (preferably 2.2 - 2.7) times as large as the axial width of the first stage of the moving blades.

[0030] The designs of the high-pressure, intermediate-pressure and low-pressure turbines described above can be rendered similar for any of the service steam temperatures, 610 - 660 (°C) of the respective turbines.

[0031] In the rotor material, alloy contents should preferably be controlled so as to become 4 - 8 in terms of a Cr equivalent which is computed by a formula given below, in order that a superior high-temperature strength, a low-temperature toughness and a high fatigue strength may be attained from the fully-tempered martensitic structure.

[0032] Besides, in the heat-resisting cast steel in an embodiment of the present invention, which is used as the casing material, alloy contents should preferably be controlled so as to become 4 - 10 in terms of the Cr equivalent which is computed by the formula given below, in order that a superior high-temperature strength, a low-temperature toughness and a high fatigue strength may be attained by controlling the alloying constituents so as to establish a martensitic structure tempered to at least 95 (%), In other words, containing at most 5 (%) of δ (delta) ferrite.

$$\text{Cr equivalent} = \text{Cr} + 6\text{Si} + 4\text{Mo} + 1.5\text{W} + 11\text{V} + 5\text{Nb}$$

$$- 40\text{C} - 30\text{N} - 30\text{B} - 2\text{Mn} - 4\text{Ni} - 2\text{Co}$$

[0033] Regarding the 12Cr heat-resisting steel in an embodiment of the present invention, especially in a case where the steel is used with steam at or above 621 (°C), it should preferably be endowed with a 625-°C 10^5-h creep rupture strength of at least 10 (kgf/mm^2) and a room-temperature absorbed impact energy of at least 1 (kgf-m).

[0034] Now, the materials specified in the present Invention will be itemized as (1) - (3) below.

[0035] (1) There will be elucidated the reasons for restricting the constituents of the heat-resisting ferritic steel which is used in the present invention for making the rotors, blades, nozzles and inner-casing tightening bolts of the high-pressure and intermediate-pressure steam turbines, and the first-stage diaphragm of the intermediate-pressure portion:

[0036] The constituent C (carbon) is an element which is indispensable to ensuring hardenability upon quenching, and precipitating carbides in a tempering heat-treatment process so as to enhance a high-temperature strength. Besides, the element C is required at a level of at least 0.05 (%) in order to attain a high tensile strength. However, In a case where the C content exceeds 0.20 (%), the ferritic steel comes to have an unstable metallographic structure and spoils the long-time creep rupture strength thereof when exposed to high temperatures for a prolonged period of time. Therefore, the C content is restricted to within 0.05 - 0.20 (%). It should desirably be within 0.08 - 0.14 (%), and particularly preferably be within 0.09 - 0.14 (%).

[0037] The constituent Mn (manganese) is added as a deoxidizer etc., and the deoxidizing effect thereof is achieved by a small amount of addition. A large amount of addition exceeding 1.5 (%) is unfavorable because it lowers the creep rupture strength. Especially, a range of 0.03 - 0.20 (%) or a range of 0.3 - 0.7 (%) is preferable, and a range of 0.35 - 0.65 (%) is more preferable for the latter. As the Mn content is made lower, a higher strength is attained. On the other hand, as the Mn content is made higher, the workability of the ferritic steel improves.

[0038] The constituent Si (silicon) is also added as a deoxidizer, but the Si deoxidation is dispensed if a steelmaking technique such as the vacuum C deoxidation or the like is made. A lower Si content is effective to prevent the production of the deleterious δ ferrite structure, and to prevent the degradation of the toughness of the ferritic steel attributed to grain-boundary segregation, etc. Accordingly, the addition of the constituent Si needs to be suppressed to 0.15 (%) or below. The Si content of the ferritic steel should desirably be at most 0.07 (%), and should particularly preferably be at most 0.05 (%).

[0039] The constituent Ni (nickel) is an element which is very effective to heighten the toughness and to prevent the production of the δ ferrite. The addition of the element Ni at a level of less than 0.05 (%) is unfavorable because it has an insufficient effect, and the addition thereof at more than 1.0 (%) is also unfavorable because of degradation in the creep rupture strength. Especially, a range of 0.3 - 0.7 (%) is preferable, and a range of 0.4 - 0.65 (%) is more preferable.

[0040] The constituent Cr (chromium) is an element which is indispensable to enhancing the high-temperature strength and high-temperature oxidation resistance of the ferritic steel. The element Cr is required at least 9 (%). However, when the Cr content exceeds 13 (%), the deleterious δ ferrite structure is produced, which lowers the high-temperature strength and the toughness. Therefore, the Cr content is restricted to within 9-12 (%). Especially, a range of 10 -12 (%) is preferable, and a range of 10.8 - 11.8 (%) is more preferable.

[0041] The addition of the constituent Mo (molybdenum) is intended to enhance the high-temperature strength. However, in a case where the constituent W (tungsten) is contained at a level of more than 1 (%), Mo addition at a level of exceeding 0.5 (%) lowers the toughness and fatigue strength of the ferritic steel. Therefore, the Mo content is limited to, at most, 0.5 (%). Especially, a range of 0.05 - 0.45 (%) is preferable, and a range of 0.1 - 0.3 (%) is more preferable.

[0042] The constituent W (tungsten) suppresses the coarsening of carbides due to the agglomerations thereof at high temperatures, and it turns the matrix of the ferritic steel into a solid solution and strengthens this matrix. It is therefore effective to remarkably enhance the long-term strength of the ferritic steel at the high temperatures of at least 620 (°C). The W content of the ferritic steel should preferably be 1- 1.5 (%) at 620 (°C), 1.6 - 2.0 (%) at 630 (°C), 2.1 - 2.5 (%) at 640 (°C), 2.5 - 3.0 (%) at 650 (°C) and 3.1 - 3.5 (%) at 660 (°C). Besides, when the W content exceeds 3.5 (%), the δ ferrite is produced, which lowers the toughness. Therefore, the W content is restricted to within 1 - 3.5 (%). Especially, a range of 2.4 - 3.0 (%) is preferable, and a range of 2.5 - 2.8 (%) is more preferable.

[0043] The constituent V (vanadium) is effective to heighten the creep rupture strength by precipitating the carbonitrides of this constituent V. When the V content of the ferritic steel is less than 0.05 (%), the effect is insufficient. On the other hand, when the V content exceeds 0.3 (%), the 8 ferrite is produced, which lowers the fatigue strength. Especially, a range of 0.10 - 0.25 (%) is preferable, and a range of 0.15 - 0.25 (%) is more preferable.

[0044] The constituent Nb (niobium) is an element which is very effective to precipitate NbC (niobium carbide) and enhance the high-temperature strength. However, when the element Nb is added in an excessively large amount, the coarse grains of eutectic NbC appear, especially in a large-sized steel ingot, which causes significant lowering of the strength and precipitation of the δ ferrite, which lowers the fatigue strength. It is therefore necessary to suppress the amount of the element Nb to 0.20 (%) or below. On the other hand, when the Nb amount is less than 0.01 (%), the effect is insufficient. Especially, a range of 0.02 - 0.15 (%) is preferable, and a range of 0.04 - 0.10 (%) is more preferable.

[0045] The constituent Co (cobalt) is an important element, and is a feature which distinguishes the present invention from the prior-art techniques. In the present invention, owing to the addition of the element Co, the high-temperature strength is remarkably improved, and the toughness is also heightened. These effects are considered to be based on the interaction between the elements Co and W, and they are the characterizing phenomena of the alloy of the present invention containing the element W in the amount of at least 1 (%). In order to realize such effects of the element Co, the lower limit of the Co amount in the alloy of the present invention is set at 2.0 (%). On the other hand, even when the element Co is added in excess, greater effects are not attained, and moreover, the ductility of the ferritic steel is lowered. Therefore, the upper limit of the Co amount is set at 10 (%). The Co amount should desirably be selected from 2 - 3 (%) for 620 (°C), 3.5 - 4.5 (%) for 630 (°C), 5 - 6 (%) for 640 (°C), 6.5 - 7.5 (%) for 650 (°C), and 8 - 9 (%) for 660 (°C). But an efficient strength can be obtained by addition of at least 2 (%) of Co for any degree of temperature at most 650 (°C).

[0046] The constituent N (nitrogen) is also an important element and is a feature which distinguishes the present invention from the prior-art techniques. The element N is effective to improve the creep rupture strength and to prevent the production of the 8 ferrite structure. However, when the N content of the ferritic steel is less than 0.01 (%), the effects are not sufficient. On the other hand, when the N content exceeds 0.05 (%), the toughness is lowered, and the creep rupture strength is also lowered. Especially, a range of 0.01 - 0.03 (%) is preferable, and a range of 0.01 - 0.025 (%) is more preferable.

[0047] The constituent B (boron) is effective to enhance the high-temperature strength by the action of intensifying grain boundaries, and the action of turning into solid solutions in carbides $M_{23}C_6$ to hinder the $M_{23}C_6$ type carbides from coarsening due to the agglomerations thereof. It is effective to add the constituent B to a level in excess of 0.001 (%). However, when the B content exceeds 0.03 (%), the weldability and forgeability of the ferritic steel are degraded. Therefore, the B content is limited to within 0.001 - 0.03 (%). It should desirably be 0.001 - 0.01 (%) or 0.01 - 0.02 (%).

[0048] The addition of the constituent/constituents Ta (tantalum), Ti (titanium) or/and Zr (zirconium) is effective to heighten the toughness. A sufficient effect is attained by adding at most 0.15 (%) of Ta, at most 0.1 (%) of Ti or/and at most 0.1 (%) of Zr singly or in combination. In a case where the constituent Ta is added at a level of 0.1 (%) or above, the addition of the constituent Nb (niobium) can be omitted.

[0049] The rotor shaft and, at least, the first-stage ones of the moving blades and fixed blades in the present invention should preferably be made for a steam temperature of 620 - 630 (°C) out of steel of fully-tempered martensitic structure which contains 0.09 - 0.20 (%) of C, at most 0.15 (%) of Si, 0.05 - 1.0 (%) of Mn, 9.5 - 12.5 (%) of Cr, 0.1 - 1.0 (%) of Ni, 0.05 - 0.30 (%) of V, 0.01 - 0.06 (%) of N, 0.05 - 0.5 (%) of Mo, 2 - 3.5 (%) of W, 2 - 4.5 (%) of Co, 0.001 - 0.030 (%) of B, and at least 77 (%) of Fe (iron). Besides, they should preferably be made for a steam temperature of 635 - 660 (°C) out of steel of fully-tempered martensitic structure in which the aforementioned Co content is replaced with 5 - 8 (%), and which contains at least 78 (%) of Fe. Especially, a high strength is attained by decreasing the Mn content to 0.03 - 0.2 (%) and the B content to 0.001 - 0.01 (%) for both the aforementioned temperatures. The martensitic steel should particularly preferably contain 0.09 - 0.20 (%) of C, 0.1 - 0.7 (%) of Mn, 0.1 - 1.0 (%) of Ni, 0.10 - 0.30 (%) of V, 0.02 - 0.05 (%) of N, 0.05 - 0.5 (%) of Mo, and 2 - 3.5 (%) of W, along with 2 - 4 (%) of Co and 0.001 - 0.01 (%) of B for a temperature of or below 630 (°C) or 5.5 - 9.0 (%) of Co and 0.01 - 0.03 (%) of B for a temperature of 630 - 660 (°C). The martensitic steel including the former percentage of Co can be used at the temperature between 620 - 650 (%).

[0050] The Cr equivalent which is obtained by the formula mentioned before is set at 4 - 10.5 for the rotor shafts of the high-pressure and intermediate-pressure steam turbines, and a range of 6.5 - 9.5 is particularly preferable therefor. The same applies to the other components of these steam turbines stated before.

[0051] Regarding the rotor material of the high-pressure and intermediate-pressure steam turbines of the present invention, the fatigue strength and the toughness lower due to the coexistence of the δ ferrite structure. Therefore, the tempered martensitic structure which is homogeneous, is favorable for the heat-resisting ferritic steel. In order to obtain the tempered martensitic structure, the Cr equivalent which is computed by the formula mentioned before must be set at, at most, 10 by controlling the alloy contents. On the other hand, when the Cr equivalent is too small, it lowers the creep rupture strength, and hence, it must be set at, at least, 4. Especially, a range of 5 - 8 is preferable as the Cr equivalent.

[0052] At least one of the rotor shaft, each moving blade and each fixed blade in the present invention should preferably be made of steel which satisfies at least one of conditions; a (B + N) content of 0.050 (%) or below, an (N/B) ratio of 1.5 or above (preferably, 1.5 - 2.0), a (B/Co) ratio of 0.0035 or above (preferably, 0.0035 - 0.008, and more preferably, 0.004 - 0.006), a (Co/Mo) ratio of 18 or below (preferably, 8-18, and more preferably, 11 - 16), and a (Co/Nb) ratio of 30 or above (preferably, 30 - 70). Steel which satisfies all the conditions, is more preferable. These elements correlate organically.

[0053] Further, there will be elucidated the reasons for restricting the constituents of each of the Ni-based precipitation-strengthened alloys which can be applied to, at least, the first stages of the moving blades of the high-pressure and intermediate-pressure turbines in the present invention.

[0054] When added at least 0.03 (%), the element C (carbon) precipitates carbides during use in a solid-solution state or at high temperatures, to thereby enhance the yield strength and creep strength of the alloy at high temperatures. However, in a case where the C content exceeds 0.2 (%), the carbides are drastically precipitated during the use at the high temperatures, to thereby lower the high-temperature pulling contraction percentage of the alloy. Therefore, the C content should preferably be 0.03 - 0.15 (%).

[0055] The element Cr (chromium) needs to be contained at least 12 (%) in order to enhance the yield strength and creep strength of the alloy at high temperatures and to further enhance the high-temperature oxidation resistance and sulfurization-corrosion resistance of the alloy, in the solid-solution state of this element Cr in the alloy. However, when the Cr content exceeds 20 (%), the σ phase of steel is precipitated to lower the contraction percentage of the alloy in the high-temperature tensile test thereof. Therefore, the preferable range of the Cr content is 12 - 20 (%).

[0056] When added in excess of 9 (%), the element Mo (molybdenum) remarkably enhances the yield strength of the alloy at high temperatures and also the creep rupture strength thereof, in the solid-solution state of this element Mo in the alloy. However, when contained in excess of 20 (%), the element Mo abruptly degrades the yield strength at the high temperatures contrariwise. Further, it spoils the cold working property of the alloy, and it precipitates the σ phase to lower the contraction percentage of the alloy in the high-temperature tension thereof. Therefore, the preferable range of the Mo content is 12 - 20 (%).

[0057] When added at most 12 (%), the element Co (cobalt) remarkably enhances the creep rupture strengths of the alloy at the room temperature and at high temperatures, in the solid-solution state of this element Co in the alloy. However, when contained in excess of 12 (%), the element Co abruptly degrades the high-temperature ductility of the alloy, and it precipitates the σ phase to lower the contraction percentage of the alloy in the high-temperature tension thereof. Therefore, the preferable range of the Co content is 5 - 12 (%).

[0058] When added 0.5 -1.5 (%), the element Al (aluminum) turns into a solid solution in the alloy and precipitates the γ prime phase of steel during use at high temperatures for a long time period, to thereby enhance the yield strength and creep rupture strength of the alloy in the high-temperature tension thereof. However, in a case where the Al content exceeds 1.5 (%), the contraction percentage of the alloy degrades in the high-temperature tension thereof. Therefore, the preferable range of the Al content is 0.5 - 1.2 (%).

[0059] When added 2 - 3 (%), the element TI (titanium) turns into a solid solution in the alloy and precipitates the γ prime phase during use at high temperatures for a long time period, to thereby enhance the yield strength and creep rupture strength of the alloy in the high-temperature tension thereof. However, in a case where the Ti content exceeds 3 (%), the contraction percentage of the alloy degrades in the high-temperature tension thereof.

[0060] Since the element Fe (iron) lowers the creep rupture strength of the alloy, the containment thereof ought to be avoided as far as possible. Even in a case where the element Fe is contained as an impurity, it ought to be limited to, at most, 5 (%).

[0061] The elements Si (silicon) and Mn (manganese) are respectively added at most 0.3 (%) and at most 0.2 (%) as deoxidizers or in order to enhance the hot working property of the alloy. It is the most preferable, however, to add neither of these elements Si and Mn.

[0062] The element B (boron) segregates at the austenitic grain boundary of steel in a very small amount, and enhances the creep rupture strength and high-temperature ductility of the alloy. This element B is effective when contained at least 0.003 (%). However, it degrades both the hot plastic working property and high-temperature ductility of the alloy when contained in excess of 0.015 (%). Therefore, the B content ought to be set at 0.003 - 0.015 (%).

[0063] The element Mg (magnesium) and the rare-earth elements segregate at the austenitic grain boundaries of the alloy, and enhance the creep rupture strength thereof. Besides, the element Zr (zirconium) is an intense element for forming a carbide. When added in a very small amount, this element Zr enhances the creep rupture strength of the alloy owing to its action synergic with the formation of other carbides by the elements Ti etc. However, when these elements are added in excess, the ductility of the alloy at high temperatures degrades for such reasonsthatthe binding powers of grain boundaries lower and that coarse carbide grains are formed. Therefore, it is preferable to add the element Mg at most 0.1 (%), the rare-earth elements at most 0.5 (%) and the element Zr at most 0.5 (%), and it is particularly preferable to add the element Mg 0.005 - 0.05 (%), the rare-earth elements 0.005 - 0.1 (%) and the element Zr 0.01 - 0.2 (%).

Structure and Annealing:

[0064] The alloy in an embodiment of the present invention is subjected to a treatment for turning an ingot into a solid solution, and thereafter to a treatment for ageing.

[0065] The solid-solution treatment is carried out by holding the ingot at 1,050- 1,200 (°C) for 30 (minutes) - 10 (hours), and subsequently cooling the heated ingot with water, air or the like. The water cooling is performed by throwing the alloy at a predetermined temperature into the body of water. Alternatively, when the alloy is flat, water is sprayed onto the surfaces of the alloy at a predetermined temperature.

[0066] The ageing treatment is carried out in such a way that the material subjected to the above solid-solution treatment is heated and held at 700 - 870 (°C) for 4 - 24 (hours).

Melting:

[0067] The alloy in an embodiment of the present invention should preferably be molten In a non-oxidizing atmosphere. Raw materials to be used for the alloy are pure metals. From the standpoints of heightening the available percentages of the alloy elements and preventing the dispersion of the alloy composition, therefore, the raw materials should preferably be heated in vacuum until they are about to melt and drop, and they are thereafter molten by introducing a non-oxidizing gas.

[0068] Further, the raw materials thus molten are subjected to vacuum arc remelting or electroslag remelting. Then, the desired alloy can be obtained.

[0069] Each of the Ni-based precipitation-strengthened alloys should exhibit a preferable tensile strength of 90 (kg/mm^2) or above, or a more preferable one of 100 (kg/mm^2) or above, at the room temperature, and a preferable tensile strength of 80 (kg/mm^2) or above, at 732 (°C). It should also exhibit a preferable elongation percentage of 10 (%) or above.

[0070] Regarding each of the rotors in an embodiment of the present invention, alloying raw materials to be brought into the desired composition are melted in an electric furnace, the molten materials are deoxidized by carbon vacuum deoxidation, the deoxidized materials are cast into a metal mold, and the molded article is forged into an electrode.

The electrode thus fabricated is subjected to electroslag remelting, and the resulting slag is forged and formed into the shape of the rotor. The forging must be carried out at a temperature of 1150 (°C) or below in order to prevent forging cracks. After the forged steel has been annealed, it is heated to 1000 - 1100 (°C) and then quenched, and it is tempered twice in the sequence of a temperature range of 550 - 650 (°C) and a temperature range of 670 - 770 (°C). Thus, the steam turbine rotor which is usable in steam at or above 620 (°C) can be manufactured.

[0071] Regarding each of the components in an embodiment of the present invention, which includes the blades, nozzles and inner-casing tightening bolts of the high-pressure and intermediate-pressure steam turbines, and the first-stage diaphragm of the intermediate-pressure portion, an ingot is prepared in such a way that the alloying raw materials to be brought into the desired composition are melted by vacuum melting, and that the molten materials are cast in a metal mold in vacuum. The ingot is hot-forged into a predetermined shape at the same temperature as stated before. After the forged ingot has been heated to 1050 - 1150 (°C), it is subjected to water cooling or oil quenching. Subsequently, the resulting ingot is tempered in a temperature range of 700 - 800 (°C), and it is machined into the component of desired shape. The vacuum melting is carried out under a vacuum condition of $1{,}33 \cdot 10^{-2}$ to 13,3 Pa (10^{-1} - 10^{-4} (mmHg)). In particular, although the heat-resisting steel can be applied to all the stages of the blades and nozzles of the high-pressure portion and intermediate-pressure portion, they are especially necessary for the first stages of both the sorts of component.

[0072] The steam-turbine rotor shaft made of the 12 weight-% Crtype martensitic steel should preferably be so constructed that buildup welding layers of good bearing characteristics are formed on the surface of the parent metal forming each journal portion of the rotor shaft. More specifically, the buildup welding layers are formed in the number of, at least 3, preferably 5 -10 by the use of a weld metal being steel. The Cr content of the steel as the weld metal is lowered successively from the first layer to any of the second -fourth layers, whereas the layers of and behind the fourth layer are formed of the steel having an identical Cr content. Herein, the Cr content of the weld metal for the deposition of the first layer is rendered about 2 - 6 (weight-%) less than that of the parent metal, and the Cr contents of the welding layers of and behind the fourth layer are set at 0.5 - 3 (weight-%), preferably at 1 - 2.5 (weight%).

[0073] In the present invention, the buildup welding is favorable for the improvement of the bearing characteristics of the journal portion In view of the highest safety, but it becomes very difficuft due to increase in the B content of the steel. Therefore, in the case where the B content is set at 0.02 (%) or above in order to attain a higher strength, it is recommended to adopt a construction in which the journal portion is inserted into a sleeve made of low-alloy steel having a Cr content of 1-3 (%), through shrinkage fit. The material composition of the sleeve is the same as that of the buildup welding layers to be explained later.

[0074] The buildup welding layers are preferably in the number of 5 - 10. Abrupt decrease In the amount of Cr in the first welding layer causes the development of high residual tensile stress or welding cracks, so that the Cr content of the weld metal of the first welding layer cannot be sharply lowered. As stated before, therefore, the Cr contents need to be gradually lowered with the enlarged number of welding layers. Further, since the desired Cr content and a desired thickness need to be held as the surface layer of the journal portion, the welding layers need to be in the number of 5 or more. By the way, even when the number of welding layers is larger than 10, no greater effect is achieved. Regarding a large-sized structural member such as the steam-turbine rotor shaft, the buildup welding layers must not have their composition influenced by the parent metal and need to be endowed with the desired composition as well as the desired thickness. Herein, three layers are required as a thickness for preventing the influence of the parent metal. Besides, layers of desired characteristics need to be stacked on the three layers to a desired thickness, and at least two layers are required as the desired thickness. By way of example, a thickness of about 18 (mm) is required as the desired thickness of the finally finished buildup welding layers. In order to form such a thickness, at least five buildup welding layers are necessitated even when a final finish margin to be machined is excluded. The third layer et seq. should preferably be mainly made of the tempered martensitic structure from which the carbides have been precipitated. Especially, the composition of the fourth welding layer et seq. should preferably contain in terms of weight, 0.01 - 0.1 (%) of C,0.3 - 1 (%) of Si, 0.3 - 1.5 (%) of Mn, 0.5 - 3 (%) of Cr and 0.1 -1.5 (%) of Mo, the balance being Fe.

[0075] Moreover, in the buildup welding layers, the Cr content is lowered successively from the first layer to any of the second - fourth layers. In performing the buildup welding, welding rods whose Cr contents are gradually lowered are used for the respective layers. Then, the buildup welding layers of the desired composition can be formed without incurring the problem of lowered ductility or welding cracks of the first-layerwelding zone attributed to the sharp decrease of the chromium content in the first-layer welding zone. In this way, it is possible to form buildup welding layers in which the chromium contents in the vicinities of the parent metal and the first-layer zone do not exhibit a very large difference, and in which the final layer has the good bearing characteristics as stated above.

[0076] The weld metal which is applied to the first-layer welding has its chromium content rendered about 2 - 6 (weight-%) lower than the chromium content of the parent metal. When the Cr content of the weld metal is less than 2 (%) that of the parent metal, the pertinent Cr content of the buildup welding layer cannot be lowered sufficiently, and the effect is slight. To the contrary, when the value exceeds 6 (%), the Cr content of the buildup welding layer lowers suddenly from that of the parent metal, and the difference between the Crcontents gives rise to a large difference between the coefficients of thermal expansion of both the metals, to thereby cause development of high residual tensile stress or welding cracks. Incidentally, since a higher Cr content results in a smaller coefficient of thermal expansion, the buildup welding layer of lower Cr content has larger coefficient of thermal expansion than the parent metal and is formed with the high residual tensile stress by the welding. Therefore, the welding with steel of still lower Cr content produces a hard layer due to the high residual stress and causes development of welding cracks. Accordingly, the Cr content of the weld metal needs to be set at, at most, 6 (%) smaller than that of the parent metal. Owing to the use of such a weld metal, the chromium content of the first-layer welding layer becomes lower than that of the parent metal by as little as about 1 - 3 (%) because the weld metal mixes with the parent metal. Thus, favorable welding is attained.

[0077] The layers of and behind the fourth layer need to be formed using weld metal which is made of steel having an identical Cr content. In the buildup welding, the buildup welding layers up to the third layer are influenced by the composition of the parent metal. Since, however, the fourth buildup welding layer et seq. are composed only of the employed weld metal without this influence, they can be formed to satisfy the characteristics required for the journal portion of the steam-turbine rotor shaft. Besides, as stated before, the thickness of the buildup welding layers required for the large-sized structural member operating as the steam-turbine rotor shaft is about 18 (mm). Accordingly, in order to ensure the alloying constituents required for the final layer and the sufficient thickness required in the case of the constituents, two or more layers are deposited as the fourth layer et seq. by the use of the weld metal having the same Cr content. Thus, the final layer which satisfies the characteristics required for the journal portion as stated before can be formed having the sufficient thickness.

[0078] (2) There will be elucidated the reasons for restricting the constituents of the heat-resisting ferritic steel which is used in an embodiment of the present invention for making the inner casings, control-valve valve casings, combinational-reheater-valve valve casings, main-steam leading pipes, main-steam inlet pipes and reheat-steam Inlet pipes of the high-pressure and intermediate-pressure steam turbines, the nozzle box of the high-pressure turbine, the first-stage diaphragm of the intermediate-pressure turbine, and the main-steam inlet flange and elbow and the main-steam stop valve of the high-pressure turbine:

[0079] In the casing material of the heat-resisting ferritic cast steel, especially, the NI/W ratio is controlled to 0.25 - 0.75, thereby obtaining the casing material of the heat-resisting cast steel which meets a 625-°C 10^5-h creep rupture strength of at least 9 (kgf/mm^2) and a room-temperature absorbed impact energy of at least 1 (kgf-m) that are required of the high-pressure and intermediate-pressure inner casings, main-steam stop valve and control valve casing of the turbine under the ultra-supercritical pressure of at least 250 (kgf/cm^2) at 621 (°C).

[0080] In the heat-resisting cast steel in an embodiment of the present invention used as the casing material, the Cr equivalent which is computed in terms of the alloy contents (weight-%) of the following formula should preferably be controlled so as to become 4 - 10, in order to attain a superior high-temperature strength, a superior low-temperature toughness and a high fatigue strength:

$$\text{Cr equivalent} = Cr + 6Si + 4Mo + 1.5W + 11V + 5Nb - 40C - 30N - 308 - 2Mn - 4Ni - 2Co$$

[0081] Since the 12Cr heat-resisting steel in an embodiment of the present invention is used in the steam at or above 621 (°C), it must be endowed with the 625-°C 10^5-h creep rupture strength of et least 9 (kgf/mm^2) and the room-temperature absorbed impact energy of at least 1 (kgf-m). Further, in order to ensure a still higher reliability, this steel should preferably be endowed with a 625-°C 10^5-h creep rupture strength of at least 10 (kgf/mm^2) and a room-temperature absorbed impact energy of at least 2 (kgf-m).

[0082] The constituent C (carbon) is an element which is required at a level of least 0.06 (%) in order to attain a high tensile strength. However, in a case where the C content exceeds 0.16 (%), the steel comes to have an unstable metallographic structure and degraded the long-time creep rupture strength thereof when exposed to high temperatures for a long time period. Therefore, the C content is restricted to within 0.06 - 0.16 (%). It should preferably be within 0.09 - 0.14 (%).

[0083] The constituent N (nitrogen) is effective to improve the creep rupture strength and to prevent the production of the 8 ferrite structure. However, when the N content of the steel is less than 0.01 (%), the effects are not sufficient. On the other hand, even when the N content exceeds 0.1 (%), no remarkable effects are attained. Moreover, the toughness is lowered, and the creep rupture strength is also lowered. Especially, a range of 0.02 - 0.4 (%) is preferable.

[0084] The constituent Mn (manganese) is added for a deoxidizer, and the effect thereof is achieved by a small amount of addition. A large amount of addition exceeding 1 (%) is unfavorable because it lowers the creep rupture strength. Especially, a range of 0.4 - 0.7 (%) is preferable.

[0085] The constituent Si (silicon) is also added as a deoxidizer, but the Si deoxidation is dispensed with when the steelmaking technique employed is vacuum C deoxidation or the like. A lower Si content is effective to prevent the production of the deleterious δ ferrite structure. Accordingly, the addition of the constituent Si needs to be suppressed to 0.5 (%) or below. The Si content of the steel should preferably be 0.1 - 0.4 (%).

[0086] The constituent V (vanadium) is effective to heighten the creep rupture strength. When the V content of the steel is less than 0.05 (%), the effect is insufficient. On the other hand, when the V content exceeds 0.35 (%), the δ ferrite is produced which lowers the fatigue strength. Especially, a range of 0.15 - 0.25 (%) is preferable.

[0087] The constituent Nb (niobium) is an element which is very effective to enhance the high-temperature strength. However, when the element Nb is added In an excessively large amount, the coarse grains of eutectic NbC (niobium carbide) appear especially in a large-sized steel ingot, to thereby cause substantial lowering of the strength and precipitation of the δ ferrite which lowers the fatigue strength. It is therefore necessary to suppress the amount of the element Nb to 0.15 (%) or below. On the other hand, when the Nb amount is less than 0.01 (%), the effect is insufficient. Especially in the case of the large-sized steel ingot, a range of 0.02 - 0.1 (%) is preferable, and a range of 0.04 - 0.08 (%) is more preferable.

[0088] The constituent Ni (nickel) is an element which is very effective to heighten the toughness and to prevent the production of the δ ferrite. The addition of the element Ni at a level of less than 0.2 (%) is unfavorable because of insufficient effects, and the addition thereof at the level of more than 1.0 (%) is also unfavorable because of degradation in the creep rupture strength. Especially, a range of 0.4 - 0.8 (%) is preferable.

[0089] The constituent Cr (chromium) is effective to improve the high-temperature strength and high-temperature oxidation resistance of the 12Cr steel. Herein, a Cr content exceeding 12 (%) causes production of the deleterious 8 ferrite structure, and a Cr content below 8 (%) results in an insufficient oxidation resistance to the high-temperature high-pressure steam. Besides, the addition of the element Cr is effective to enhance the creep rupture strength. However, the Cr addition in an excessive amount causes production of the deleterious 8 ferrite structure and for lowering of the toughness. Especially, a range of 8.0 - 10 (%) is preferable, and a range of 8.5 - 9.5 (%) is more preferable.

[0090] The constituent W (tungsten) is effective to remarkably enhance the high-temperature long-term strength of the 12Cr steel. When the amount of the element W is smaller than 1 (%), the effect is insufficient as the heat-resisting steel which is used at 620 - 660 (°C). On the other hand, when the amount of the element W exceeds 4 (%), the toughness is lowered. The W content of the steel should preferably be selected according to the temperature, such as 1.0 - 1.5 (%) at 620 (°C), 1.6 - 2.0 (%) at 630 (°C), 2.1 - 2.5 (%) at 640 (°C), 2.6 - 3.0 (%) at 650 (°C) and 3.1 - 3.5 (%) at 660 (°C). Particularly, the steel contains 1.5 -1.9 (%) of W can be used at the temperature at most 650 (°C).

[0091] The constituents W and Ni correlate with each other. The 12Cr steel whose strength and toughness are both superior, can be obtained by setting the Ni/W ratio at 0.25 - 0.75.

[0092] The addition of the constituent Mo (molybdenum) is intended to enhance the high-temperature strength. However, in a case where the constituent W (tungsten) is contained at a level of more than 1 (%), the Mo addition exceeding 1.5 (%) lowers the toughness and fatigue strength of the steel. Therefore, the Mo content is recommended to be at most 1.5 (%). Especially, a range of 0.4 - 0.8 (%) is preferable, and a range of 0.55 - 0.70 (%) is more preferable.

[0093] The addition of the constituent/constituents Ta (tantalum), Ti (titanium) or/and Zr (zirconium) is effective to heighten the toughness. A sufficient effect is attained by adding at most 0.15 (%) of Ta, at most 0.1 (%) of Ti or/and at most 0.1 (%) of Zr singly or in combination. In a case where the constituent Ta is added at a level of 0.1 (%) or above, the addition of the constituent Nb (niobium) can be omitted.

[0094] Regarding the heat-resisting cast steel which is used as the casing material, the fatigue strength and the toughness are lowered due to the coexistence of the δ ferrite structure. Therefore, the tempered martensitic structure which is homogeneous is favorable. In order to obtain the tempered martensitic structure, the Cr equivalent which is computed by the formula mentioned before must be set at, at most, 10 by controlling the alloy contents. On the other hand, when the Cr equivalent is too small, it lowers the creep rupture strength, and hence, it must be set at 4 or above. Especially, a range of 6 - 9 is preferable as the Cr equivalent.

[0095] The addition of the constituent B (boron) remarkably enhances the high-temperature (620 (°C) or above) creep rupture strength of the steel. Herein, when the B content of the steel exceeds 0.003 (%), the weldability thereof worsens. Therefore, the upper limit of the B content is set at 0.003 (%). Especially, the upper limit of the B content of the large-sized casing should preferably be set at 0.0028 (%). Further, a range of 0.0005 - 0.0025 (%) is preferable, and a range of 0.001 - 0.002 (%) is particularly preferable.

[0096] Since the casing covers the high-pressure steam at temperatures of at least 620 (°C), it undergoes a high stress ascribable to the internal pressure thereof. From the viewpoint of preventing the creep rupture of the casing, therefore, the 10^5-h creep rupture strength of at least 10 (kgf/mm^2) is required of the steel. Moreover, during the starting operation of the turbine, the casing undergoes a thermal stress at the time of a low metal temperature. From the viewpoint of preventing the brittle fracture of the casing, therefore, the room-temperature absorbed impact energy of at least 1 (kgf-m) is required of the steel. For the higher temperature side of the steam, the steel can be strengthened by containing at most 10 (%) of Co (cobalt). Especially, the Co content should more preferably be selected from 1 - 2 (%) for 620 (°C), 2.5 - 3.5 (%) for 630 (°C), 4 - 5 (%) for 640 (°C), 5.5 - 6.5 (%) for 650 (°C), and 7 - 8 (%) for 660 (°C). But even the steel which does not contain Co can be used at each temperature.

[0097] The casing in an embodiment of the present invention should preferably be made of steel which satisfies at least either of conditions; a (W/Mo) ratio of 2.85 or above (preferably, 2.85 - 4.50, and more preferably, 3 - 4), and an

(Mo/Cr) ratio of 0.04 - 0.08 (preferably, 0.05 - 0.06). Steel which satisfies both the conditions, is more preferable.

[0098] In fabricating the casing having few defects, a high degree of manufacturing technology is required because the casing is a large-sized structural member whose ingot has a weight of about 50 (tons). As the casing material of the heat-resisting ferritic cast steel a satisfactory one can be prepared in such a way that alloying raw materials to be brought into the desired composition are melted by an electric furnace and then refined by a ladle, and that the resulting raw materials are thereafter cast into a sand mold. The cast steel in which casting defects such as shrinkage holes are involved in small numbers, can be obtained by sufficiently refining and deoxidizing the raw materials before the casting.

[0099] After the cast steel has been annealed at 1000 - 1150 (°C), it is normalized by heating it to 1000 -1100 (°C) and then quenching it. Subsequently, the resulting steel is tempered twice in the sequence of a temperature range of 550 - 750 (°C) and a temperature range of 670 - 770 (°C). Thus, the steam turbine casing which is usable in the steam at or above 620 (°C) can be manufactured. When the annealing and normalizing temperatures are below 1000 (°C), carbonitrides cannot be sufficiently turned into a solid solution, and when they are excessively high, grain coarsening is caused. Besides, the two tempering operations decompose retained austenite entirely, so that the steel can be rendered the tempered martensitic structure which is homogeneous. Owing to the above method of preparation, the 625-°C 10^5-h creep rupture strength of at least 10 (kgf/mm^2) and the room-temperature absorbed impact energy of at least 1 (kgf-m) are attained, and the prepared steel can be fabricated into the steam turbine casing which is usable in steam at or above 620 (°C).

[0100] The casing material in an embodiment of the present invention is set at the Cr equivalent stated before, and the δ ferrite content thereof should preferably be 5 (%) or less, and more preferably 0 (%).

[0101] Except for the inner casing for the intermediate-pressure steam turbine, which is made of cast steel, the components mentioned before should preferably be made of forged steel.

[0102] (3) Others:

(a) The rotorshaft of the low-pressure steam turbine should preferably be made of low-alloy steel having a fully-tempered bainitic structure which contains in terms of weight, 0.2 - 0.3 (%) of C, at most 0.1 (%) of Si, at most 0.2 (%) of Mn, 32 - 4.0 (%) of Ni, 1.25 - 2.25 (%) of Cr, 0.1 - 0.6 (%) of Mo and 0.05 - 0.25 (%) of V. The low-alloy steel should preferably be manufactured by the same manufacturing method as the ferritic steel of the high-pressure and intermediate-pressure rotor shafts, as explained before. Especially, the manufacture should preferably be a superclean (highly pure) one employing raw materials which contain at most 0.05 (%) of Si and at most 0.1 (%) of Mn, and in which impurities such as P, S, As, Sb and Sn are decreased to the utmost so as to amount to 0.025 (%) or less in total. It is favorable that each of the P and S contents of the raw materials is at most 0.010 (%), that each of the Sn and As contents is at most 0.005 (%), and that the Sb content is at most 0.001 (%).

(b) Blades for the low-pressure turbine except a final-stage moving one, and nozzles therefor should preferably be made of fully-tempered martensitic steel which contains 0.05 - 0.2 (%) of C, 0.1 - 0.5 (%) of Si, 0.2 -1.0 (%) of Mn, 10 -13 (%) of Cr and 0.04 - 0.2 (%) of Mo.

(c) Both inner and outer casings for the low-pressure turbine should preferably be made of cast carbon steel which contains 02 - 0.3 (%) of C, 0.3 - 0.7 (%) of Si and at most 1 (%) of Mn.

(d) The casings of a main-steam stop valve and a steam control valve for the low-pressure turbine should preferably be made of fully-tempered martensitic steel which contains 0.1 - 0.2 (%) of C, 0.1 - 0.4 (%) of Si, 0.2 - 1.0 (%) of Mn, 8.5 -10.5 (%) of Cr, 0.3 - 1.0 (%) of Mo, 1.0 - 3.0 (%) of W, 0.1 - 0.3 (%) of V, 0.03 - 0.1 (%) of Nb, 0.03 - 0.08 (%) of N and 0.0005 - 0.003 (%) of B.

(e) A Ti alloy is employed for the final-stage moving blade of the low-pressure turbine. More specifically, the Ti alloy contains 5 - 8 (weight-%) of Al and 3 - 6 (weight-%) of V for the length of the final-stage moving blade exceeding 40 (inches), and these contents can be increased with the length. Especially, a high-strength material containing 5.5 - 6.5 (%) of Al and 3.5 - 4.5 (%) of V is preferable for the length of 43 (inches), and a high-strength material containing 4 - 7 (%) of Al, 4 - 7 (%) of V and 1 - 3 (%) of Sn for the length of 46 (inches).

(f) Outer casings for the high-pressure and intermediate-pressure steam turbines should preferably be fabricated of cast steel of fully-tempered bainitic structure which contains 0.05 - 0.20 (%) of C, 0.05 - 0.5 (%) of Si, 0.1 - 1.0 (%) of Mn, 0.1 - 0.5 (%) of Ni, 1 - 2.5 (%) of Cr, 0.5 1.5 (%) of Mo and 0.1 - 0.3 (%) of V, and which favorably contains at least either of 0.001 - 0.01 (%) of B and at most 0.2 (%) of Ti.

BRIEF DESCRIPTION OF THE DRAWINGS

[0103] Fig. 1 is a sectional design view of a high-pressure steam turbine made of ferritic steel according to the present invention.

[0104] Fig. 2 is a sectional design view of an intermediate-pressure steam turbine made of ferritic steel according to the present invention.

[0105] Fig. 3 is a sectional design view of a low-pressure steam turbine according to the present invention.
[0106] Fig. 4 is an arrangement diagram of a coal-fired power plant according to the present invention.
[0107] Fig. 5 is a sectional view of a rotor shaft for the high-pressure steam turbine according to the present invention.
[0108] Fig. 6 is a sectional view of a rotor shaft for the intermediate-pressure steam turbine according to the present invention.
[0109] Fig. 7 is a graph showing the creep rupture strengths of rotor shaft and blade materials.
[0110] Fig. 8 is a graph showing the relationships between the creep rupture time periods and Co contents of alloys.
[0111] Fig. 9 is a graph showing the relationships between the creep rupture time periods and B contents of the alloys.
[0112] Fig. 10 is a graph showing the relationship between the creep rupture strengths and W contents of the alloys.
[0113] Fig. 11 is a graph showing the creep rupture strengths of casing materials.
[0114] Fig. 12 is a table (Table 1) exemplifying the specifications of a boiler which is operated under specified steam conditions.
[0115] Fig. 13 is a table (Table 2) indicating the specifications of a steam turbine which is operated under specified conditions.
[0116] Fig. 14 is a table (Table 3) for explaining the alloy contents of steel materials which are employed in the present invention.
[0117] Fig. 15 is a table (Table 4) for explaining the mechanical properties and heat treatment conditions of the steel materials which are listed in Table 3.
[0118] Fig. 16 is a table (Table 5) indicating the chemical constituents of welding rods which were used in buildup welding.
[0119] Fig. 17 is a table (Table 6) indicating those welding rods in Table 5 which were used in the respective layers of the buildup welding.
[0120] Fig. 18 is a table (Table 7) indicating the chemical constituents of moving blades materials according to the present invention.
[0121] Fig. 19 is a table (Table 8) for explaining the strengths of the rotor shaft and blade materials (in Fig. 7) according to the present invention.
[0122] Fig. 20 is a table (Table 9) indicating the ratios of percentages of the constituents.
[0123] Fig. 21 is a table (Table 10) indicating the chemical constituents of inner casing materials according to the present invention.
[0124] Fig. 22 is a table (Table 11) indicating the test results of the inner casing materials (in Fig. 21) according to the present invention.

PREFERRED EMBODIMENTS OF THE INVENTION

(Embodiment 1)

[0125] Due to sudden rises in the prices of fuel after the Oil crisis, a pulverized-coal direct-fired boiler and a steam turbine at steam temperatures of 600 - 649 (°C) have been required in orderto increase thermal efficiencies on the basis of enhanced steam conditions. One example of the boiler which is operated under such steam conditions, is indicated in Table 1 of Fig. 12.
[0126] Since steam oxidation is attendant upon such a higher-temperature operation, 8 - 10-% Cr steel is employed instead of conventional 2.25-% Cr steel. Besides, since the maximum sulfur content and the maximum chlorine content become 1 (%) and 0.1 (%), respectively, regarding high-temperature corrosion ascribable to pulverized-coal direct-firing gas, an austenitic stainless steel pipe functioning as a superheater tube is made of a material which contains 20 - 25 (%) of Cr and 20 - 35 (%) of Ni, which contains Al and Ti in very small amounts of at most 0.5 (%), and 0.5 - 3 (%) of Mo, and which more preferably contains at most 0.5 (%) of Nb. Pulverized-coal direct firing becomes high-temperature burning. Accordingly, it is desirable, from the view point of decreasing nitrogen oxides NO_x, to employ a burner which makes flames of higher temperatures by feeding inner peripheral air and secondary outer peripheral air that form burning flames based on the primary air and pulverized coal, and also reducing flames around the burning flames.
[0127] The pulverized-coal fired boiler becomes larger in size as its capacity enlarges. The boiler has a width of 31 (m) and a depth of 16 (m) in the class of 1050 (MW), and a width of 34 (m) and a depth of 18 (m) in the class of 1400 (MW).
[0128] Table 2 in Fig. 13 indicates the main specifications of a steam turbine plant which has an output of 1050 (MW) and a steam temperature of 625 (°C). In this embodiment, a cross-compound type 4-flow exhaust system is adopted, and a final-stage blade in each of the low-pressure turbines (LP's) is 43 (inches) long. An HP (high-pressure turbine) - IP (intermediate-pressure turbine) connection has a rotational speed of 3600 (r/min), while the two LP's have a rotational speed of 1800 (r/min). In a high-temperature portion, components are made of principal materials which are listed in the table. The high-pressure portion (HP) undergoes the steam temperature of 625 (°C) and a pressure of 250 (kg/cm^2). The intermediate-pressure portion (IP) has its steam heated to 625 (°C) by a reheater (R/H), and is operated

under a pressure of 170 - 180 (kg/cm^2). Steam enters the low-pressure portions (LP's) at a temperature of 450 (°C), and it is sent to a condenser at a temperature of at most 100 (°C) and in a vacuum of 722 (mmHg).

[0129] Fig. 1 is a sectional design view of the high-pressure steam turbine. This high-pressure steam turbine is provided with a high-pressure rotor shaft 23 on which high-pressure moving blades 16 are assembled in a high-pressure inner casing 18 and a high-pressure outer casing 19 surrounding the inner casing 18. The steam at the high temperature and under the high pressure as stated before is generated by the boiler explained before. The generated steam is passed through a main steam pipe and then through a main steam inlet 28 defined by a flange and elbow 25, whereupon it is guided to the moving blades 16 of the double-flow first stage from a nozzle box 38. The first stage has the double-flow construction, and eight other stages are disposed on one side of the high-pressure steam turbine along the rotor shaft 23. Fixed blades are respectively provided in correspondence with the moving blades 16. The moving blades 16 are double-tenon type tangential entry dovetail blades, and the first-stage blade is about 35 (mm) long. The length of the rotor shaft 23 between the centers of bearings 1 and 2 is about 5.25 (m), and the smallest diameter part of this rotor shaft corresponding to the fixed blades has a diameter of about 620 (mm), so that the ratio of the length to the diameter is about 8.5.

[0130] The widths of those parts of the rotor shaft 23 on which the moving blades 16 are assembled are substantially equal at the first stage and final stage, and they become smaller toward the downstream side of the steam stepwise at the five types stages, namely the first stage, second stage, third - fifth stages, sixth stage and seventh - eighth stages. The axial width of the assembled part of the second stage is 0.64 times as wide as that of the assembled part of the final stage.

[0131] Those parts of the rotor shaft 23 which correspond to the fixed blades are smaller in diameter than those parts thereof on which the moving blades 16 are assembled. The axial widths of the parts corresponding to the fixed blades become smaller stepwise from the width between the second-stage moving blade and the third-stage moving blade, to the width between the final-stage moving blade and the penultimate-stage moving blade, the latter width being 0.86 times as wide as the former width. Concretely, the axial widths of the parts corresponding to the fixed blades become smaller at the second - sixth stages and the sixth - ninth stages.

[0132] In this embodiment, the blades and nozzles of the first stage are made of materials indicated in Table 3 of Fig. 14 to be explained later, whereas those of all the other stages are made of 12-% Cr steel which contains no W, Co or B. The blade parts of the moving blades 16 in this embodiment are 35 - 50 (mm) long at the first stage, and become longer at the respective stages from the second stage toward the final stage. Especially, the lengths of the blade parts of the second - final stages are set at 65 - 210 (mm), depending upon the output of the steam turbine. The number of the stages is 9 - 12. Herein, the lengths of the blade parts at the respective stages increase at ratios of 1.10 - 1.15 in terms of the lengths of the downstream-side blade parts adjoining the upstream-side ones, and the ratios gradually enlarge on the downstream side.

[0133] As stated above, those parts of the rotor shaft 23 on which the moving blades 16 are assembled are larger in diameter compared with those parts thereof which correspond to the fixed blades. In this regard, the axial widths of the moving-blade assembled parts become larger with the lengths of the blade parts of the moving blades 16. The ratios of the aforementioned axial widths to the lengths of the blade parts of the moving blades 16 are 0.65 - 0.95 at the second - final stages, and become smaller stepwise from the second stage toward the final stage.

[0134] As also stated above, the axial widths of those parts of the rotor shaft 23 which correspond to the fixed blades become smaller stepwise from the width between the second stage and the third stage, to the width between the final stage and the penultimate stage. The ratios of the aforementioned axial widths to the lengths of the blade parts of the moving blades 16 are 0.7 1.7 at the second - final stages, and become smaller stepwise from the upstream-side blade part toward the downstream-side blade part.

[0135] The high-pressure steam turbine shown in Fig. 1 further includes a thrust bearing 5, a first shaft packing 10, a second shaft packing 11, a high-pressure spacer 14, a front bearing box 26, a journal portion 27, a high-pressure steam exhaust port 30, a reheat steam inlet 32, and a thrust-bearing wear interrupter 39.

[0136] Fig. 2 is a sectional view of the intermediate-pressure steam turbine. This intermediate-pressure steam turbine rotates a generator (G in Fig. 13) conjointly with the high-pressure steam turbine, by the use of steam which is obtained in such a way that steam exhausted from the high-pressure steam turbine is heated again to 625 (°C) by a reheater (R/H in Fig. 13). Herein, the intermediate-pressure turbine has a rotational speed of 3600 (revolutions/min). Likewise to the high-pressure turbine, the intermediate-pressure turbine includes an intermediate-pressure inner casing 21 and an outer casing 22. It is provided with fixed blades in opposition to intermediate-pressure moving blades 17. The moving blades 17 have a double-flow construction of six stages, and they are disposed in a substantially symmetrical arrangement on both sides of an intermediate-pressure rotor shaft 24 in the lengthwise direction thereof. The distance between the centers of bearings 3 and 4 in which the rotor shaft 24 is journaled, is about 5.5 (m). The moving blade of the first stage has a length of about 92 (mm), and that of the final stage has a length of about 235 (mm). The dovetail of the double-flow construction is in an inverted-chestnut shape. That part of the rotor shaft 24 which corresponds to the fixed blade preceding the final-stage moving blade 17 has a diameter of about 630 (mm), and the ratio of the inter-bearing distance of this rotor shaft to the aforementioned diameter is about 8.7.

[0137] The axial widths of those parts of the rotor shaft 24 of the intermediate-pressure steam turbine of this embodiment on which the moving blades 17 are assembled become larger toward the downstream side of the steam stepwise at the three sorts of stages of the first stage, the fourth and fifth stages and the final stage. The axial width of the assembled part of the final stage is about 1.4 times as large as that of the assembled part of the first stage.

[0138] Besides, those parts of the rotor shaft 24 of the intermediate-pressure steam turbine which correspond to the fixed blades are smaller in diameter than those parts thereof on which the moving blades 17 are assembled. The axial widths of the parts corresponding to the fixed blades become smaller toward the downstream side of the steam stepwise at the four moving-blade stages of the first stage, second stage, third stage and final stage, and the axial width at the final stage is about 0.7 time as large as the axial width at the first stage.

[0139] In this embodiment, the blades and nozzles of the first stage are made of the materials indicated in Table 3 of Fig. 14 to be explained later, whereas those of all the other stages are made of the 12-% Cr steel which contains no W, Co or B. The blade parts of the moving blades 17 in this embodiment become longer at the respective stages from the first stage toward the final stage. The lengths of the blade parts of the first - final stages are set at 90 - 350 (mm), preferably 100 - 300 (mm), depending upon the output of the steam turbine. The number of the stages is 6 - 9. Herein, the lengths of the blade parts at the respective stages increase at ratios of 1.1 - 1.2 in terms of the lengths of the downstream-side blade parts adjoining the upstream-side ones.

[0140] As stated above, those parts of the rotor shaft 24 on which the moving blades 17 are assembled are larger in diameter compared with those parts thereof which correspond to the fixed blades. In this regard, the axial widths of the moving-blade assembled parts become larger with the lengths of the blade parts of the moving blades 17. The ratios of the aforementioned axial widths to the lengths of the blade parts of the moving blades 17 are 0.5 - 0.7 at the first - final stages, and become smaller stepwise from the first stage toward the final stage.

[0141] As also stated above, the axial widths of those parts of the rotor shaft 24 which correspond to the fixed blades become smaller stepwise from the width between the first stage and the second stage, to the width between the final stage and the penultimate stage. The ratios of the aforementioned axial widths to the lengths of the blade parts of the moving blades 17 are 0.5 - 1.5, and become smaller stepwise from the upstream-side blade part toward the downstream-side blade part.

[0142] The intermediate-pressure steam turbine shown in Fig. 2 further includes shaft packings 12 and 13, an intermediate-pressure spacer 15, a first inner casing 20 (associated with the second inner casings 21), reheat steam inlets 29, steam exhaust ports 30, crossover pipes 31, and a warming steam inlet 40.

[0143] Fig. 3 is a sectional view of the low-pressure turbine. Two low-pressure turbines are connected in tandem, and they have the same design. Moving blades 41 are provided as eight stages on both sides of a rotor shaft 44 in the lengthwise direction thereof, and these moving blades on both sides are substantially in a bilaterally symmetric arrangement. Besides, fixed blades 42 are disposed in correspondence with the moving blades 41. The moving blade 41 of the final stage is 1,092.2 (mm) (43 (inches)) long, and is made of a Ti-based alloy. The moving blades 41 of all the stages are double-tenon type tangential entry dovetail blades. A nozzle box 45 is of double-flow type. The Ti-based alloy is subjected to age hardening, and it contains 6 (%) of Al and 4 (%) of V in terms of weight. The rotor shafts 44 are made of forged steel of fully-tempered bainitic structure prepared from superclean materials (high purity materials) which consist of 3.75 (%) of Ni, 1.75 (%) of Cr, 0.4 (%) of Mo, 0.15 (%) of V, 0.25 (%) of C, 0.05 (%) of Si, 0.10 (%) of Mn, and the balance of Fe. All the moving blades and the fixed blades except the final-stage ones are made of 12-% Cr steel containing 0.1 (%) of Mo. Cast steel containing 0.25 (%) of C is employed as the material of the inner and outer casings. The distance between the centers of bearings 43 in this embodiment is 7500 (mm). Those parts of the rotor shaft 44 which correspond to the fixed blades 42 have a diameter of about 1280 (mm), while those parts thereof on which the moving blades 41 are assembled have a diameter of about 2275 (mm). The ratio of the inter-bearing distance to the smaller diameter of the rotor shaft 44 is about 5.9.

[0144] In the low-pressure turbine of this embodiment, the axial widths of the moving-blade assembled parts of the rotor shaft 44 gradually enlarge at the five sorts of stages of the first - third stages, the fourth stage, the fifth stage, the sixth - seventh stages and the eighth stage. The width of the final stage is about 2.5 times as large as that of the first stage.

[0145] Besides, those parts of the rotor shaft 44 which correspond to the fixed blades 42 are smaller in diameter than those parts thereof on which the moving blades 41 are assembled. The axial widths of the parts corresponding to the fixed blades 42 become larger toward the downstream side of the steam gradually at the three sorts of moving-blade stages of the first stage, the fifth - sixth stages and the seventh stage, and the width at the final stage is about 1.9 times as large as the width at the first stage.

[0146] The blade parts of the moving blades 41 in this embodiment become longer at the respective stages from the first stage toward the final stage. The lengths of the blade parts of the first - final stages are set at 90 - 1270 (mm), depending upon the output of the steam turbine. The number of the stages is 8

[0147] Herein, the lengths of the blade parts at the respective stages enlarge at ratios of 1.3 - 1.6 in terms of the lengths of the downstream-side blade parts adjoining the upstream-side ones.

[0148] As stated above, those parts of the rotor shaft 44 on which the moving blades 41 are assembled are larger in diameter compared with those parts thereof which correspond to the fixed blades 42. In this regard, the axial widths of the moving-blade assembled parts become larger with the lengths of the blade parts of the moving blades 41. The ratios of the aforementioned axial widths to the lengths of the blade parts of the moving blades 41 are 0.15 - 0.91 at the first - final stages, and become smaller stepwise from the first stage toward the final stage.

[0149] Also, the axial widths of those parts of the rotor shaft 44 which correspond to the fixed blades 42 become smaller stepwise from the width between the first stage and the second stage, to the width between the final stage and the penultimate stage. The ratios of the aforementioned axial widths to the lengths of the blade parts of the moving blades 41 are 0.25 - 1.25, and become smaller stepwise from the upstream-side blade part toward the downstream-side blade part.

[0150] Apart from this embodiment, it is also possible to similarly construct a large-capacity power plant of 1000 (MW) class in which steam inlets to a high-pressure steam turbine and an intermediate-pressure steam turbine are at a temperature of 610 (°C), while steam inlets to two low-pressure steam turbines are at a temperature of 385 (°C).

[0151] Fig. 4 is a diagram showing the typical plant layout of a coal-fired high-temperature high-pressure steam turbine plant.

[0152] The high-temperature high-pressure steam turbine plant in this embodiment is chiefly configured of a coal-fired boiler 51, a high-pressure turbine 52, an intermediate-pressure turbine 53, low-pressure turbines 54 and 55, steam condensers 56, condensate pumps 57, a low-pressure feed water heater system 58, a deaerator 59, a pressuring pump 60, a boiler feed pump 61 and a high-pressure feed water heater system 63. Herein, ultra-supercritical steam generated by the boiler 51 enters the high-pressure turbine 52 to generate power. Thereafter, exhaust steam from the high-pressure turbine 52 is reheated by the boiler 51, and the resulting steam enters the intermediate-pressure turbine 53 to generate power again. Exhaust steam from the intermediate-pressure turbine 53 enters the low-pressure turbines 54 and 55 to generate power, and it is thereafter condensed by the condensers 56. The resulting condensate is sent to the low-pressure feed water heater system 58 and deaerator 59 by the condensate pumps 57. Feed water deaerated by the deaerator 59 is sent by the pressurizing pump 60 and boiler feed pump 61 to the high-pressure feed water heater system 63, in which the water is heated and from which it is returned to the boiler 51.

[0153] Here in the boiler 51, the feed water is turned into high temperature and high pressure steam by passing through an economizer 64, a vaporizer 65 and a superheater 66. Meantime, the combustion gas of the boiler 51 having heated the steam comes out of the economizer 64, and it thereafter enters an air heater 67 to heat air. In the illustrated plant, the boiler feed pump 61 is driven by a boiler feed pump driving turbine which is operated by steam extracted from the intermediate-pressure turbine 53.

[0154] In the high-temperature high-pressure steam turbine plant thus constructed, the temperature of the feed water having emerged from the high-pressure feed water heater system 63 is much high erthan a feed water temperature in the prior-art thermal power plant, and hence, the temperature of the combustion gas having emerged from the economizer 64 disposed in the boiler 51 becomes much higher than in the prior-art boiler as an inevitable consequence. Therefore, heat is recovered from the exhaust gas of the boiler 51 so as to prevent the gas temperature from lowering.

[0155] Numerals 68 in Fig. 4 indicate generators which are respectively joined to the HP - IP connection and the tandem LP connection.

[0156] By the way, apart from this embodiment, it is possible to similarly construct a tandem compound type power plant in which the same high-pressure turbine, intermediate-pressure turbine and one or two low-pressure turbines as described above are joined in tandem so as to rotate a single generator for power generation. In the generator whose output power is in the 1050 (MW) class as in this embodiment, a shaft of higher strength is employed for the generator. Especially, the generator shaft should preferably be made of steel of fully-tempered bainitic structure which contains 0.15 - 0.30 (%) of C, 0.1 - 0.3 (%) of Si, at most 0.5 (%) 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, and which has a room-temperature tensile strength of 93 (kg/mm^2) or above, particularly 100 (kg/mm^2) or above, and a 50% FATT (Fracture Appearance Transition Temperature) of 0 (°C) or below, particularly -20 (°C) or below. The steel should preferably be such that a magnetizing force at 21.2 (kG) is at most 985 (AT/cm), that impurities P, S, Sn, Sb and As contained is at the total amount of most 0.025 (%), and that a ratio Ni/Cr is at most 2.0.

[0157] Figs. 5 and 6 are front views showing examples of the high-pressure and intermediate-pressure turbine rotor shafts, respectively. The exemplified high-pressure turbine shaft has a construction which consists of a multistage side and a single-stage side, and in which blades totaling eight stages are assembled on both sides so as to laterally center on the first-stage blade of the multistage side. The exemplified intermediate-pressure turbine shaft has a construction in which multistage blades are assembled in a bilaterally symmetric arrangement so as to total six stages on each side and to be substantially bounded by the laterally central part of this shaft. Although the rotor shaft for each low-pressure turbine is not specifically exemplified, the rotor shaft of any of the high-pressure, intermediate-pressure and low-pressure turbines is formed with a center hole, through which the presence of defects is examined by a ultrasonic test, a visual test and a fluorescent penetrant inspection. Incidentally, numerals 27 in each of Figs. 5 and 6 denote the journal parts of the corresponding rotor shaft.

[0158] Table 3 in Fig. 14 indicates the chemical constituents (weight-%) which were used for the principal components of the high-pressure turbine, intermediate-pressure turbine and low-pressure turbines in an example of this embodiment. In this example, all the high-temperature parts of the high-pressure and intermediate-pressure turbines were made of the steel materials of ferritic crystalline structure which had a coefficient of thermal expansion of 12×10^{-6} (/ °C), so that no problems ascribable to discrepancy in the coefficients of thermal expansion occurred.

[0159] Regarding each of the rotors of the high-pressure and intermediate-pressure portions, an electrode was prepared in such a way that the heat-resisting cast steel mentioned in Table 3 was melted in an amount of 30 (tons) by an electric furnace, that the molten steel was subjected to carbon vacuum deoxidation and then poured into a metal mold, and that the molded steel was forged. Further, the electrode was subjected to electroslag remelting so as to melt from the upper part of the cast steel to the lower part thereof, and the resulting steel was forged into a rotor shape having a maximum diameter of 1050 (mm) and a length of 5700 (mm). The forging was carried out at temperatures of at most 1150 (°C) in orderto prevent any forging cracks. Besides, after the forged steel was annealed, it was heated to 1050 (°C) and was subjected to water spray quenching. Subsequently, the resulting steel was tempered twice at temperatures of 570 (°C) and 690 (°C), and it was machined into the shape shown in Fig. 5 or Fig. 6. In this example, the upper part side of the electroslag ingot was used as the first-stage blade side of the rotor shaft, and the lower part side as used as the final-stage blade side.

[0160] Regarding the blades and nozzles of the high-pressure portion and intermediate-pressure portion, the heat-resisting steel materials also mentioned in Table 3 of Fig. 14 were melted by a vacuum arc furnace, and they were forged and molded into the shapes of blade and nozzle blanks each having a width of 150 (mm), a height of 50 (mm) and a length of 1000 (mm). The forging was carried out at temperatures of at most 1150 (°C) in order to prevent any forging cracks. Besides, the forged steel was heated to 1050 (°C), subjected to oil quenching and tempered at 690 (°C). Subsequently, the resulting steel was machined into the predetermined shapes.

[0161] Regarding the inner casings of the high-pressure portion and intermediate-pressure portion, the casing of each main-steam stop valve and the casing of each steam control valve, the heat-resisting cast steel materials mentioned in Table 3 were melted by an electric furnace and then refined by a ladle. The resulting materials were thereafter poured into sand molds. The cast steel, which did not suffer any casting defects such as shrinkage holes, could be obtained by sufficiently refining and deoxidizing the materials before the pouring. The weldability of each of the casing materials was evaluated in conformity with "JIS Z3158". A preheating temperature, an inter-pass temperature and a post-heating starting temperature were set at 200 (°C), and a post-heating treatment was conducted at 400 (°C) for 30 (minutes). No welding cracks were noted in either of the materials of the present invention, and the weldability was good.

[0162] Table 4 shown in Fig. 15 indicates the heat treatment conditions of the ferritic steel materials listed in Table 3 of Fig. 14, and the mechanical properties of the principal members of the high-temperature steam turbines made of the materials as tested by cutting these members.

[0163] From results of the tests of the central parts of the rotor shafts, it has been verified that the special qualities (625-°C 10^5-h strength $\geqq$ 13 kgf/mm^2, and 20-°C absorbed impact energy $\geqq$ 1.5 kg-m) required of the high-pressure and intermediate-pressure turbine rotors can be satisfactorily met. Thus, it has been proved that the steam turbine rotors usable in steam of 620 (°C) or above can be manufactured.

[0164] Besides, as the results of the property tests of the blades, it has been verified that the special quality (625-°C 10^5-h strength $\geqq$ 15 kgf/mm^2) required of the first-stage blades of the high-pressure and intermediate-pressure turbines can be satisfactorily met. Thus, it has been proved that the steam turbine blades usable in steam of 620 (°C) or above can be manufactured.

[0165] Further, as the results of the property tests of the casings, it has been verified that the special qualities (625-°C 10^5-h strength $\geqq$ 10 kgf/mm^2, and 20-°C absorbed impact energy $\geqq$ 1 kg-m) required of the high-pressure and intermediate-pressure turbine casings can be satisfactorily met, and that weld metal materials can be deposited to the casings. Thus, it has been proved that the steam turbine casings usable in steam of 620 (°C) or above can be manufactured.

[0166] Fig. 7 is a graph showing the relationships between the 105-h creep rupture strength and temperature for different rotor shaft materials. It has been found that the materials according to the present invention satisfy the requirements, which the 10^5-h creep rupture strength is equal to or stronger than 13kg/mm^2, at 610 - 640 (°C). Incidentally, the 12Cr rotor material is the prior-art material which contains no B, W or Co.

[0167] In an example of this embodiment, bearing characteristics were improved in such a way that Cr - Mo low-alloy steel was deposited on each journal portion of the rotor shaft by buildup welding. The buildup welding was carried out as stated below.

[0168] Welding rods employed in the buildup welding were shielded-arc ones having diameters of 4.0 (mm). Table 5 shown in Fig. 16 indicates the chemical constituents (weight-%) of deposited metals which were formed by the welding operations with the shielded-arc welding rods. The constituents of the deposited metals were substantially the same as those of the corresponding weld metals (which shall be called the "welding rods A - D" below).

[0169] The conditions of the buildup welding were a welding current of 170 (A), a voltage of 24 (V) and a rate of 26 (cm/min).

[0170] Eight layers were welded onto the surface of the parent metal described before, as the buildup welding by combining the used welding rods A - D for the respective layers as listed in Table 6 of Fig. 17. The thickness of each layer was 3 - 4 (mm), the total thickness of the eight layers forming each of samples Nos. 1 - 3 was about 28 (mm), and the surface of each sample was ground to about 5 (mm).

[0171] As the conditions of execution of the welding operations, a preheating temperature, an inter-pass temperature and a stress-relief-annealing (SR) starting temperature were 250 - 350 (°C), and the SR was conducted by holding the deposited layers at 630 (°C) for 36 (hours).

[0172] All the samples Nos. 1 - 3 conformed to the present invention, and the chemical constituents of the fifth layer et seq. in each sample were C or D mentioned in Table 5 of Fig. 16.

[0173] In order to confirm the quality of such a welding zone, buildup welding was similarly conducted on a flat member, and the resulting flat member was subjected to a side-bend test of 160°. All this time, no cracks were noted in the welding zone.

[0174] Further, when the bearings were subjected to a slide test on the basis of the revolutions of the rotor shafts in the present invention, none of them were adversely affected. The oxidation resistances of the bearings were also excellent.

[0175] Apart from this embodiment, it is possible to similarly construct a tandem type power plant in which the high-pressure turbine, intermediate-pressure turbine and one or two low-pressure turbines are joined in tandem so as to rotate a single generator at 3600 (r/ min).

[0176] Table 7 in Fig. 18 lists the chemical constituents of the Ni-based precipitation-strengthened alloys each of which was applied to the first - third stages of the moving blades in the high-pressure turbine and the first stage of the moving blades in the intermediate-pressure turbine. Each of these alloys was produced in such a way that an ingot was prepared by vacuum arc remelting, followed by hot forging, that the hot-forged ingotwas subsequently heated at 1,070 - 1,200 (°C) for 1 - 8 (hours) In accordance with the alloy composition of the pertinent alloy as a treatment for turning the ingot into a solid solution, followed by air cooling, and that the air-cooled material was heated at 700 - 870 (°C) for 4 - 24 (hours) as an ageing treatment.

(Embodiment 2)

[0177] Each of a number of alloys, having chemical constituents listed in Table 8 of Fig. 19, was cast into an ingot of 10 (kg) by vacuum induction melting, and the ingot was forged into a rod of 30 (mm-square). Table 9 of Fig. 20 indicates the ratios of percentages of the constituents. Regarding the rotor shaft of a large-sized steam turbine, each of the alloys was quenched under the conditions of 1050 (°C) × 5 (hours) and 100 (°C/h) cooling and was subjected to primary tempering of 570 (°C) × 20 (hours) and the secondary tempering of 690 (°C) × 20 (hours), by simulating the central part of the rotor shaft. On the other hand, regarding the blade of the turbine, each alloy was quenched under the condition of 1100 (°C) × 1 (hour) and was tempered under the condition of 750 (°C) × 1 (hour). Thereafter, the creep rupture tests of such alloys were executed under the conditions of 625 (°C) and 30 (kgf/mm^2). The results obtained are also listed in Table 8 of Fig. 19.

[0178] It is seen from Table 8 that the alloys No. 1 - No. 9 according to the present invention have a much longer creep rupture lifetime than the comparative alloy No. 10.

[0179] Incidentally, the comparative alloy No. 10 does not contain Co unlike the alloys of the present invention.

[0180] Figs. 8 and 9 are graphs showing those influences of the Co content and B content of the alloys (listed in Table 8 of Fig. 19) which are respectively exerted on the creep rupture strength.

[0181] As shown in Fig. 8, the creep rupture time period of the alloy becomes longer with increase in the Co content. However, the increase of the Co content by a large amount is unfavorable for the reason that the alloy is liableto become brittle when heated at 600-660 (°C). In order to enhance both the strength and toughness of the alloy, therefore, the Co content should preferably be 2 - 5 (%) for 620 - 630 (°C) and 5.5 - 8 (%) for 630 - 660 (°C) .

[0182] As shown in Fig. 9, the strength of the alloy is prone to lower with increase in the B content. It is understood that the alloy exhibits a superior strength when the B content is 0.03 (%) or below. The strength is increased by setting the B contentto 0.001 - 0.01 (%) and the Co content to 2 - 4 (%) in a temperature range of 620 - 630 (°C), and by increasing the B content to 0.01 - 0.03 (%) and the Co content to 5 - 7.5 (%) on a higher temperature side of 630 - 660 (°C).

[0183] It has been revealed that the alloy is strengthened more by a lower N content at the temperatures exceeding 600 (°C) in this embodiment. This is also apparent from the fact that sample No. 2 in Table 8 of Fig. 19 exhibits a higher strength than sample No. 8 having a higher N content. The N content of the alloy should preferably be 0.01 - 0.04 (%).

Since the constituent N was hardly contained by the vacuum melting, the parent alloy was doped with the element N.

[0184] It is seen from Fig. 7 concerning Embodiment 1 that all the alloys according to the present invention as listed in Table 8 exhibit high strengths. The rotor material indicated in Embodiment 1 corresponds to the alloy of the sample No. 2 in this embodiment.

[0185] As shown in Fig. 9, the sample No. 8 having a low Mn content of 0.09 (%) exhibits a higher strength, subject to equal Co contents. As is also apparent from this fact, the Mn content of the alloy should preferably be set at 0.03 - 0.20 (%) in order to attain a higher strength.

(Embodiment 3)

[0186] Table 10 shown in Fig. 21 indicates chemical constituents (weight-%) which concern the inner casing materials of the present invention. With the thick part of a large-sized casing assumed, the ingot of each of the listed samples was prepared in such a way that each alloy was melted in an amount of 200 (kg) by a highfrequency induction furnace, and that the molten alloy was poured into a sand mold having a maximum thickness of 200 (mm), a width of 380 (mm) and a height of 440 (mm). The samples Nos. 3 - 7 are materials according to the present invention, whereas the samples Nos. 1 and 2 are materials of the prior art. The materials of the samples Nos. 1 and 2 are Cr-Mo-V cast steel and 11Cr-1 Mo-V-Nb-N cast steel respectively which are currently used in turbines. After having been annealed by furnace cooling of 1050 (°C) × 8 (h), the samples were heat-treated (normalized and tempered) under the following conditions, assuming the thick part of the casing of the large-sized steam turbine:

Sample No. 1:

Air cooling of 1050 (°C) × 8 (h)
Air cooling of 710 (°C) × 7 (h)
Air cooling of 710 (°C) × 7 (h)

Samples No. 2 - No. 7:

Air cooling of 1050 (°C) × 8 (h)
Air cooling of 710 (°C) × 7 (h)
Air cooling of 710 (°C) × 7 (h)

[0187] The weldability of each of the samples was evaluated in conformity with "JIS Z3158". A preheating temperature, an inter-pass temperature and a post-heating starting temperature were set at 150 (°C), and a post-heating treatment was conducted at 400 (°C) for 30 (minutes).

[0188] Table 11 shown in Fig. 21 indicates the test results of the samples Nos. 1 - 7 listed in Table 10 of Fig. 21, concerning tensile characteristics at room temperature, V-notch Charpy impact absorption energy at 20 (°C), a 650-°C 10^5-h creep rupture strength, and a welding crack.

[0189] The creep rupture strength and the absorbed impact energy of each of the materials of the present invention (samples Nos. 3, 4, 6 and 7) doped with appropriate amounts of B, Mo and W, fully satisfy the special qualities (625-°C 10^5-h strength ≧ 8 kgf/mm^2, and 20-°C absorbed impact energy ≧ 1 kg-m) required of the high-temperature high-pressure turbine casing. Especially, the samples Nos. 3, 6 and 7 exhibit high strengths exceeding 9 (kgf/mm^2). Moreover, none of the materials of the present invention (except the sample No. 3) suffer from welding cracks and all have good weldability. As the result of a test concerning the relationship between the B content and the welding crack of the alloy, when the B content exceeded 0.0035 (%), the welding crack appeared. The alloy of the sample No. 3 was considered to be somewhat cracked. Regarding the influences of the constituent Mo on the mechanical properties, the alloy whose Mo content was as high as 1.18 (%) had a high creep rupture strength, but it exhibited a small impact energy value and could not meet the required toughness. On the other hand, the alloy whose Mo content was 0.11 (%) had a high toughness, but it exhibited a low creep rupture strength and could not meet the required strength.

[0190] As the result of the investigation of the influences of the constituent W on the mechanical properties, when the W content exceeds 1.1 (%), the creep rupture strength becomes remarkably high, but when it exceeds 2 (%), the room-temperature absorbed impact energy becomes low. Especially, the Ni/W ratio of the alloy is controlled to 0.25 - 0.75, thereby obtaining the casing material of the heat-resisting cast steel which meets a 625 °C 10^5-h creep rupture strength of at least 9 (kgf/mm^2) and a room-temperature absorbed impact energy of at least 1 (kgf-m) that are required of the high-pressure and intermediate-pressure inner casings, and main-steam stop valve and control valve casings of the high-temperature high-pressure turbine under a pressure of at least 250 (kgf/cm^2) at a temperature of 621 (°C). Especially, the W content and the Ni/W ratio are respectively controlled to 1.2 - 2 (%) and 0.25 - 0.75, thereby obtaining the excellent casing material of the heat-resisting cast steel which meets a 625-°C 10^5-h creep rupture strength of at least 10 (kgf/mm^2) and a room-temperature absorbed impact energy of at least 2 (kgf-m).

[0191] Fig. 10 is a graph showing the relationship between the W content and the creep rupture strength for the alloys explained above. As indicated in the figure, when the W content is at least 1.0 (%), the strength is remarkably increased, and a value of at least 8.0 (kg/mm^2) is attained, especially for a W content of at least 1.5 (%).

[0192] Fig. 11 is a graph showing the relationship between the 10^5-hour creep rupture strength and the rupture temperature for the alloys explained above. The alloy of the sample No. 7 in the present invention satisfactorily meets the required strength at temperatures of, at most, 640 (°C).

[0193] In an example, alloying raw materials to be brought into the desired composition of the heat-resisting cast steel in the present invention were melted in an amount of 1 (ton) by an electric furnace and then refined by a ladle, and the resulting raw materials were thereafter poured into a sand mold. Thus, the inner casing for the high-pressure portion or intermediate-pressure portion as described in Embodiment 1 was obtained.

[0194] After having been annealed by furnace cooling of 1050 (°C) × 8 (h), the cast steel stated above was normalized by air-blast quenching of 1050 (°C) × 8 (h) and was tempered twice by furnace cooling of 730 (°C) × 8 (h). The casing which was manufactured by way of trial and which had a fully-tempered martensitic structure, was cut and investigated. As a result, itwasverified that the manufactured casing fully satisfies the special qualities (625-°C 10^5-h strength ≧ 9 kgf/mm^2, and 20-°C absorbed impact energy ≧ 1 kg-m) required of the casing of the high-temperature high-pressure turbine of 250 (atm.) and 625 (°C), and that it can be subjected to welding.

(Embodiment 4)

[0195] This embodiment sets the steam temperature of a high-pressure steam turbine and an intermediate-pressure steam turbine at 649 (°C) in place of 625 (°C) in Embodiment 1, and the construction and size thereof are obtained by substantially the same design as in Embodiment 1. Different here from Embodiment 1 are the rotor shafts, first-stage moving blades, first-stage fixed blades and inner casings of the high-pressure and intermediate-pressure steam turbines that come into direct contact with the steam of the above temperature. In the materials of these components except the inner casings, the B content and the Co content are respectively increased to 0.01 - 0.03 (%) and 5 - 7 (%) in the foregoing materials listed in Table 8 of Fig. 19. Further, as the material of the inner casings, the W content of the material in Embodiment 1 as indicated in Table 3 of Fig. 14 is increased to 2 - 3 (%), and Co is added 3 (%). In this way, required strengths are fulfilled, and the design in the prior art can be used very meritoriously. More specifically, in this embodiment, the design concept in the prior art as it is can be used in the point that all the structural materials to be exposed to the high temperature are formed of ferritic steel. By the way, since the second-stage moving blades and fixed blades of the high-pressure and intermediate-pressure steam turbines are subject to steam inlet temperatures of about 610 (°C), the material used for the first stage in Embodiment 1 should preferably be employed for these components.

[0196] Further, the steam temperature of low-pressure steam turbines in this embodiment becomes about 405 (°C) which is somewhat higher than about 380 (°C) in Embodiment 1. However, since the material in Embodiment 1 has a satisfactorily high strength for the rotor shafts themselves of the low-pressure steam turbines, the same superclean material (high purity material) is employed.

[0197] Still further, although a turbine configuration in this embodiment is of the cross-compound type, the tandem type in which all the turbines are directly connected can also be realized at a rotational speed of 3600 (r.p. m.).

[0198] The present invention thus far described brings forth effects as stated below.

[0199] According to the present invention, it is possible to obtain heat-resisting martensitic cast steel the creep rupture strength and room-temperature toughness of which are high at 610 - 660 (°C). Therefore, all principal members for ultra-supercritical pressure turbines at individual temperatures can be made of heat-resisting ferritic steel, the basic designs of prior-art steam turbines can be used as they are, and a thermal power plant of high reliability can be built.

[0200] Heretofore, an austenitic alloy has been inevitably used at such temperatures. It has therefore been impossible to manufacture a nondefective large-sized rotor, from the viewpoint of manufactural properties. In contrast, according to heat-resisting ferritic forged steel of the present invention, the nondefective large-sized rotor can be manufactured.

[0201] Moreover, the high-temperature steam turbine made entirely of the ferritic steel according to the present invention does not use the austenitic alloy which has a large coefficient of thermal expansion. Therefore, the steam turbine has such advantages as being rapidly started with ease and being less susceptible to thermal fatigue damage.

Claims

1. A steam turbine having a rotor shaft (23, 24), moving blades (16, 17) which are assembled on said rotor shaft, fixed blades which guide an inflow of steam to said moving blades (16, 17) and an inner casing (18; 20, 21) which holds said fixed blades,

said steam flowing into a first stage of said moving blades (16, 17) at a temperature of 610 to 660°C, and
parts of said turbine being made of a ferritic heat resisting steel containing 9 to 13% by weight of Cr,
wherein said moving blades (16, 17), said fixed blades and said inner casing (18; 20, 22) are made of martensitic steel which contains 8 to 13% by weight of Cr, and
said rotor shaft (23, 24) is made of high-strength-martensitic steel of fully-tempered martensitic structure which exhibits a 10^5-hour creep rupture strength of at least 15 kg/mm^2 at a temperature corresponding to said steam temperature, and which contains 9 to 13 % by weight of Cr, 0.05 - 0.20 % of C, at most 0.15 % of Si, 0.03 - 1.5 % of Mn, 0,05 - 1.0 % of Ni, 0.05-0.35 % of V, 0.01 - 0.20 % of Nb, 0.01 - 0.06 % of N, 0.05 - 0.5 % of Mo, 1.0 - 3.5 % of W, and which has at least 78 % of Fe, the percentages being given in terms of weight; and
characterized in that
said high-strength martensitic steel of said rotor shaft (23, 24) further contains
for use at a steam temperature of 610 - 630°C: 2 - 5 % of Co and 0.0005 - 0.01 % of B; and
for use at a steam temperature of 630 - 660°C: 5 - 10 % of Co and 0.01 - 0.03 % of B,
the percentages being given in terms of weight.

2. The steam turbine of claim 1, wherein said inner casing (18; 20, 21) is made of martensitic steel which exhibits a 10^5-hour creep rupture strength of at least 10 kg/mm^2 at a temperature corresponding to said inflowing steam temperature.

3. The steam turbine of claims 1 or 2, wherein said moving blades (16, 17) and/or said fixed blades of at least said first stage are made of martensitic steel which exhibits a 10^5-hour creep rupture strength of at least 15 kg/mm^2 at a temperature corresponding to said inflowing steam temperature of said first stage, or which exhibits an anti-tension of at least 90 kg/mm^2 at room temperature.

4. The steam turbine of claims 1 or 2, wherein the first-stage blades of said moving blades (16, 17) are made of Ni-based deposited strengthen alloy which exhibits an anti-tension of at least 100 kg/mm^2 at room temperature.

5. The steam turbine of any one of claims 1 to 4, wherein
said inner casing (18; 20, 21) is made of high-strength martensitic steel which contains 0.06 - 0.16 % of C, at most 0.5 % of Si, at most 1 % of Mn, 0.2 - 1.0 % of Ni, 8- 12 % of Cr, 0,05 - 0.35 % of V, 0.01 - 0.15 % of Nb, 0.01 -0.1 % of N, at most 1.5 % of Mo, 1 - 4 % of W and 0.0005 - 0.03 % of B, and which has at least 85 % of Fe, the percentages being given in terms of weight.

6. The steam turbine of any one of claims 1 to 5 for use in high-pressure applications, wherein said moving blades (16) are arranged including at least 7 stages on each side in a lengthwise direction of said rotor shaft (23), except a first stage which is of double flow; and said rotor shaft (23) has a distance (L) of at least 5000 mm between centers of bearings in which it isjournaled, and a minimum diameter (D) of at least 600 mm at its parts which corrrespond to said fixed blades, a ratio (UD) between the distance (L) and the diameter (D) being 8.0 - 9.0.

7. The steam turbine of anyone of claims 1 to 5 for use in intermediate-pressure applications, wherein said moving blades (17) have a double-flow construction in which at least 6 stages are included on each side in a lengthwise direction of said rotor shaft (24), in a bilaterally symmetrical arrangement on both sides, and in which the first stages of the arrangement are assembled on a central part of said rotor shaft (24) in the lengthwise direction; and said rotor shaft (24) has a distance (L) of at least 5000 mm between centers of bearings in which it is journaled, and a minimum diameter (D) of at least 600 mm at its parts which correspond to said fixed blades, a ratio (L/D) between the distance (L) and the diameter (D) being 8.2 - 9.2.

8. The steam turbine of anyone of claims 1 to 6 for use in high-pressure applications wherein said moving blades (16) are arranged including at least 7 stages in a manner that lengths of said moving blades become longer from an upstream side of the steam flow to a downstream side thereof, namely, a first stage of said moving blades being no shorter than 35 mm and a final stage of said moving blades no longer than 210 mm; diameters of those parts of said rotor shaft (23) on which said moving blades are assembled are larger than diameters of those parts of said rotor shaft (23) which correspond to said fixed blades; and widths of the respective stages of the moving-blade assembling parts of said rotor shaft in an axial direction of said rotor shaft (23) are larger on the downstream side than on the upstream side, and the ratios of these widths to the lengths of said moving blades are smaller in said downstream side than said upstream side within a range of 0.6 to 1.0.

9. The steam turbine of anyone of claims 1 to 6 or 8 for use in high-pressure applications, wherein said moving blades

(16) are arranged including at least 7 stages in a manner that lengths of said moving blades become longer from an upstream side of the steam flow to a downstream side thereof, namely, a first stage of said moving blades (16) being no shorterthan 35 mm and a final stage of said moving blades (16) being no longer than 210 mm; ratios between the lengths of said moving blades of the respectively adjacent stages are at most 1.2; and said ratios are larger in said downstream side than said upstream side.

10. The steam turbine of anyone of claims 1 to 6, 8 or 9 for use in high-pressure application, wherein said moving blades (16) are arranged including at least 7 stages, in a manner that lengths of said moving blades become longer from an upstream side of the steam flow to a downstream side thereof, namely, a first stage of said moving blades being no shorter than 35 mm and a final stage of said moving blades being no longer than 210 mm; and diameters of those parts of said rotor shaft (23) which correspond to said fixed blades are smaller than the diameters of said moving blades assembling portions, and widths of those parts of said rotor shaft (23) which correspond to said fixed blades, the widths being taken in an axial direction of said rotor shaft, are smaller on the downstream side than on the upstream side, and the ratios of these widths to the lengths of the downstream-side moving blades (16) of the corresponding portion decrease toward said downstream side within a range of 0.65 to 1.8.

11. The steam turbine of anyone of claims 1 to 5 or 7 for use in intermediate-pressure applications, wherein said moving blades (17) have a double-flow construction in which at least 6 stages are included on each of two sides in a lengthwise direction of said rotor shaft (24), in a bilaterally symmetrical arrangement on both sides and lengths of said moving blades become longer from an upstream side of the steam flow to a downstream side thereof, namely, a first stage of said moving blades (17) being no shorter than 90 mm and a final stage of said moving blades (17) being no longer than 350 mm; diameters of those parts of said rotor shaft (24) on which said moving blades (17) are assembled are larger than diameters of those parts of said rotor shaft which correspond to said fixed blades; and widths of the moving-blade assembling parts of said rotor shaft in an axial direction of said rotor shaft are larger on the downstream side than on the upstream side, and the ratios of these widths to the lengths of said moving blades decrease from said upstream side toward said downstream side within a range of 0.45 to 0.75.

12. The steam turbine of anyone of claims 1 to 5, 7 or 11 for use in intermediate-pressure applications, wherein said moving blades (17) have a double-flow construction in which at least 6 stages are included on each of two sides in a lengthwise direction of said rotor shaft (24), in a bilaterally symmetrical arrangement on both sides, and lengths of said moving blades (17) become longer from an upstream side of the steam flow to a downstream side thereof, namely, a first stage of said moving blades being no shorter than 90 mm and a final stage of said moving blades being no longer than 350 mm; and the lengths of the respectively adjacent moving blades are larger on the downstream side than on the upstream side, and the ratios of the lengths of adjacent blades are at most 1.3 and increase gradually toward said downstream side.

13. The steam turbine of anyone of claims 1 to 5 or 7, 11 or 12 for use in intermediate-pressure applications, wherein said moving blades (17) have a double-flow construction in which at least 6 stages are included on each of two sides in a lengthwise direction of said rotor shaft (24), in a bilaterally symmetrical arrangement on both sides, and lengths of said moving blades (17) become longer from an upstream side of the steam flow to a downstream side thereof, namely, a first stage of said moving blades being no shorter than 90 mm and a final stage of said moving blades being no longer than 350 mm; and diameters of those parts of said rotor shaft (24) which correspond to said fixed blades being smaller than the diameters of said moving blades assembling portion of rotor shaft, and widths of those parts of said rotor shaft (24) which correspond to said fixed blades, the widths being taken in an axial direction of said rotor shaft, are smaller on the downstream side than on the upstream side, and the ratios of these widths to the lengths of the downstream-side moving blades of the corresponding portion decrease toward said downstream side within a range of 0.45 to 1.60.

14. The steam turbine of anyone of claims 1 to 6, 8 to 10 for use in high-pressure applications, wherein said moving blades (16) are arranged including at least 7 stages; diameters of those parts of said rotor shaft (23) which correspond to said fixed blades are smaller than diameters of those parts of said rotor shaft which correspond to the assembled moving blades; widths of the rotorshaft parts corresponding to said fixed blades, in an axial direction of said rotor shaft are stepwise larger on an upstream side of the steam flow than on a downstream side thereof at, at least, 2 of said stages, and the width between the final stage of said moving blades (16) and the stage thereof directly preceding said final stage is 0.75 to 0.95 times as large as the width between the second stage and the third stage of said moving blades; and widths of the rotor shaft parts corresponding to said assembled moving blades, in the axial direction of said rotor shaft, are stepwise larger on the downstream side of said steam flow than on the upstream side thereof at, at least, 3 of said stages, and the axial width of said final stage of said moving blades (16) at the moving blades assembling portion is 1 to 2 times as large as the axial width of said second stage of said moving blades (16) at the moving blades assembling portion.

15. The steam turbine of anyone of claims 1 to 5, 7, 11 to 13 for use in intermediate-pressure applications, wherein said moving blades (17) are arranged including at least 6 stages; diameters of those parts of said rotor shaft (24) which correspond to said fixed blades are smaller than diameters of those parts of said rotor shaft which correspond to the assembled moving blades; widths of the rotor shaft parts corresponding to said fixed blades, in an axial direction of said rotor shaft are stepwise larger on an upstream side of the steam flow than on a downstream side thereof at, at least, 2 of said stages, and the width between the final stage of said moving blades and the stage thereof directly preceding said final stage is 0.6 to 0.8 times as large as the width between the first stage and the second stage of said moving blades; and widths of the rotor shaft parts corresponding to said assembled moving blades, in the axial direction of said rotor shaft, are stepwise larger on the downstream side of said steam flow than on the upstream side thereof at, at least, 2 of said stages, and the axial width of said final stage of said moving blades of the moving blades assembling portion is 0.8 to 2 times as large as the axial width of said first stage of said moving blades of the moving blades assembling portion.

16. A steam-turbine power plant comprising a high-pressure turbine (52), an intermediate-pressure turbine (53) and a low-pressure turbine (54, 55), wherein steam inlets (28, 29) of each of the high-pressure and intermediate-pressure turbines (52, 53) leading to moving blades (16,17) of a first stage included in each of said high-pressure and intermediate-pressure turbines (52, 53) are at a temperature of 610 to 660 °C, the steam inlet of said low-pressure turbine (54, 55) leading to moving blades (41) of a first stage included in said low-pressure turbine is at a temperature of 380 to 475 °C, **characterised in that** said high-pressure turbine (52) is defined in any one of claims 1 to 6, 8 to 10 or 14, and said intermediate-pressure turbine (53) is defined in any one of claims 1 to 5, 7, 11 to 13 or 15.

17. The steam-turbine power plant of claim 16, wherein the first-stage moving blades (16) of said high-pressure turbine (52), and that part of a rotor shaft (23) of said high-pressure turbine on which said first-stage moving blades are assembled are held at metal temperatures which are no more than 40°C lower than a temperature of said steam inlet of said high-pressure turbine leading to said first-stage moving blades; and the first-stage moving blades (17) of said intermediate-pressure turbine (53), and that part of a rotor shaft (24) of said intermediate-pressure turbine on which said first-stage moving blades are assembled are held at metal temperature which is no more than 75°C lower than a temperature of said steam inlet of said intermediate-pressure turbine leading to said first-stage moving blades.

18. A coal-fired steam turbine power plant comprising a coal-fired boiler (51), steam turbines (52, 53, 54, 55) which are driven by steam generated by the boiler (51) and one or two generators (68) which are driven by said steam turbines generating an output of at least 1,000 MW, **characterised in that** said steam turbines include a high-pressure turbine (52.) defined in any one of claims 1 to 6, 8 to 10 or 14, an intermediate-pressure turbine (53) defined in any one of claims 1 to 5, 7, 11 to 13 or 15, said intermediate-pressure turbine (53) being joined to said high-pressure turbine (52), and two low-pressure turbines (54, 55), the steam inlets (28, 29) of each of said high-pressure and intermediate pressure turbines (52, 53) leading to moving blades (16, 17) of a first stage being at a temperature of 610 to 660°C, the steam inlet of said low pressure turbine (54, 55) leading to moving blades (41) of a first stage being at a temperature of 380 to 450°C, and said first stage of said moving blades (16, 17) of said high-pressure turbine (52) and/or of said intermediate-pressure turbine (53) being as defined in claims 3 or 4.

19. The coal-fired steam-turbine power plant of claim 18, wherein the steam heated by a superheater (66) of said boiler (51) to a temperature which is at least 3°C higher than the temperature of said steam inlet (28) of said high-pressure turbine (52) is caused to flow into said first-stage moving blades (16) of said high-pressure turbine (52), the steam leaving said high-pressure turbine (52) is heated by a reheater (66) of said boiler (51) to a temperature which is at least 2°C higherthan the temperature of said steam inlet (29) of said intermediate-pressure turbine (53) leading to the first-stage moving blades (17) thereof, whereupon the heated steam is caused to flow into said first-stage moving blades of said intermediate-pressure turbine, and the steam leaving said intermediate-pressure turbine is heated by an economiser (64) of said boiler (51) to a temperature which is at least 3°C higherthan the temperature of said steam inlet of said low-pressure turbine (54, 55) leading to the first-stage moving blades (41) thereof, whereupon the heated steam is caused to flow into said first-stage moving blades of said low pressure turbine.

20. The power plant of any one of claims 16 to 19, wherein said low-pressure steam turbine (54, 55) has a rotor shaft (44), moving blades (41) which are assembled on the rotor shaft, fixed blades (42) which guide inflow of steam to the moving blades (41), and an inner casing which holds the fixed blades (42); said moving blades (41) have a double-flow construction in which at least 8 stages are included on each side in a lengthwise direction of said rotor shaft, in a bilaterally symmetrical arrangement on both sides, and in which the first stages of the arrangement are assembled on a central part of said rotor shaft in the lengthwise direction; said rotor shaft has a distance (L) of at least 7000 mm between centers of bearings in which it is journaled, and a minimum diameter (D) of at least 1150 mm at its parts which correspond to said fixed blades, a ratio (UD) between the distance (L) and the diameter (D) being 5.4 to 6.3, and it is made of Ni-Cr-Mo-V low-alloy steel which contains 1 to 2.5 weight-% of Cr and 3.0 to 4.5 weight-% of Ni; and each of the final-stage moving blades of said arrangement has a length of at least 1016 mm (40 inches) and is made of a Ti-based alloy.

21. The power plant of any one of said claims 16 to 20, wherein said low-pressure steam turbine (54, 55) has a rotor shaft (44), moving blades (41) which are assembled on the rotor shaft, fixed blades (42) which guide inflow of steam to the moving blades, and an inner casing which holds the fixed blades; steam inlet of said low-pressure turbine which leads to a first-stage one of said moving blades is at a temperature of 380 - 450°C; and said rotor shaft is made of low-alloy steel which contains 0.2 to 0.3% of C, at most 0.05% of Si, at most 0.1% of Mn, 3.0 to 4.5% of Ni, 1.25 to 2.25% of Cr, 0.07 to 0.20% of Mo, 0.07 to 0.2% of V and at least 92.5% of Fe, the percentages being given in terms of weight.

22. The power plant of any one of claims 16 to 19, wherein said low-pressure steam turbine (54, 55) has a rotor shaft (44), moving blades (41) which are assembled on the rotor shaft, fixed blades (42) which guide inflow of steam to the moving blades, and an inner casing which holds the fixed blades; said moving blades have a double-flow construction in which at least 8 stages are included on each of two sides in a lengthwise direction of said rotor shaft, in a bilaterally symmetric arrangement on both sides and lengths of the said moving blades become longer from an upstream side of the steam flow to a downstream side, namely, a first stage of said moving blades being no shorter than 90 mm and a final stage of said moving blades being no longer than 1300 mm; diameters of those parts of said rotor shaft on which said moving blades are assembled are larger than diameters of those parts of said rotor shaft which correspond to said fixed blades; and widths of the moving-blade assembling parts of said rotor shaft in an axial direction of said rotor shaft are larger on the downstream side than on the upstream side, and the ratios of these widths to the lengths of said moving blades decrease from said upstream side toward said downstream side within a range of 0.15 to 1.0.

23. The power plant of any one of claims 16 to 22, wherein said low-pressure steam turbine (54, 55) has a rotor shaft (44), moving blades (41) which are assembled on the rotor shaft, fixed blades (42) which guide inflow of steam to the moving blades, and an inner casing which holds the fixed blades; said moving blades have a double-flow construction in which at least 8 stages are included on each of two sides in a lengthwise direction of said rotor shaft, in a bilaterally symmetrical arrangement on both sides, and lengths of the said moving blades become longer from an upstream side of the steam flow to a downstream side, namely, a first stage of said moving blade being no shorterthan 90 mm and a final stage of said moving blades being no longer than 1300 mm; and the lengths of said moving blades of the respectively adjacent stages are larger on the downstream side than on the upstream side, and their ratios increase gradually toward said downstream side within a range of 1.2 to 1.7.

24. The power plant of any one of claims 16 to 23, wherein said low-pressure steam turbine (54, 55) has a rotor shaft (45), moving blades (41) which are assembled on the rotor shaft, fixed blades (42) which guide inflow of steam to the moving blades, and an inner casing which holds the fixed blades; said moving blades have a double-flow construction in which at least 8 stages are included on each of two sides in a lengthwise direction of said rotor shaft, in a bilaterally symmetrical arrangement on both sides, and lengths of the said moving blades become longer from an upstream side of the steam flow to a downstream side, namely, a first stage of said moving blade being no shorterthan 90 mm and a final stage of said moving blades being no longer than 1300 mm; and diameters of those parts of said rotor shaft which correspond to said fixed blades being smaller than the diameters of said moving blades assembling portion of rotor shaft, and widths of those parts of said rotor shaft which correspond to said fixed blades, the widths being taken in an axial direction of said rotor shaft, are larger on the downstream side than on the upstream side, and the ratios of these widths to the lengths of the respectively adjacent moving blades of the corresponding portions on said downstream side decrease stepwise toward said downstream side within a range of 0.2 to 1.4.

25. The power plant of any one of claims 16 to 24, wherein said low-pressure steam turbine (54, 55) has a rotor shaft

(44), moving blades (41) which are assembled on the rotor shaft, fixed blades (42) which guide inflow of steam to the moving blades, and an inner casing which holds the fixed blades; said moving blades have a double-flow construction in which at least 8 stages are included on each of two sides in an axial direction of said rotor shaft, in a bilaterally symmetrical arrangement on both sides; diameters of those parts of said rotor shaft which correspond to said fixed blades are smaller than diameters of those parts of said rotor shaft which correspond to the assembled moving blades; widths of the rotor shaft parts corresponding to said fixed blades, in the axial direction of said rotor shaft, are stepwise larger on an upstream side of the steam flow than on a downstream side thereof at, at least, 3 of said stages, and the width between the final stage of said moving blades and the stage thereof directly preceding said final stage is 1.5 to 2.5 times as large as the width between the first stage and the second stage of said moving blades; and widths of the rotor shaft parts corresponding to said assembled moving blades, in said axial direction of said rotor shaft are stepwise larger on the downstream side of said steam flow than on the upstream side thereof at, at least, 3 of said stages, and the axial width of said final stage of said moving blades is 2 to 3 times as large as the axial width of said first stage of said moving blades.

26. The steam-turbine of any one of claims 1 to 15, further comprising buildup welding layers made of metal which has better bearing characteristics than these of a parent metal of said rotor shaft, formed on the surface of each journal portion of said rotor shaft.

27. The steam-turbine of claim 26, wherein said buildup welding layers are formed in the number of at least three.

28. The steam-turbine of claim 27, wherein said buildup welding layers are formed in the number of five to ten.

29. The steam-turbine of any one of claims 26 to 28, wherein the most peripheral layer of said buildup welding layers is made of low-alloy steel which contains 0.5 to 3 weight-% of Cr.

30. The steam-turbine of claim 29, wherein the most peripheral layer of said buildup welding layers is made of low-alloy steel which contains 0.01 to 0.15 weight-% of C, 0.3 to 1 weight-% of Si, 0.3 to 1.5 weight-% of Mn, and 0.5 to 3 weight-% of Cr, 0.1 to 1.5 weight-% of Mo.

Patentansprüche

1. Dampfturbine mit einem Rotorschaft (23, 24), auf dem Rotorschaft angebrachten beweglichen Blättern (16, 17), feststehenden Blättern, die einen Dampf-Zustrom zu den beweglichen Blättern (16, 17) leiten, und einem die feststehenden Blätter haltenden Innengehäuse (18; 20, 21), wobei

der Dampf bei einer Temperatur von 610 bis 660 °C in eine erste Stufe der beweglichen Blätter (16, 17) strömt,

Teile der Turbine aus einem wärmebeständigen ferritischen Stahl mit 9 bis 13 Gew. % Cr hergestellt sind,

die beweglichen Blätter (16, 17), die feststehenden Blätter und das Innengehäuse (18; 20, 22) aus martensitischem Stahl mit 8 bis 13 Gew. % Cr hergestellt sind,

der Rotorschaft (23, 24) aus hochfestem martensitischen Stahl mit voll getemperter martensitischer Struktur hergestellt ist, der eine 10^5-Stunden-Zeitstandfestigkeit von mindestens 15 kg/mm^2 bei einer der genannten Dampftemperatur entsprechenden Temperatur zeigt und der 9 bis 13 Gew. % Cr, 0,05 - 0,20 % C, maximal 0,15 % Si, 0,03 - 1,5 % Mn, 0,05 - 1,0 % Ni, 0,05 - 0,35 % V, 0,01 - 0,20 % Nb, 0,01 - 0,06 % N, 0,05 - 0,5 % Mo, 1,0 - 3,5 % W enthält und mindestens 78 % Fe aufweist, wobei die Prozent-Angaben auf das Gewicht bezogen sind,

dadurch gekennzeichnet, daß

der hochfeste martensitische Stahl des Rotorschafts (23, 24)

zur Verwendung bei einer Dampftemperatur von 610 bis 630 °C 2 - 5 % Co und 0,0005 - 0,01 % B und

zur Verwendung bei einer Dampftemperatur von 630 bis 660 °C 5 - 10 % Co und 0,01 - 0,03 % B

enhält, wobei die Prozent-Angaben auf das Gewicht bezogen sind.

2. Dampfturbine nach Anspruch 1, wobei das Innengehäuse (18; 20, 21) aus martensitischem Stahl hergestellt ist, der eine 10^5-Stunden-Zeitstandfestigkeit von mindestens 10 kg/mm^2 bei einer der Temperatur des zuströmenden Dampfs entsprechenden Temperatur zeigt.

3. Dampfturbine nach Anspruch 1 oder 2, wobei die beweglichen Blätter (16, 17) und/oder die feststehenden Blätter mindestens der ersten Stufe aus martensitischem Stahl hergestellt sind, der eine 10^5-Stunden-Zeitstandfestigkeit von mindestens 15 kg/mm^2 bei einer der Temperatur des zuströmenden Dampfs der ersten Stufe entsprechenden Temperatur zeigt oder bei Raumtemperatur eine Gegenspannung von mindestens 90 kg/mm^2 zeigt.

4. Dampfturbine nach Anspruch 1 oder 2, wobei unter den beweglichen Blättern (16, 17) die Blätter der ersten Stufe aus einer auf Nickel beruhenden abgeschiedenen Verstärkungslegierung hergestellt sind, die bei Raumtemperatur eine Gegenspannung von mindestens 100 kg/mm^2 zeigt.

5. Dampfturbine nach einem der Ansprüche 1 bis 4, wobei
das Innengehäuse (18; 20, 21) aus einem hochfesten martensitischen Stahl hergestellt ist, der 0,06 - 0,16 % C, maximal 0,5 % Si, maximal 1 % Mn, 0,2 - 1,0 % Ni, 8 - 12 % Cr, 0,05 - 0,35 % V, 0,01 - 0,15 % Nb, 0,01 - 0,1 % N, maximal 1,5 % Mo, 1 - 4 % W und 0,0005 - 0,03 % B enthält und mindestens 85 % Fe aufweist, wobei die Prozent-Angaben auf das Gewicht bezogen sind.

6. Dampfturbine nach einem der Ansprüche 1 bis 5 zur Verwendung in Hochdruck-Anwendungen, wobei die beweglichen Blätter (16) mit Ausnahme einer ersten Doppelstrom-Stufen in mindestens 7 Stufen auf jeder Seite in Längsrichtung des Rotorschafts (23) angeordnet sind und der Rotorschaft (23) zwischen der jeweiligen Mitte von Lagern, in denen er wellengelagert ist, einen Abstand (L) von mindestens 5000 mm und an seinen Teilen, die den feststehenden Blättern entsprechen, einen Minimalduchmesser (D) von mindestens 600 mm aufweist, wobei das Verhältnis (L/D) zwischen dem Abstand (L) und dem Durchmesser (D) 8,0 - 9.0 beträgt.

7. Dampfturbine nach einem der Ansprüche 1 bis 5 zur Verwendung in Mitteldruck-Anwendungen, wobei die beweglichen Blätter (17) einen Doppelstrom-Aufbau aufweisen, bei dem auf jeder Seite in Längsrichtung des Rotorschafts (24), in wechselweise symmetrischer Anordnung auf beiden Seiten, 6 Stufen enthalten sind und bei dem die ersten Stufen der Anordnung auf einem Mittelteil des Rotorschafts (24) in Längsrichtung angebracht sind; wobei der Rotorschaft (24) zwischen der jeweiligen Mitte von Lagern, in denen er wellengelagert ist, einen Abstand (L) von mindestens 5000 mm und an seinen Teilen, die den feststehenden Blättern entsprechen, einen Minimalduchmesser (D) von mindestens 600 mm aufweist, wobei das Verhältnis (L/D) zwischen dem Abstand (L) und dem Durchmesser (D) 8,2 - 9.2 beträgt.

8. Dampfturbine nach einem der Ansprüche 1 bis 6 zur Verwendung in Hochdruck-Anwendungen, wobei die beweglichen Blätter (16) so in mindestens 7 Stufen angeordnet sind, daß die jeweilige Länge der beweglichen Blätter von einer stromaufwärts-Seite des Dampfstroms zu dessen stromabwärts-Seite länger wird, wobei eine erste Stufe der beweglichen Blätter nicht kürzer als 35 mm und eine letzte Stufe der beweglichen Blätter nicht länger als 210 mm ist; wobei die Durchmesser derjenigen Teile des Rotorschafts (23), auf denen die beweglichen Blätter angebracht sind, größer als die Durchmesser derjenigen Teile des Rotorschafts (23) sind, die den feststehenden Blättern entsprechen; und wobei in Axialrichtung des Rotorschafts (23) die jeweilige Weite der entsprechenden Stufen der Teile des Rotorschafts zur Anbringung der beweglichen Blätter auf einer stromabwärts-Seite größer als auf einer stromaufwärts-Seite ist und die Verhältnisse dieser Weiten zu den Längen der beweglichen Blätter innerhalb eines Bereichs von 0,6 - 1,0 auf der stromabwärts-Seite kleiner als auf der stromaufwärts-Seite sind.

9. Dampfturbine nach einem der Ansprüche 1 bis 6 oder 8 zur Verwendung in Hochdruck-Anwendungen, wobei die beweglichen Blätter (16) so in mindestens 7 Stufen angeordnet sind, daß die jeweilige Länge der beweglichen Blätter von einer stromaufwärts-Seite des Dampfstroms zu dessen stromabwärts-Seite länger wird, wobei eine erste Stufe der beweglichen Blätter (16) nicht kürzer als 35 mm und eine letzte Stufe der beweglichen Blätter (16) nicht länger als 210 mm ist; wobei die Verhältnisse zwischen den Längen der beweglichen Blätter der jeweils benachbarten Stufen maximal 1,2 betragen und diese Verhältnisse auf der stromabwärts-Seite größer als auf der stromaufwärts-Seite sind.

10. Dampfturbine nach einem der Ansprüche 1 bis 6, 8 oder 9 zur Verwendung in Hochdruck-Anwendungen, wobei die beweglichen Blätter (16) in mindestens 7 Stufen so angeordnet sind, daß die jeweilige Länge der beweglichen Blätter von einer stromaufwärts-Seite des Dampfstroms zu dessen stromabwärts-Seite länger wird, wobei eine erste Stufe der beweglichen Blätter nicht kürzer als 35 mm und eine letzte Stufe der beweglichen Blätter nicht länger als 210 mm ist; wobei die Durchmesser derjenigen Teilen des Rotorschafts (23) die den feststehenden Blättern entsprechen, kleiner als die Durchmesser der Abschnitte zur Anbringung der beweglichen Blätter sind und die in Axialrichtung des Rotorschafts genommene jeweilige Weite derjenigen Teile des Rotorschafts (23), die den feststehenden Blättern entsprechen, auf der stromabwärts-Seite kleiner als auf der stromaufwärts-Seite ist und die Verhältnisse dieser Weiten zu den Längen der stromabwärts-seitigen beweglichen Blätter (16) des entsprechenden Abschnitts innerhalb eines Bereichs von 0,65 - 1,8 zur stromabwärts-Seite hin abnehmen.

11. Dampfturbine nach einem der Ansprüche 1 bis 5 oder 7 zur Verwendung in Mitteldruck-Anwendungen, wobei die beweglichen Blätter (17) einen Doppelstrom-Aufbau aufweisen, bei dem auf jeder von zwei Seiten in Längsrichtung

des Rotorschafts (24), in wechselweise symmetrischer Anordnung auf beiden Seiten, mindestens 6 Stufen enthalten sind und die jeweilige Länge der beweglichen Blätter von einer stromaufwärts-Seite des Dampfstroms zu dessen stromabwärts-Seite länger wird, wobei eine erste Stufe der beweglichen Blätter (17) nicht kürzer als 90 mm und eine letzte Stufe der beweglichen Blätter (17) nicht länger als 350 mm ist; wobei die Durchmesser derjenigen Teile des Rotorschafts (24), auf denen die beweglichen Blätter (17) angebracht sind, größer als die Durchmesser derjenigen Teile des Rotorschafts sind, die den feststehenden Blättern entsprechen; und wobei in Axialrichtung des Rotorschafts die jeweilige Weite der Teile des Rotorschafts zur Anbringung der beweglichen Blätter auf der stromabwärts-Seite größer als auf der stromaufwärts-Seite ist und die Verhältnisse dieser Weiten zu den Längen der beweglichen Blätter innerhalb eines Bereichs von 0,45 - 0,75 von der stromaufwärts-Seite zur stromabwärts-Seite abnehmen.

12. Dampfturbine nach einem der Ansprüche 1 bis 5, 7 oder 11 zur Verwendung in Mitteldruck-Anwendungen, wobei die beweglichen Blätter (17) einen Doppelstrom-Aufbau aufweisen, bei dem auf jeder von zwei Seiten in Längsrichtung des Rotorschafts (24), in wechselweise symmetrischer Anordnung auf beiden Seiten, mindestens 6 Stufen enthalten sind und die jeweilige Länge der beweglichen Blätter von einer stromaufwärts-Seite des Dampfstroms zu dessen stromabwärts-Seite länger wird, wobei eine erste Stufe der beweglichen Blätter nicht kürzer als 90 mm und eine letzte Stufe der beweglichen Blätter nicht länger als 350 mm ist; und wobei die Längen der entsprechenderweise benachbarten beweglichen Blätter auf der stromabwärts-Seite größer als auf der stromaufwärts-Seite sind und die Verhältnisse der Längen benachbarter Blätter maximal 1,3 betragen und zur stromabwärts-Seite stetig zunehmen.

13. Dampfturbine nach einem der Ansprüche 1 bis 5 oder 7, 11 oder 12 zur Verwendung in Mitteldruck-Anwendungen, wobei die beweglichen Blätter (17) einen Doppelstrom-Aufbau aufweisen, in dem auf jeder von zwei Seiten in Längsrichtung des Rotorschafts (24), in wechselweise symmetrischer Anordnung auf beiden Seiten, mindestens 6 Stufen vorhanden sind und die jeweilige Länge der beweglichen Blätter (17) von einer stromaufwärts-Seite des Dampfstroms zu dessen stromabwärts-Seite länger wird, wobei eine erste Stufe der beweglichen Blätter nicht kürzer als 90 mm und eine letzte Stufe der beweglichen Blätter nicht länger als 350 mm ist; wobei die Durchmesser derjenigen Teile des Rotorschafts (24), die den feststehenden Blättern entsprechen, kleiner als die Durchmesser des Abschnitts des Rotorschafts zur Anbringung der beweglichen Blätter sind und die jeweilige in Axialrichtung des Rotorschafts genommene Weite derjenigen Teile des Rotorschafts (24), die den feststehenden Blättern entsprechen, auf der stromabwärts-Seite kleiner als auf der stromaufwärts-Seite ist und die Verhältnisse dieser Weiten zu den Längen der stromabwärts-seitigen beweglichen Blätter des entsprechenden Abschnitts innerhalb eines Bereichs von 0,45 - 1,60 zur stromabwärts-Seite hin abnehmen.

14. Dampfturbine nach einem der Ansprüche 1 bis 6, 8 bis 10 zur Verwendung in Hochdruck-Anwendungen, wobei die beweglichen Blätter (16) in mindestens 7 Stufen angeordnet sind; wobei die Durchmesser derjenigen Teile des Rotorschafts (23) die den feststehenden Blättern entsprechen, kleiner als die Durchmesser derjenigen Teile des Rotorschafts sind, die den angebrachten beweglichen Blättern entsprechen; wobei in Axialrichtung des Rotorschafts die jeweilige Weite der Rotorschaftsteile, die den feststehenden Blättern entsprechen, bei mindestens zwei der Stufen auf einer stromaufwärts-Seite des Dampfstroms schrittweise größer als auf dessen stromabwärts-Seite ist und die Weite zwischen der letzten Stufe der beweglichen Blätter (16) und der der letzten Stufe direkt vorhergehenden Stufe 0,75 - 0,95 mal so groß wie die Weite zwischen der zweiten Stufe und der dritten Stufe der beweglichen Blätter ist; und wobei in Axialrichtung des Rotorschafts die jeweilige Weite der Rotorschaftsteile, die den angebrachten beweglichen Blättern entsprechen, bei mindestens drei der Stufen auf der stromabwärts-Seite des Dampfstroms schrittweise größer als auf dessen stromaufwärts-Seite ist und die axiale Weite der letzten Stufe der beweglichen Blätter (16) am Abschnitt zur Anbringung der beweglichen Blätter 1 bis 2 mal so groß wie die axiale Weite der zweiten Stufe der beweglichen Blätter (16) bei dem Abschnitt zur Anbringung der beweglichen Blätter ist.

15. Dampfturbine nach einem der Ansprüche 1 bis 5, 7, 11 bis 13 zur Verwendung in Mitteldruck-Anwendungen, wobei die beweglichen Blätter (17) in mindestens 6 Stufen angeordnet sind; wobei die Durchmesser derjenigen Teile des Rotorschafts (24), die den feststehenden Blättern entsprechen, kleiner als die Durchmesser derjenigen Teile des Rotorschafts sind, die den angebrachten beweglichen Blättern entsprechen; wobei in Axialrichtung des Rotorschafts die jeweilige Weite derjenigen Rotorschaftsteile, die den feststehenden Blättern entsprechen, bei mindestens zwei der Stufen auf einer stromaufwärts-Seite des Dampfstroms größer als auf dessen stromabwärts-Seite ist und die Weite zwischen der letzten Stufe der beweglichen Blätter und der der letzten Stufe direkt vorhergehenden Stufe 0,6 - 0,8 mal so groß wie die Weite zwischen der ersten Stufe und der zweiten Stufe der beweglichen Blätter ist; und wobei in Axialrichtung des Rotorschafts die jeweilige Weite der Rotorschansteile, die den angebrachten beweglichen Blättern entsprechen, bei mindestens zwei der Stufen auf der stromabwärts-Seite des Dampfstroms schrittweise größer als auf dessen stromaufwärts-Seite ist und die axiale Weite der letzten Stufe der beweglichen Blätter des Abschnitts zur Anbringung der beweglichen Blätter 0,8 - 2 mal so groß wie die axiale Weite der ersten Stufe der beweglichen Blätter des Abschnitts zur Anbringung der beweglichen Blätter ist.

16. Dampfturbinen-Kraftwerk mit einer Hochdruck-Turbine (52), einer Mitteldruck-Turbine (53) und einer Niederdruck-Turbine (54, 55), wobei Dampfeinlässe (28, 29) für jeweils die Hochdruck- und die Mitteldruck-Turbine (52, 53), die jeweils in der Hochdruck- und der Mitteldruck-Turbine (52, 53) zu beweglichen Blättern (16, 17) einer ersten Stufe führen, eine Temperatur von 610 - 660°C aufweisen und der Dampfeinlaß der Niederdruck-Turbine (54, 55), der zu beweglichen Blättern (41) einer ersten Stufe in der Niederdruck-Turbine führt, eine Temperatur von 380 - 475°C aufweist, **dadurch gekennzeichnet, daß** die Hochdruck-Turbine (52) in einem der Ansprüche 1 bis 6, 8 bis 10 oder 14 und die Mitteldruck-Turbine (53) in einem der Ansprüche 1 bis 5, 7, 11 bis 13 oder 15 definiert ist.

17. Dampfturbinen-Kraftwerk nach Anspruch 16, wobei die beweglichen Blätter (16) der ersten Stufe der Hochdruck-Turbine (52) und derjenige Teil eines Rotorschafts (23) der Hochdruck-Turbine, auf dem die beweglichen Blätter der ersten Stufe angebracht sind, bei Metalltemperaturen gehalten sind, die sich nicht mehr als 40 °C unter einer Temperatur des Dampfeinlasses der Hochdruck-Turbine befinden, der zu den beweglichen Blättern der ersten Stufe führt; und wobei die beweglichen Blätter (17) der ersten Stufe der Mitteldruck-Turbine (53) und der Teil eines Rotorschafts (24) der Mitteldruck-Turbine, auf dem die beweglichen Blätter der ersten Stufe angebracht sind, bei einer Metalltemperatur gehalten sind, die sich nicht mehr als 75 °C unter einer Temperatur des Dampfeinlasses der Mitteldruck-Turbine, der zu den beweglichen Blättern der ersten Stufe führt, befindet.

18. Kohlebefeuertes Dampfturbinen-Kraftwerk mit einem kohlegefeuerten Kessel (51), Dampfturbinen (52, 53, 54, 55), die von von dem Kessel (51) erzeugtem Dampf angetrieben werden, und einem oder zwei Generatoren (68) die von von den Dampfturbinen angetrieben werden und eine Ausgabe von mindestens 1000 MW erzeugen, **dadurch gekennzeichnet, daß** die Dampfturbinen eine Hochdruck-Turbine (52) nach einem der Ansprüche 1 bis 6, 8 bis 10 oder 14, eine Mitteldruck-Turbine (53) nach einem der Ansprüche 1 bis 5, 7, 11 bis 13 oder 15, wobei die Mitteldruck-Turbine (53) mit der Hochdruck-Turbine (52) verbunden ist, und zwei Niederdruck-Turbinen (54, 55) enthält, wobei sich der jeweilige Dampfeinlaß (28, 29) der Hochdruck- und der Mitteldruck-Turbine (52, 53), der zu beweglichen Blättern (16, 17) einer ersten Stufe führt, auf einer Temperatur von 610 bis 660 °C befindet und sich der Dampfeinlaß der Niederdruck-Turbine (54, 55), der zu beweglichen Blättern (41) einer ersten Stufe führt, auf einer Temperatur von 380 - 450: °C befindet und die erste Stufe der beweglichen Blätter (16, 17) der Hochdruck-Turbine (52) und/oder der Mitteldruck-Turbine (53) nach Anspruch 3 oder 4 definiert ist.

19. Kohlebefeuertes Dampfturbinen-Kraftwerk nach Anspruch 18, wobei der von einem Überhitzer (66) des Kessels (51) auf eine um mindestens 3 °C höhere Temperatur als die Temperatur des Dampfeinlasses (28) der Hochdruck-Turbine (52) erhitzte Dampf in die beweglichen Blätter (16) der ersten Stufe der Hochdruck-Turbine (52) strömen gelassen wird, wobei der die Hochdruck-Turbine (52) verlassende Dampf von einem Wiedererhitzer (66) des Kessels (51) auf eine um mindestens 2 °C höhere Temperatur als die Temperatur des Dampfeinlasses (29) der Mitteldruck-Turbine (53), der zu deren beweglichen Blättern (17) der ersten Stufe führt, erhitzt wird, woraufhin bewirkt wird, daß der erhitzte Dampf in die beweglichen Blätter der ersten Stufe der Mitteldruck-Turbine strömt, und wobei der die Mitteldruck-Turbine verlassende Dampf von einem Abgasvorwärmer (64) des Kessels (51) auf eine um mindestens 3 °C höhere Temperatur als die Temperatur des Dampfeinlasses der Niederdruck-Turbine (54, 55) erhitzt wird, der zu deren beweglichen Blättern der ersten Stufe führt, woraufhin der erhitzte Dampf in die beweglichen Blätter der ersten Stufe der Niederdruck-Turbine strömen gelassen wird.

20. Kraftwerk nach einem der Ansprüche 16 bis 19, wobei die Niederdruck-Dampfturbine (54, 55) einen Rotorschaft (44), auf dem Rotorschaft angebrachte bewegliche Blätter (41), feststehende Blätter (42), die einen Dampf-Zustrom auf die beweglichen Blätter (41) leiten, und ein die feststehenden Blätter (42) haltendes Innengehäuse aufweist; wobei die beweglichen Blätter (41) einen Doppelstrom-Aufbau aufweisen, bei dem auf jeder Seite in Längsrichtung des Rotorschafts, in wechselweise symmetrische Anordnung auf beiden Seiten, mindestens 8 Stufen enthalten sind, wobei die ersten Stufen der Anordnung in Längsrichtung auf einem Mittelteil des Rotorschafts angebracht sind; wobei der Rotorschaft zwischen der jeweiligen Mitte von Lagern, in denen er wellengelagert ist, einen Abstand (L) von mindestens 7000 mm und einen Minimaldurchmesser (D) an seinen den feststehenden Blätter entsprechenden Teilen von mindestens 1150 mm aufweist, wobei ein Verhältnis (L/D) zwischen dem Abstand (L) und dem Durchmesser (D) 5,4 - 6,3 beträgt und wobei er aus niederlegiertem Ni-Cr-Mo-V-Stahl mit 1 bis 2,5 Gew. % Cr und 3,0 bis 4,5 Gew. % Ni hergestellt ist; und wobei die beweglichen Blätter der letzten Stufe der Anordnung jeweils eine Länge von mindestens 1016 mm (40 Zoll) aufweisen und aus einer Legierung auf Ti-

Basis hergestellt sind.

21. Kraftwerk nach einem der Ansprüche 16 bis 20, wobei die Niederdruck-Dampfturbine (54, 55) einen Rotorschaft (44), auf dem Rotorschaft angebrachte bewegliche Blätter (41), feststehende Blätter, (42), die einen Dampf-Zustrom zu den beweglichen Blättern leiten, und ein die feststehenden Blätter haltendes Innengehäuse aufweist; wobei sich der Dampfeinlaß der Niederdruck-Turbine, der zu einem erststufigen der beweglichen Blätter führt, auf einer Temperatur von 380 - 450 °C befindet; und wobei der Rotorschaft aus niederlegiertem Stahl hergestellt ist, der 0,2 - 0,3 % C, maximal 0,05 % Si, maximal 0,1 % Mn, 3,0 bis 4,5 % Ni, 1,25 - 2.25 % Cr, 0,07 - 0,20 % Mo, 0,07 - 0,2 % V und mindestens 92,5 % Fe enthält, wobei die Prozentangaben auf das Gewicht bezogen sind.

22. Kraftwerk nach einem der Ansprüche 16 bis 19, wobei die Niederdruck-Dampfturbine (54, 55) einen Rotorschaft (44), auf dem Rotorschaft angebrachte bewegliche Blätter (41), feststehende Blätter (42), die einen Dampf-Zustrom zu den beweglichen Blättern leiten, und ein die feststehenden Blätter haltendes Innengehäuse aufweist; wobei die beweglichen Blätter einen Doppelstrom-Aufbau aufweisen, bei dem auf jeder von zwei Seiten in Längsrichtung des Rotorschafts, in wechselweise symmetrischer Anordnung auf beiden Seiten, mindestens 8 Stufen enthalten sind und die jeweilige Länge der beweglichen Blätter von einer stromaufwärts-Seite des Dampfstroms zu einer stromabwärts-Seite länger wird, wobei eine erste Stufe der beweglichen Blätter nicht größer als 90 mm und eine letzte Stufe der beweglichen Blätter nicht länger als 1300 mm ist; wobei die Durchmesser derjenigen Teile des Rotorschafts, auf denen die beweglichen Blätter angebracht sind, größer als die Durchmesser derjenigen Teile des Rotorschafts sind, die den feststehenden Blättern entsprechen; und wobei in Axialrichtung des Rotorschafts die jeweilige Weite der Teile des Rotorschafts zur Anbringung der beweglichen Blätter auf der stromabwärts-Seite größer als auf der stromaufwärts-Seite ist und die Verhältnisse dieser Weiten zu den Längen der beweglichen Blätter innerhalb eines Bereichs von 0,15 - 1,0 von der stromaufwärts-Seite zur stromabwärts-Seite hinabnimmt.

23. Kraftwerk nach einem der Ansprüche 16 bis 22, wobei die Niederdruck-Dampfturbine (54, 55) einen Rotorschaft (44), auf dem Rotorschaft angebrachte bewegliche Blätter (41), feststehende Blätter (42), die einen Dampf-Zustrom zu den beweglichen Blättern leiten, und ein die feststehenden Blätter haltendes Innengehäuse aufweist; wobei die beweglichen Blätter einen Doppelstrom-Aufbau aufweisen, der auf jeder von zwei Seiten in Längsrichtung des Rotorschafts, in wechselweise symmetrischer Anordnung auf beiden Seiten, mindestens 8 Stufen enthält, wobei die Längen der beweglichen Blätter von einer stromaufwärts-Seite des Dampfstroms zu einer stromabwärts-Seite länger werden, wobei eine erste Stufe der beweglichen Blätter nicht kürzer als 90 mm und eine letzte Stufe der beweglichen Blätter nicht länger als 1300 mm ist; und wobei die Längen der beweglichen Blätter entsprechenderweise benachbarter Stufen auf der stromabwärts-Seite größer als auf der stromaufwärts-Seite sind und ihre Verhältnisse zur stromabwärts-Seite hin innerhalb eines Bereichs von 1,2 - 1,7 stetig zunehmen.

24. Kraftwerk nach einem der Ansprüche 16 bis 23, wobei die Niederdruck-Dampfturbine (54, 55) einen Rotorschaft (45), auf dem Rotorschaft angebrachte bewegliche Blätter (41), feststehende Blätter (42), die einen Dampf-Zustrom zu den beweglichen Blättern leiten, und ein die feststehenden Blätter haltendes Innengehäuse aufweist; wobei die beweglichen Blätter einen Doppelstrom-Aufbau aufweisen, der auf jeder von zwei Seiten in Längsrichtung des Rotorschafts, in wechselweise symmetrische Anordnung auf beiden Seiten, mindestens 8 Stufen beinhaltet, wobei die Längen der beweglichen Blätter von einer stromaufwärts-Seite des Dampfstroms zu einer stromabwärts-Seite länger werden, wobei eine erste Stufe der beweglichen Blätter nicht kürzer als 90 mm und eine letzte Stufe der beweglichen Blätter nicht länger als 1300 mm ist; und wobei die Durchmesser derjenigen Teile des Rotorschafts, die den feststehenden Blättern entsprechen, kleiner als die Durchmesser des Abschnitts des Rotorschafts zur Anbringung der beweglichen Blätter sind und die jeweilige in Axialrichtung des Rotorschafts genommene Weite derjenigen Teile des Rotorschafts, die den feststehenden Blättern entsprechen, auf der stromabwärts-Seite größer als auf der stromaufwärts-Seite ist und die Verhältnisse dieser Weiten zu den Längen entsprechenderweise benachbarter beweglicher Blätter entsprechender Abschnitte auf der stromabwärts-Seite schrittweise innerhalb eines Bereichs von 0,2 - 1,4 zur stromabwärts-Seite abnehmen.

25. Kraftwerk nach einem der Ansprüche 16 bis 24, wobei die Niederdruck-Dampfturbine (54, 55) einen Rotorschaft (44), auf dem Rotorschaft angebrachte bewegliche Blätter (41), feststehende Blätter (42), die einen Dampf-Zustrom zu den beweglichen Blättern leiten, und ein die feststehenden Blätter haltendes Innengehäuse aufweist; wobei die beweglichen Blätter einen Doppelstrom-Aufbau aufweisen, der auf jeder von zwei Seiten in Axialrichtung des Rotorschafts, in wechselweise symmetrische Anordnung auf beiden Seiten, mindestens 8 Stufen beinhaltet; wobei die Durchmesser derjenigen Teile des Rotorschafts, die den feststehenden Blättern entsprechen, kleiner als die Durchmesser derjenigen Teile des Rotorschafts sind, die den angebrachten beweglichen Blättern entsprechen; wobei die jeweilige Weite in Axialrichtung des Rotorschafts derjenigen Teile des Rotorschafts, die den feststehenden Blättern entsprechen, bei mindestens drei der Stufen auf einer stromaufwärts-Seite des Dampfstroms schrittweise größer als auf dessen stromabwärts-Seite ist und die Weite zwischen der letzten Stufe der beweglichen Blätter und der der letzten Stufe direkt vorausgehenden Stufe 1,5 - 2,5 mal so groß wie die Weite zwischen der ersten Stufe und der zweiten Stufe der beweglichen Blätter ist; und wobei die jeweilige Weite der Rotorschaftsteile, die den angebrachten beweglichen Blättern entsprechen, bei mindestens drei der Stufen in Axialrichtung des Rotorschafts auf der stromabwärts-Seite des Dampfstroms schrittweise größer als auf dessen stromaufwärts-Seite ist und die Axialweite der letzten Stufe der beweglichen Blätter 2 bis 3 mal so groß wie die Axialweite der ersten Stufe der beweglichen Blätter ist.

26. Dampfturbine nach einem der Ansprüche 1 bis 15 mit aufgebrachten Schweißschichten, die aus einem Metall mit besseren Lagereigenschaften als ein Muttermetall des Rotorschafts hergestellt sind und auf der Oberfläche jedes Wellenlagerabschnitts des Rotorschafts ausgebildet sind.

27. Dampfturbine nach Anspruch 26, wobei mindestens drei aufgebrachte Schweißschichten gebildet sind.

28. Dampfturbine nach Anspruch 27, wobei 5 bis 10 aufgebrachte Schweißschichten ausgebildet sind.

29. Dampfturbine nach einem der Ansprüche 26 bis 28, wobei die äußerste Schicht der aufgebrachten Schweißschichten aus einem niederlegierten Stahl mit 0,5 bis 3 Gew. % Cr hergestellt ist.

30. Dampfturbine nach Anspruch 29, wobei die äußerste Schicht der aufgebrachten Schweißschichten aus einem niederlegierten Stahl mit 0,01 bis 0,15 Gew. % C, 0,3 bis 1 Gew.Si, 0,3 bis 1,5 Gew. % Mn und 0,5 bis 3 Gew. % Cr sowie 0,1 bis 1,5 Gew. % Mo hergestellt ist.

Revendications

1. Turbine à vapeur ayant un arbre de rotor (23, 24), des aubes mobiles (16, 17) qui sont assemblées sur ledit arbre de rotor, des aubes fixes qui guident un écoulement de vapeur entrante vers lesdites aubes mobiles (16, 17) et un carter intérieur (18 ; 20, 21) qui maintient lesdites aubes fixes,

ladite vapeur s'écoulant dans un premier étage desdites aubes mobiles (16, 17) à une température comprise entre 610 et 660°C, et

des parties de ladite turbine étant constituées d'un acier ferritique résistant à la chaleur contenant 9 à 13 % en poids de Cr,

lesdites aubes mobiles (16, 17), lesdites aubes fixes et ledit carter intérieur (18 ; 20, 22) étant constitués d'acier martensitique qui contient 8 à 13 % en poids de Cr, et

ledit arbre de rotor (23, 24) étant constitué d'acier martensitique à résistance élevée ayant une structure martensitique entièrement trempée qui présente une résistance à la rupture par fluage à 10^5 heures d'au moins 15 kg/ mm^2 à une température correspondant à ladite température de vapeur, et qui contient de 9 à 13 % en poids de Cr, de 0,05 à 0,20 % de C, au plus 0,15 % de Si, de 0,03 à 1,5 % de Mn, de 0,05 à 1,0 % de Ni, de 0,05 à 0,35 % de V, de 0,01 à 0,20 % de Nb, de 0,01 à 0,06 % de N, de 0,05 à 0,5 % de Mo, de 1,0 à 3,5 % de W, et qui a au moins 78 % de Fe, les pourcentages étant donnés en termes de poids, et

caractérisée en ce que

ledit acier martensitique à résistance élevée dudit arbre de rotor (23, 24) contient en outre

pour une utilisation à une température de vapeur comprise entre 610 et 630°C : de 2 à 5 % de Co et de 0,0005 à 0,01 % de B, et

pour une utilisation à une température de vapeur comprise entre 630 et 660°C : de 5 à 10 % de Co et de 0,01 à 0,03 % de B,

les pourcentages étant donnés en termes de poids.

2. Turbine à vapeur selon la revendication 1, dans laquelle ledit carter intérieur (18 ; 20, 21) est constitué d'acier martensitique qui présente une résistance à la rupture par fluage à 10^5 heures d'au moins 10 kg/mm^2 à une température correspondant à ladite température de vapeur entrante.

3. Turbine à vapeur selon la revendication 1 ou 2, dans laquelle lesdites aubes mobiles (16, 17) et/ou lesdites aubes fixes d'au moins ledit premier étage sont constituées d'acier martensitique qui présente une résistance à la rupture par fluage à 10^5 heures d'au moins 15 kg/mm à une température correspondant à ladite température de vapeur entrante dudit premier étage, et qui présente une anti-traction d'au moins 90 kg/mm^2 à la température ambiante.

4. Turbine à vapeur selon la revendication 1 ou 2, dans laquelle les aubes de premier étage parmi lesdites aubes mobiles (16, 17) sont constituées d'alliage renforcé à base de nickel, déposé, qui présente une anti-traction d'au moins 100 kg/mm^2 à température ambiante.

5. Turbine à vapeur selon l'une quelconque des revendications 1 à 4, dans laquelle ledit carter intérieur (18 ; 20, 21) est constitué d'acier martensitique à résistance élevée qui contient de 0,06 à 0,16 % de C, au plus 0,5 % de Si, au plus 1 % de Mn, de 0,2 à 1,0 % de Ni, de 8 à 12 % de Cr, de 0,05 à 0,35 % de V, de 0,01 à 0,15 % de Nb, de 0,01 à 0,1 % de N, au plus 1,5 % de Mo, de 1 à 4 % de W, et de 0,0005 à 0,03 % de B, et qui a au moins 85 % de Fe, les pourcentages étant donnés en termes de poids

6. Turbine à vapeur selon l'une quelconque des revendications 1 à 5, destinée à être utilisée dans des applications haute-pression, dans laquelle lesdites aubes mobiles (16, 17) sont agencées en incluant au moins 7 étages de chaque côté dans la direction longitudinale dudit arbre de rotor (23), à l'exception d'un premier étage qui est à écoulement double, et ledit arbre de rotor (23) a une distance (L) d'au moins 5000 mm entre les centres des paliers dans lesquels il est tourillonné, et un diamètre minimum (D) d'au moins 600 mm au niveau de ses parties qui correspondent auxdites aubes fixes, un rapport (L/D) entre la distance (L) et le diamètre (D) étant de 8,0 à 9,0.

7. Turbine à vapeur selon l'une quelconque des revendications 1 à 5, destinée à être utilisée dans des applications à pression intermédiaire, dans laquelle lesdites aubes mobiles (17) ont une construction à double écoulement dans laquelle au moins 6 étages sont inclus de chaque côté dans la direction longitudinale dudit arbre de rotor (24), selon un agencement bilatéralement symétrique sur les deux côtés, et dans lequel les premiers étages de l'agencement sont assemblés sur une partie centrale dudit arbre de rotor (24) dans la direction longitudinale, et ledit arbre de rotor (24) a une distance (L) d'au moins 5000 mm entre les centres des paliers dans lesquels il est tourillonné, et un diamètre minimum (D) d'au moins 600 mm au niveau de ses parties qui correspondent auxdites aubes fixes, un rapport (L/D) entre la distance (L) et le diamètre (D) étant de 8,2 à 9,2.

8. Turbine à vapeur selon l'une quelconque des revendications 1 à 6, destinée à être utilisée dans des applications haute-pression dans laquelle lesdites aubes mobiles (16) sont agencées en incluant au moins 7 étages d'une manière telle que les longueurs desdites aubes mobiles deviennent plus longues à partir d'un côté amont de l'écoulement de vapeur vers un côté aval de celui-ci, c'est-à-dire qu'un premier étage dédites aubes mobiles n'étant pas plus courtes que 35 mm et un étage final desdites aubes mobiles n'étant pas plus longues que 210 mm, les diamètres des parties dudit arbre de rotor (23) sur lesquelles lesdites aubes mobiles sont assemblées sont plus grands que les diamètres des parties dudit arbre de rotor (23) qui correspondent auxdites aubes fixes, et les largeurs des étages respectifs des parties d'assemblage d'aubes mobiles dudit arbre de rotor dans la direction axiale dudit arbre de rotor (23) sont plus grandes sur le côté aval que sur le côté amont, et les rapports de ces largeurs sur les longueurs desdites aubes mobiles sont plus petits dans ledit côté aval que dans ledit côté amont dans une plage allant de 0,6 à 1,0.

9. Turbine à vapeur selon l'une quelconque des revendications 1 à 6 ou 8, destinée à être utilisée dans des applications haute-pression dans laquelle lesdites aubes mobiles (16) sont agencées en incluant au moins 7 étages d'une manière telle que les longueurs desdites aubes mobiles deviennent plus longues à partir du côté amont de l'écoulement de vapeur vers le côté aval de celui-ci, à savoir, un premier étage dédites aubes mobiles (16) n'étant pas plus courtes que 35 mm et un étage final dédites aubes mobiles (16) n'étant pas plus longues que 210 mm, les rapports entre les longueurs desdites aubes mobiles des étages respectivement adjacents sont au maximum de 1,2, et lesdits rapports sont plus grands du côté aval que du côté amont.

10. Turbine à vapeur selon l'une quelconque des revendications 1 à 6, 8 ou 9, destinée à être utilisée dans une application haute-pression, dans laquelle lesdites aubes mobiles (16) sont agencées en incluant au moins 7 étages, d'une manière telle que les longueurs desdites aubes mobiles deviennent plus longues depuis un côté amont de l'écoulement de vapeur vers un côté aval de celui-ci, à savoir, un premier étage dédites aubes mobiles n'étant pas plus courtes que 35 mm et un étage final desdites aubes mobiles n'étant pas plus longues que 210 mm, et les diamètres des parties dudit arbre de rotor (23) qui correspondent auxdites aubes fixes sont plus petits que les diamètres desdites parties d'assemblage d'aubes mobiles, et les largeurs des parties dudit arbre de rotor (23) qui correspondent auxdites aubes fixes, les largeurs étant prises dans la direction axiale dudit arbre de rotor, sont plus petites sur le côté aval que sur le côté amont, et les rapports de ses largeurs sur les longueurs des aubes mobiles (16) de la partie correspondante diminuent en direction dudit côté aval dans une plage allant de 0,65 à 1,8.

11. Turbine à vapeur selon l'une quelconque des revendications 1 à 5 ou 7, destinée à être utilisée dans des applications à pression intermédiaire, dans laquelle lesdites aubes mobiles (17) ont une construction à double écoulement dans laquelle au moins 6 étages sont inclus sur chacun des deux côtés dans la direction longitudinale dudit arbre de rotor (24), dans un agencement bilatéralement symétrique sur les deux côtés et les longueurs desdites aubes mobiles deviennent plus longues à partir d'un côté amont de l'écoulement de vapeur vers un côté aval de celui-ci, à savoir, un premier étage dédites aubes mobiles (17) n'étant pas plus court que 90 mm et un étage final dédites aubes mobiles (17) n'étant pas plus long que 350 mm, les diamètres des parties dudit arbre de rotor (24) sur lesquelles lesdites aubes mobiles (17) sont assemblées sont plus grands que les diamètres des parties dudit arbre de rotor qui correspondent auxdites aubes fixes, et les largeurs des parties d'assemblage d'aubes mobiles dudit arbre de rotor dans la direction axiale dudit arbre de rotor sont plus grandes sur le côté aval que sur le côté amont, et les rapports de ces largeurs sur les longueurs desdites aubes mobiles diminuent à partir du côté amont vers ledit côté aval dans une plage allant de 0,45 à 0,75.

12. Turbine à vapeur selon l'une quelconque des revendications 1 à 5, 7 ou 11, destinée à être utilisée dans des applications à pression intermédiaire, dans laquelle lesdites aubes mobiles (17) ont une construction à double écoulement dans laquelle au moins 6 étages sont inclus sur chacun des deux cotés dans la direction longitudinale dudit arbre de rotor (24), dans un agencement bilatéralement symétrique sur les deux côtés, et les longueurs desdites aubes mobiles (17) deviennent plus longues depuis un côté amont de l'écoulement de vapeur vers un côté aval de celui-ci, à savoir, un premier étage desdites aubes mobiles n'étant pas plus courtes que 90 mm et un étage final dédites aubes mobiles n'étant pas plus longues que 350 mm, et les longueurs des aubes mobiles respectivement adjacentes sont plus grandes sur le côté aval que sur le côté amont, et les rapports des longueurs d'aubes adjacentes sont au maximum de 1,3 et augmentent graduellement en direction dudit côté aval.

13. Turbine à vapeur selon l'une quelconque des revendications 1 à 5 ou 7, 11 ou 12, destinée à être utilisée dans des applications à pression intermédiaire, dans laquelle lesdites aubes mobiles (17) ont une construction à double écoulement dans laquelle au moins 6 étages sont inclus sur chacun des deux cotés dans la direction longitudinale dudit arbre de rotor (24), dans un agencement bilatéralement symétrique sur les deux côtés, et les longueurs desdites aubes mobiles (17) deviennent plus longues depuis un côté amont de l'écoulement de vapeur vers un côté aval de celui-ci, à savoir, un premier étage desdites aubes mobiles n'étant pas plus courtes que 90 mm et un étage final dédites aubes mobiles n'étant pas plus longues que 350 mm, et les diamètres des parties dudit arbre de rotor (24) qui correspondent auxdites aubes fixes étant plus petits que les diamètres de ladite partie d'assemblage d'aubes mobiles de l'arbre de rotor, et les largeurs des parties dudit arbre de rotor (24) qui correspondent auxdites aubes fixes, les largeurs étant prises dans la direction axiale dudit arbre de rotor, sont plus petites sur le côté aval que sur le côté amont, et les rapports de ces largeurs sur les longueurs des aubes mobiles côté aval de la partie correspondante diminuent en direction dudit côté aval dans une plage allant de 0,45 à 1,60.

14. Turbine à vapeur selon l'une quelconque des revendications 1 à 6, 8 à 10, destinée à être utilisée dans des applications à haute-pression, dans laquelle lesdites aubes mobiles (16) sont agencées incluant au moins 7 étages, les diamètres des parties dudit arbre de rotor (23) qui correspondent auxdites aubes fixes sont plus petits que les diamètres des parties dudit arbre de rotor qui correspondent aux aubes mobiles assemblées, les largeurs des parties d'arbre de rotor correspondant auxdites aubes fixes, dans la direction axiale dudit arbre de rotor, sont plus grandes de manière étagée sur le côté amont de l'écoulement de vapeur que sur le côté aval de celui-ci, au moins au niveau de deux desdits étages, et la largeur entre l'étage final desdites aubes mobiles (16) et l'étage de celles-ci directement précédant ledit étage final est de 0,75 à 0,95 fois aussi grande que la largeur existant entre le deuxième étage et le troisième étage desdites aubes mobiles, et les largeurs des parties d'arbre de rotor correspondant auxdites aubes mobiles assemblées, dans la direction axiale dudit arbre de rotor, sont plus grandes de manière étagée sur le côté aval dudit écoulement de vapeur que sur le côté amont de celui-ci, au moins au niveau de 3 desdits étages, et la largeur axiale dudit étage final dédites aubes mobiles (16) au niveau de la partie d'assemblage d'aubes mobiles est de 1 à 2 fois aussi grande que la largeur axiale dudit deuxième étage dédites aubes mobiles (16) au niveau de la partie d'assemblage d'aubes mobiles.

15. Turbine à vapeur selon l'une quelconque des revendications 1 à 5, 7, 11 à 13, destinée à être utilisée dans des applications à pression intermédiaire, dans laquelle lesdites aubes mobiles (17) sont agencées incluant au moins 6 étages, les diamètres des parties dudit arbre de rotor (24) qui correspondent auxdites aubes fixes sont plus petits que les diamètres des parties dudit arbre de rotor qui correspondent aux aubes mobiles assemblées, les largeurs des parties d'arbre de rotor correspondant auxdites aubes fixes, dans la direction axiale dudit arbre de rotor, sont plus grandes de manière étagée sur le côté amont de l'écoulement de vapeur que sur le côté aval de celui-ci, au moins au niveau de deux desdits étages, et la largeur entre l'étage final desdites aubes mobiles et l'étage de celles-ci directement précédant ledit étage final est de 0,6 à 0,8 fois aussi grande que la largeur entre le premier étage et le deuxième étage desdites aubes mobiles, et les largeurs desdites parties d'arbre de rotor correspondant auxdites aubes mobiles assemblées, dans la direction axiale dudit arbre de rotor, sont plus grandes de manière étagée sur le côté aval dudit écoulement de vapeur que sur le côté amont de celui-ci, au moins au niveau de 2 desdits étages, et la largeur axiale dudit étage final dédites aubes mobiles de la partie d'assemblage d'aubes mobiles est de 0,8 à 2 fois aussi grande que la largeur axiale dudit premier étage dédites aubes mobiles de la partie d'assemblage d'aubes mobiles.

16. Centrale électrique à turbine à vapeur comportant une turbine haute-pression (52), une turbine à pression intermédiaire (53) et une turbine basse-pression (54, 55), dans laquelle des entrées de vapeur (28, 29) de chacune des turbines haute-pression et à pression intermédiaire (52, 53) aboutissant à des aubes mobiles (16, 17) d'un premier étage inclus dans chacune desdites turbines haute-pression et à pression intermédiaire (52, 53) sont à une température de 610 à 660°C, l'entrée de vapeur de ladite turbine basse-pression (54, 55) aboutissant aux aubes mobiles (41) d'un premier étage inclus dans ladite turbine basse-pression est à une température de 380 à 475°C, **caractérisée en ce que** ladite turbine haute-pression (52) est définie par l'une quelconque des revendications 1 à 6, 8 à 10 ou 14, et ladite turbine à pression intermédiaire (53) est définie par l'une quelconque des revendications 1 à 5, 7, 11 à 13 ou 15.

17. Centrale électrique à turbine à vapeur selon la revendication 16, dans laquelle les aubes mobiles de premier étage (16) de ladite turbine haute-pression (52) et la partie d'un arbre de rotor (23) de ladite turbine haute-pression sur laquelle lesdites aubes mobiles de premier étage sont assemblées sont maintenues à des températures de métal qui ne sont pas plus de 40°C plus basses que la température de ladite entrée de vapeur de ladite turbine haute-pression aboutissant auxdites aubes mobiles de premier étage, et les aubes mobiles de premier étage (17) de ladite turbine à pression intermédiaire (53), et la partie d'un arbre de rotor (24) de ladite turbine à pression intermédiaire sur laquelle lesdites aubes mobiles de premier étage sont assemblées sont maintenues à une température de métal qui n'est pas plus de 75 °C plus basse que la température de ladite entrée de vapeur de ladite turbine à pression intermédiaire aboutissant auxdites aubes mobiles de premier étage.

18. Centrale électrique à turbine à vapeur fonctionnant au charbon comportant une chaudière à charbon (51), des turbines à vapeur (52, 53, 54, 55) qui sont entraînées par la vapeur produite par la chaudière (51) et un ou deux générateurs (68) qui sont entraînés par lesdites turbines à vapeur créant une sortie d'au moins 1000 MW, **caractérisée en ce que** lesdites turbines à vapeur comportent une turbine haute-pression (52) définie par l'une quelconque des revendications 1 à 6, 8 à 10 ou 14, une turbine à pression intermédiaire (53) définie par l'une quelconque des revendications 1 à 5, 7, 11 à 13 ou 15, ladite turbine à pression intermédiaire (53) étant reliée à ladite turbine haute-pression (52), et deux turbines basse-pression (54, 55), les entrées de vapeur (28, 29) de chacune desdites turbines haute-pression et à pression intermédiaire (52, 53) aboutissant à des aubes mobiles (16, 17) d'un premier étage étant à une température de 610 à 660°C, l'entrée de vapeur de ladite turbine basse-pression (54, 55) aboutissant aux aubes mobiles (41) d'un premier étage étant à une température de 380 à 450°C, et ledit premier étage dédites aubes mobiles (16, 17) de ladite turbine haute-pression (52) et/ou de ladite turbine à pression intermédiaire (53) étant comme défini dans les revendications 3 ou 4.

19. Centrale électrique à turbine à vapeur, fonctionnant au charbon, selon la revendication 18, dans laquelle la vapeur chauffée par un surchauffeur (66) de ladite chaudière (51) jusqu'à une température qui est d'au moins 3°C plus élevée que la température de ladite entrée de vapeur (28) de ladite turbine haute-pression (52) est amenée à s'écouler dans lesdites aubes mobiles de premier étage (16) de ladite turbine haute-pression (52), la vapeur quittant ladite turbine haute-pression (52) est chauffée par un réchauffeur (66) de ladite chaudière (51) jusqu'à une température qui est d'au moins 2°C plus élevée que la température de ladite entrée de vapeur (29) de ladite turbine à pression intermédiaire (53) aboutissant aux aubes mobiles de premier étage (17) de celle-ci, après quoi la vapeur chauffée est amenée à s'écouler dans lesdites aubes mobiles de premier étage de ladite turbine à pression intermédiaire et la vapeur quittant ladite turbine à pression intermédiaire est chauffée par un économiseur (64) de ladite chaudière (51) jusqu'à une température qui est d'au moins 3°C plus élevée que la température de ladite entrée de vapeur de ladite turbine basse-pression (54, 55) aboutissant aux aubes mobiles de premier étage (41) de celle-ci, après quoi la vapeur chauffée est amenée à s'écouler dans lesdites aubes mobiles de premier étage de ladite turbine basse-pression.

20. Centrale électrique selon l'une quelconque des revendications 16 à 19, dans laquelle ladite turbine à vapeur basse-pression (54, 55) a un arbre de rotor (44), des aubes mobiles (41) qui sont assemblées sur l'arbre de rotor, des aubes fixes (42) qui guident l'écoulement de vapeur entrant vers les aubes mobiles (41), et un carter intérieur qui maintient les aubes fixes (42), lesdites aubes mobiles (41) ont une construction à double écoulement dans laquelle au moins 8 étages sont inclus sur chaque côté dans la direction longitudinale dudit arbre de rotor, selon un agencement bilatéralement symétrique sur les deux côtés, et dans lequel les premiers étages de l'agencement sont assemblés sur une partie centrale dudit arbre de rotor dans la direction longitudinale, ledit arbre de rotor a une distance (L) d'au moins 7000 mm entre les centres des paliers dans lesquels il est tourillonné, et un diamètre minimum (D) d'au moins 1150 mm au niveau de ses parties qui correspondent auxdites aubes fixes, un rapport (L/D) entre la distance (L) et le diamètre (D) étant de 5,4 à 6,3, et il est constitué d'un acier allié à faible teneur en Ni-Cr-Mo-V qui contient de 1 à 2,5 en poids de Cr et 3,0 à 4,5 en poids de Ni, et chacune des aubes mobiles d'étage final dudit agencement a une longueur d'au moins 1016 mm (40 pouces) et est constituée d'un alliage à base de Ti.

21. Centrale électrique selon l'une quelconque des revendications 16 à 20, dans laquelle ladite turbine à vapeur basse-pression (54, 55) a un arbre de rotor (44), des aubes mobiles (41) qui sont assemblées sur l'arbre de rotor, des aubes fixes (42) qui guident l'écoulement de vapeur entrante vers les aubes mobiles, et un carter intérieur qui maintient les aubes fixes, une entrée de vapeur de ladite turbine basse-pression qui aboutit à un premier étage dédites aubes mobiles est à une température de 380 à 450°C, et ledit arbre de rotor est constitué d'un acier allié à faible teneur qui contient 0,2 à 0,3 % de C, au maximum 0,05 % de Si, au maximum 0,1 % de Mn, de 3,0 à 4,5 % de Ni, de 1,25 à 2,25 % de Cr, de 0,07 à 0,20 % de Mo, de 0,07 à 0,2 % de V et au moins 92,5 % de Fe, les pourcentages étant donnés en termes de poids.

22. Centrale électrique selon l'une quelconque des revendications 16 à 19, dans laquelle ladite turbine à vapeur basse-pression (54, 55) a un arbre de rotor (44), des aubes mobiles (41) qui sont assemblées sur l'arbre de rotor, des aubes fixes (42) qui guident l'écoulement de vapeur entrante vers les aubes mobiles, et un carter intérieur qui maintient les aubes fixes, lesdites aubes mobiles ont une construction à double écoulement dans laquelle au moins 8 étages sont inclus sur chacun des deux côtés dans la direction longitudinale dudit arbre de rotor, selon un agencement bilatéralement symétrique sur les deux côtés et les longueurs desdites aubes mobiles deviennent plus longues à partir d'un côté amont de l'écoulement de vapeur vers un côté aval, à savoir un premier étage desdites aubes mobiles n'étant pas plus courtes que 90 mm, et un étage final dédites aubes mobiles n'étant pas plus longues que 1300 mm, les diamètres des parties dudit arbre de rotor sur lesquelles lesdites aubes mobiles sont assemblées sont plus grands que les diamètres des parties dudit arbre de rotor qui correspondent auxdites aubes fixes, et les largeurs desdites parties d'assemblage d'aubes mobiles dudit arbre de rotor dans la direction axiale dudit arbre de rotor sont plus grandes sur le côté aval que sur le côté amont, et les rapports de ces largeurs sur les longueurs desdites aubes mobiles diminuent depuis le côté amont vers le côté aval dans une plage allant de 0,15 à 1,0.

23. Centrale électrique selon l'une quelconque des revendications 16 à 22, dans laquelle ladite turbine à vapeur basse-pression (54, 55) a un arbre de rotor (44), des aubes mobiles (41) qui sont assemblées sur l'arbre de rotor, des aubes fixes (42) qui guident l'écoulement entrant de vapeur vers les aubes mobiles, et un carter intérieur qui maintient les aubes fixes, lesdites aubes mobiles ont une construction à double écoulement dans laquelle au moins 8 étages sont inclus sur chacun des deux côtés dans la direction longitudinale dudit arbre de rotor, selon un agencement bilatéralement symétrique sur les deux côtés, et les longueurs desdites aubes mobiles deviennent plus longues depuis le côté amont de l'écoulement de vapeur vers le côté aval, à savoir, un premier étage dédites aubes mobiles n'étant pas plus courtes que 90 mm, et un étage final dédites aubes mobiles n'étant pas plus longues que 1300 mm, et les longueurs desdites aubes mobiles des étages respectivement adjacents sont plus grandes sur le côté aval que sur le côté amont, et leurs rapports augmentent graduellement en direction dudit côté aval dans une plage allant de 1,2 à 1,7.

24. Centrale électrique selon l'une quelconque des revendications 16 à 23, dans laquelle ladite turbine à vapeur basse-pression (54, 55) a un arbre de rotor (44), des aubes mobiles (41) qui sont assemblées sur l'arbre de rotor, des aubes fixes (42) qui guident l'écoulement entrant de vapeur vers les aubes mobiles, et un carter intérieur qui maintient les aubes fixes, lesdites aubes mobiles ont une construction à double écoulement dans laquelle au moins 8 étages sont inclus sur chacun des deux côtés dans la direction longitudinale dudit arbre de rotor, selon un agencement bilatéralement symétrique sur les deux côtés, et les longueurs desdites aubes mobiles deviennent plus longues depuis un côté amont de l'écoulement de vapeur vers un côté aval, à savoir, un premier étage dédites aubes mobiles n'étant pas plus courtes que 90 mm, et un étage final dédites aubes mobiles n'étant pas plus longues que 1300 mm, et les diamètres des parties dudit arbre de rotor qui correspondent auxdites aubes fixes sont plus petits que les diamètres de ladite partie d'assemblage d'aubes mobiles de l'arbre de rotor, et les largeurs des parties dudit arbre de rotor qui correspondent auxdites aubes fixes, les largeurs étant prises dans la direction axiale dudit arbre de rotor, sont plus grandes sur le côté aval que sur le côté amont, et les rapports de ces largeurs sur les longueurs des aubes mobiles respectivement adjacentes des parties correspondantes dudit côté aval diminuent de manière étagée en direction dudit côté aval dans une plage allant de 0,2 à 1,4.

25. Centrale électrique selon l'une quelconque des revendications 16 à 24, dans laquelle ladite turbine à vapeur basse-pression (54, 55) a un arbre de rotor (44), des aubes mobiles (41) qui sont assemblées sur l'arbre de rotor, des aubes fixes (42) qui guident l'écoulement entrant de vapeur vers les aubes mobiles, et un carter intérieur qui maintient les aubes fixes, lesdites aubes mobiles ont une construction à double écoulement dans laquelle au moins 8 étages sont inclus sur chacun des deux côtés dans la direction axiale dudit arbre de rotor, selon un agencement bilatéralement symétrique sur les deux côtés, les diamètres des parties dudit arbre de rotor qui correspondent auxdites aubes fixes sont plus petits que les diamètres des parties dudit arbre de rotor qui correspondent aux aubes mobiles assemblées, les largeurs des parties d'arbre de rotor correspondant auxdites aubes fixes, dans la direction axiale dudit arbre de rotor,- sont plus grandes de manière étagée sur le côté amont de l'écoulement de vapeur que sur le côté aval de celui-ci, au moins au niveau de 3 desdits étages, et la largeur entre l'étage final desdites aubes mobiles et l'étage de celles-ci directement précédant ledit étage final est de 1,5 à 2,5 fois aussi grande que la largeur existant entre le premier étage et le deuxième étage desdites aubes mobiles, et les largeurs des parties d'arbre de rotor correspondant auxdites aubes mobiles assemblées, dans ladite direction axiale dudit arbre de rotor, sont plus grandes de manière étagée sur le côté aval dudit écoulement de vapeur que sur le côté amont de celui-ci, au moins au niveau de 3 desdits étages, et la largeur axiale dudit étage final dédites aubes mobiles est de 1 à 3 fois aussi grande que la largeur axiale dudit premier étage dédites aubes mobiles.

26. Turbine à vapeur selon l'une quelconque des revendications 1 à 15, comportant de plus une accumulation de couches de soudure constituées d'un métal qui a de meilleures caractéristiques de palier que celles d'un métal parent dudit arbre de rotor, formées sur la surface de chaque partie de tourillon dudit arbre de rotor.

27. Turbine à vapeur selon la revendication 26, dans laquelle lesdites couches de soudure accumulées sont formées au nombre d'au moins trois.

28. Turbine à vapeur selon la revendication 27, dans laquelle lesdites couches de soudure accumulées sont formées selon un nombre de cinq à dix.

29. Turbine à vapeur selon l'une quelconque des revendications 26 à 28, dans laquelle la couche la plus périphérique desdites couches de soudure accumulée est constituée d'acier faiblement allié qui contient de 0,5 à 3 % en poids de Cr.

30. Turbine à vapeur selon la revendication 29, dans laquelle la couche la plus périphérique desdites couches de soudure accumulée est constituée d'acier faiblement allié qui contient de 0,01 à 0,15 % en poids de C, de 0,3 à 1 % en poids de Si, de 0,3 à 1,5 % en poids de Mn, et de 0,5 à 3 % en poids de Cr, de 0,1 à 1,51 en poids de Mo.

FIG. 1

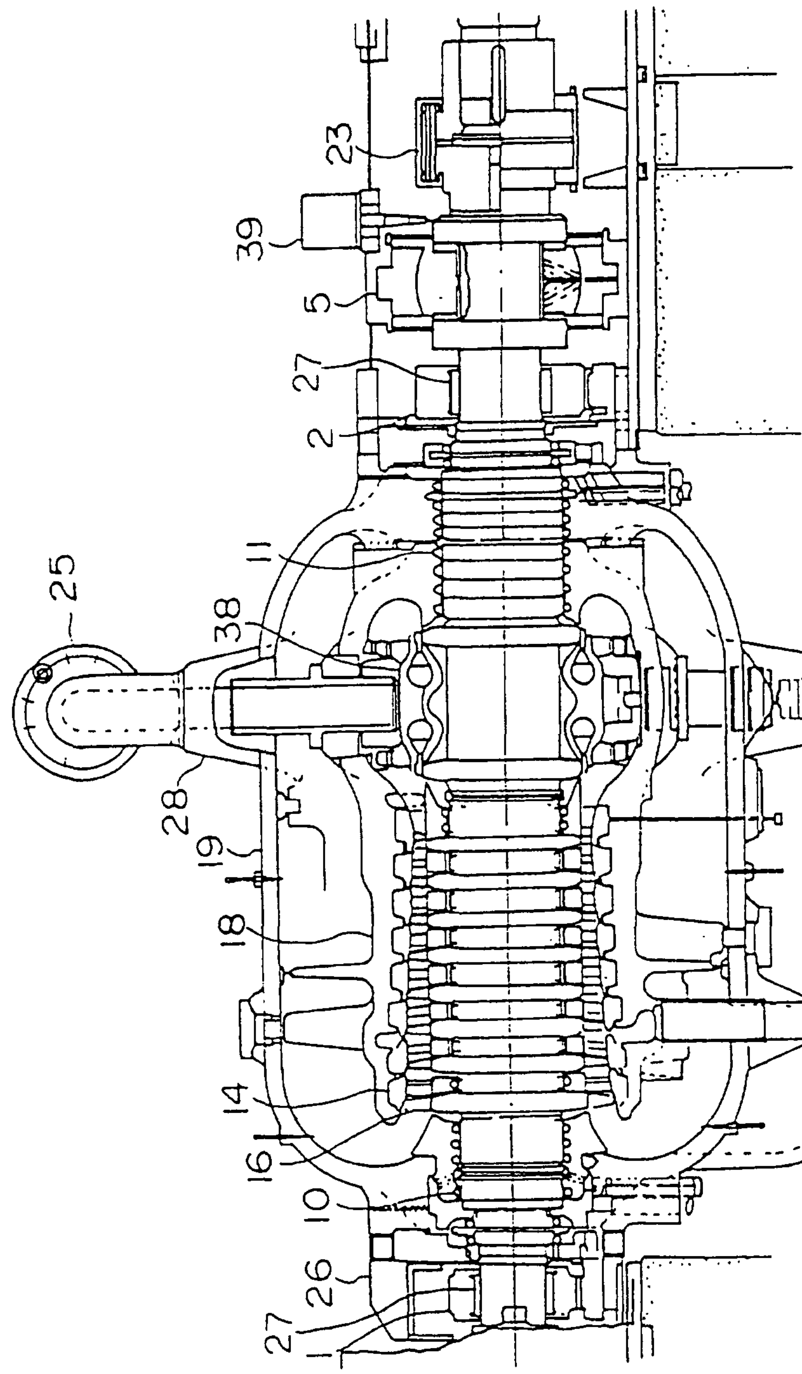


FIG. 2

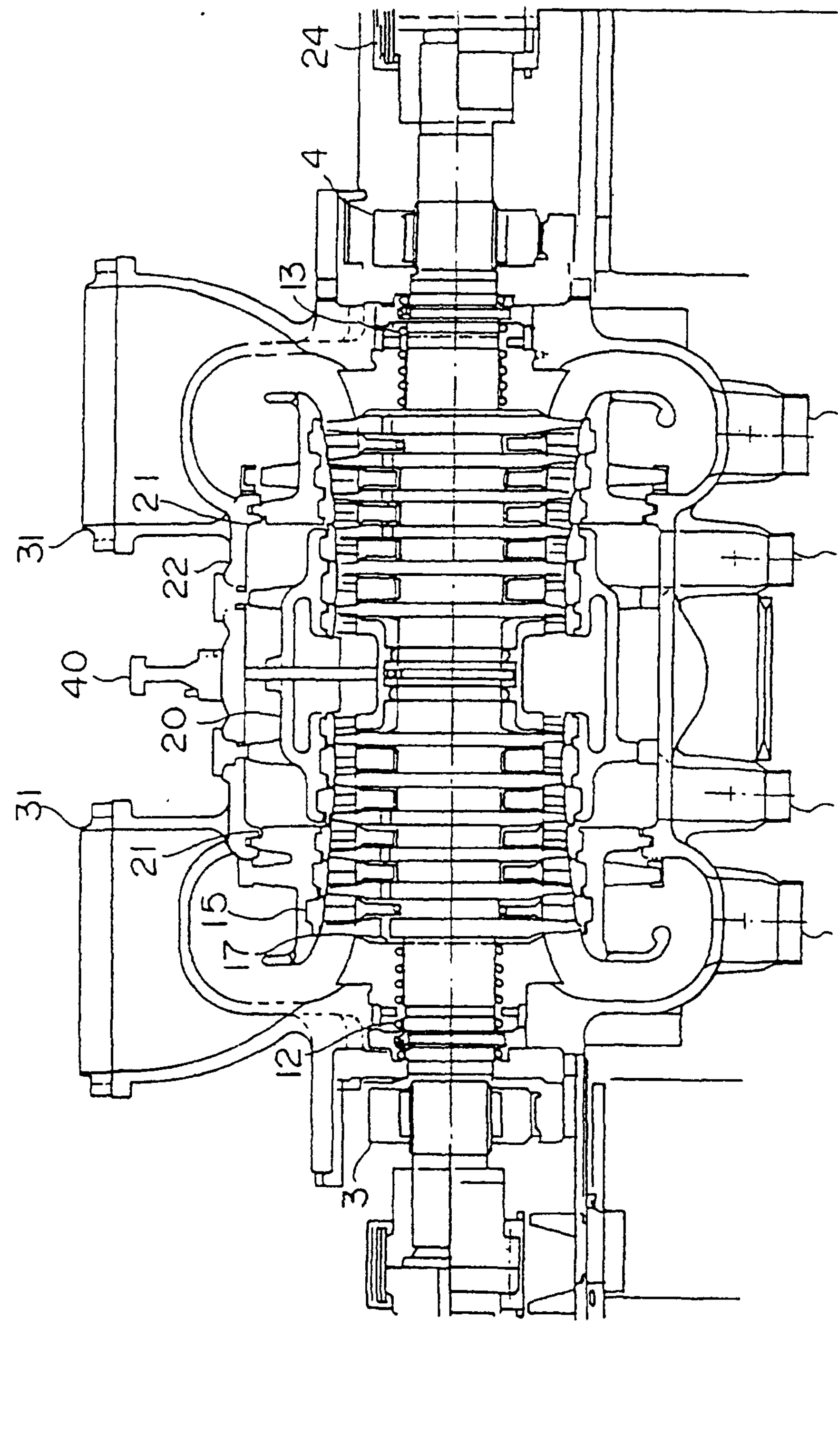


FIG. 3

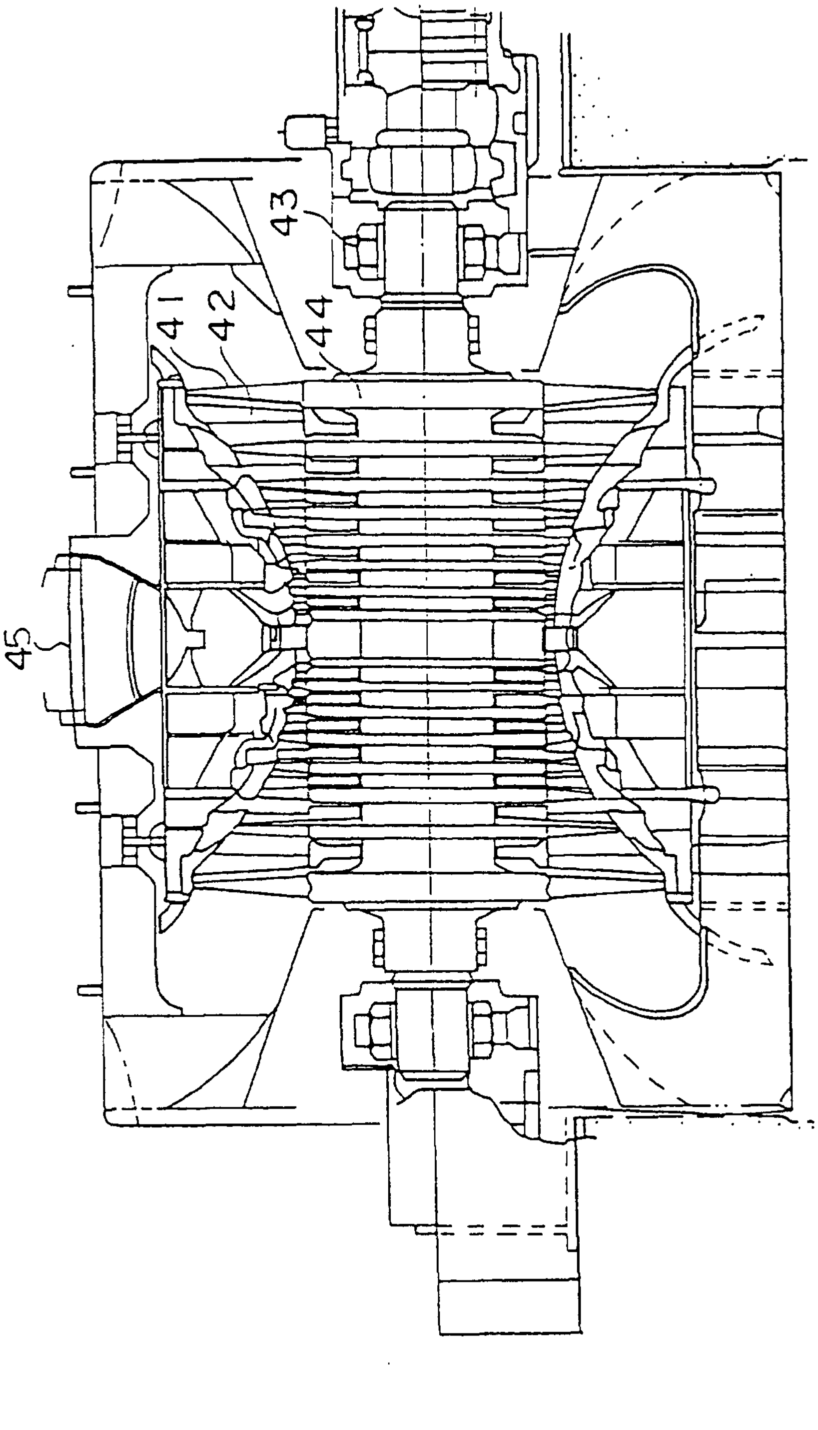
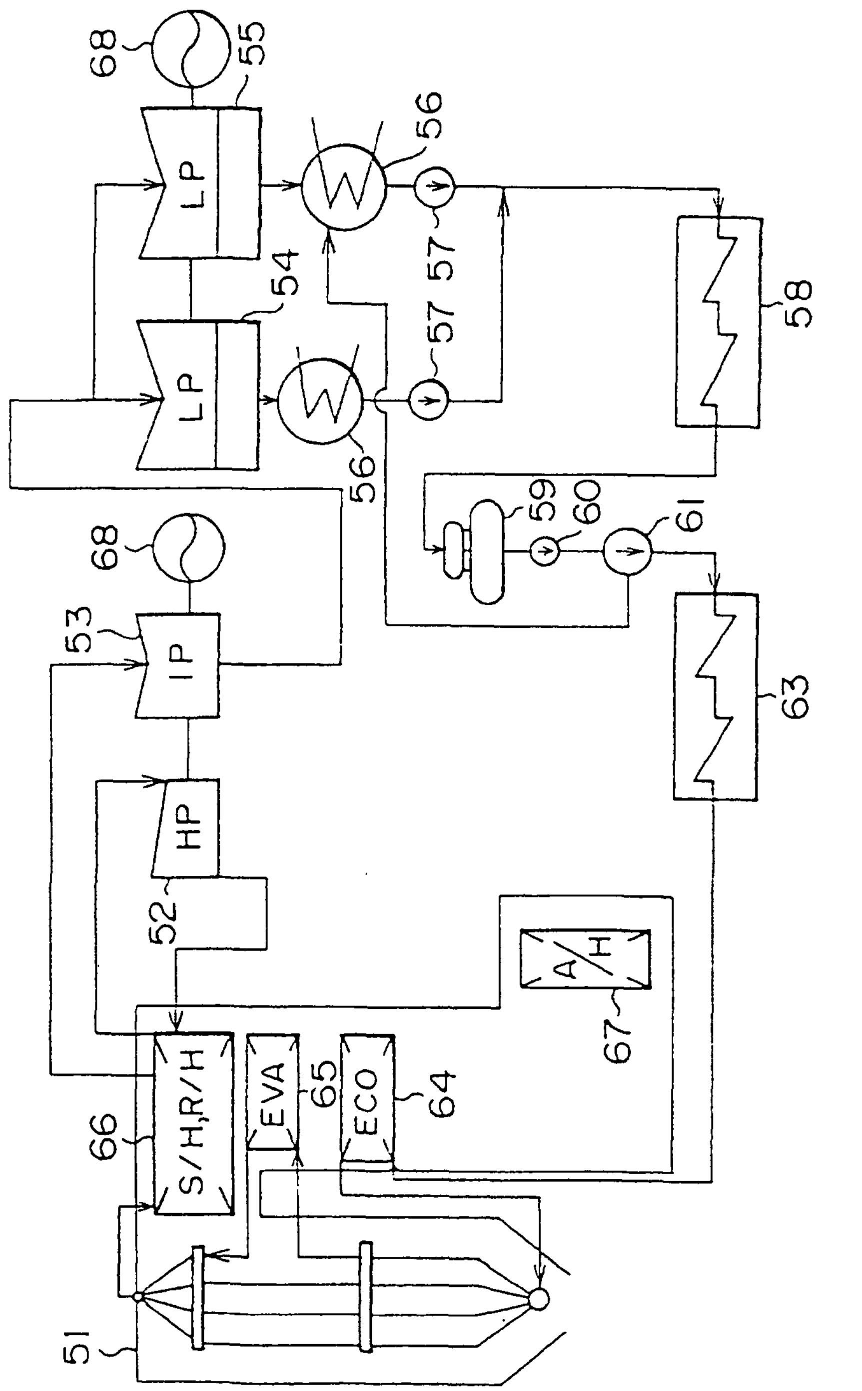


FIG. 4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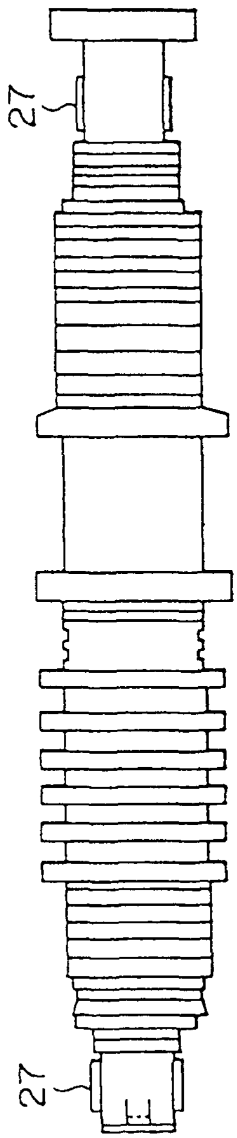
ECO
64
51

FIG. 5



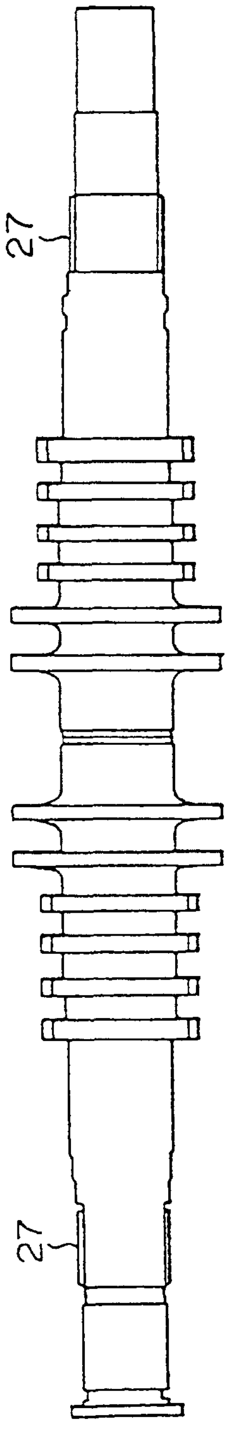


FIG. 6

FIG. 7

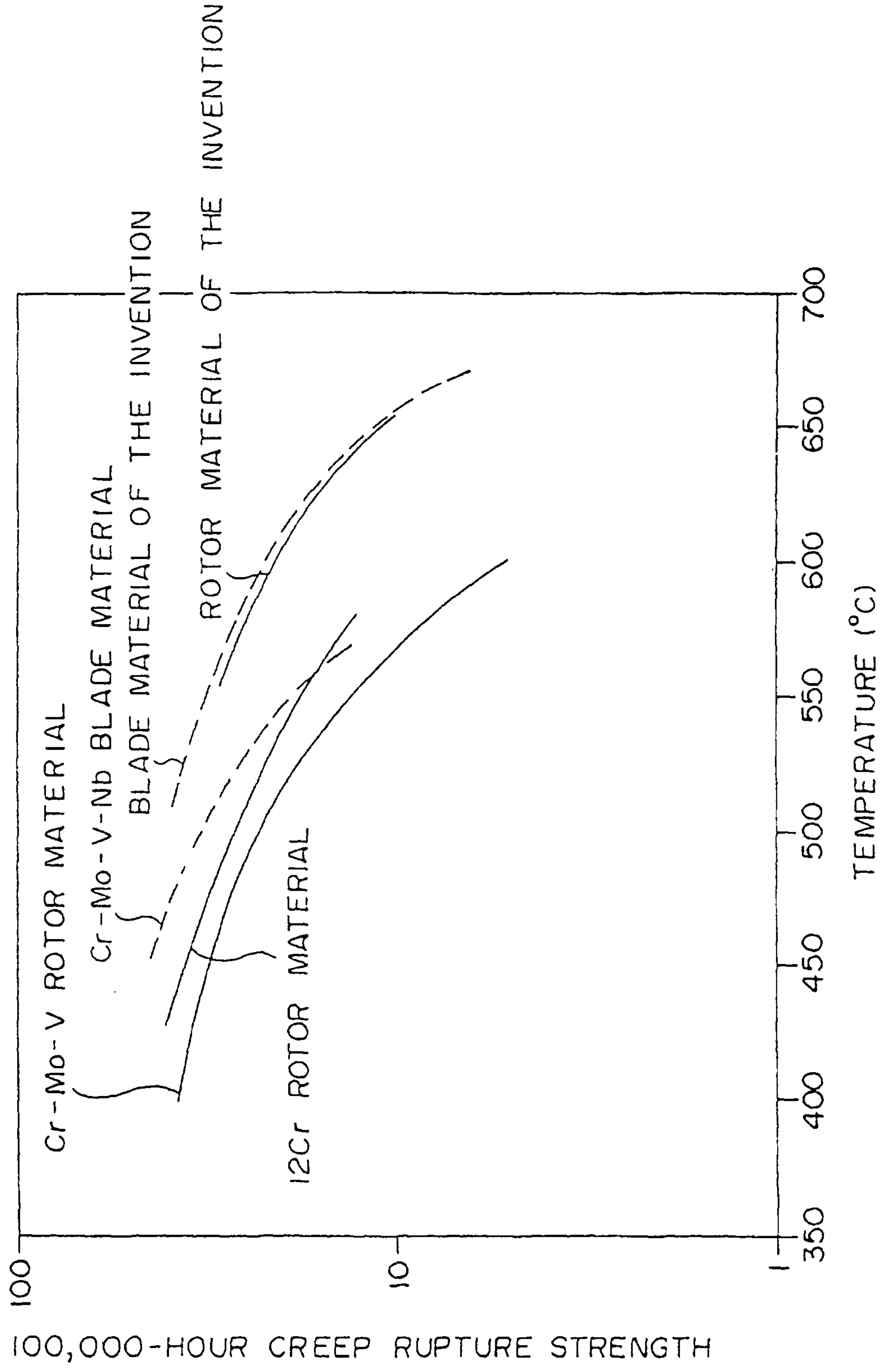

Cr-Mo-V ROTOR MATERIAL
Cr-Mo-V-Nb BLADE MATERIAL
BLADE MATERIAL OF THE INVENTION
ROTOR MATERIAL OF THE INVENTION
12Cr ROTOR MATERIAL
100
10
1
350
400
450
500
550
600
650
700
TEMPERATURE (°C)
100,000-HOUR CREEP RUPTURE STRENGTH

FIG. 8

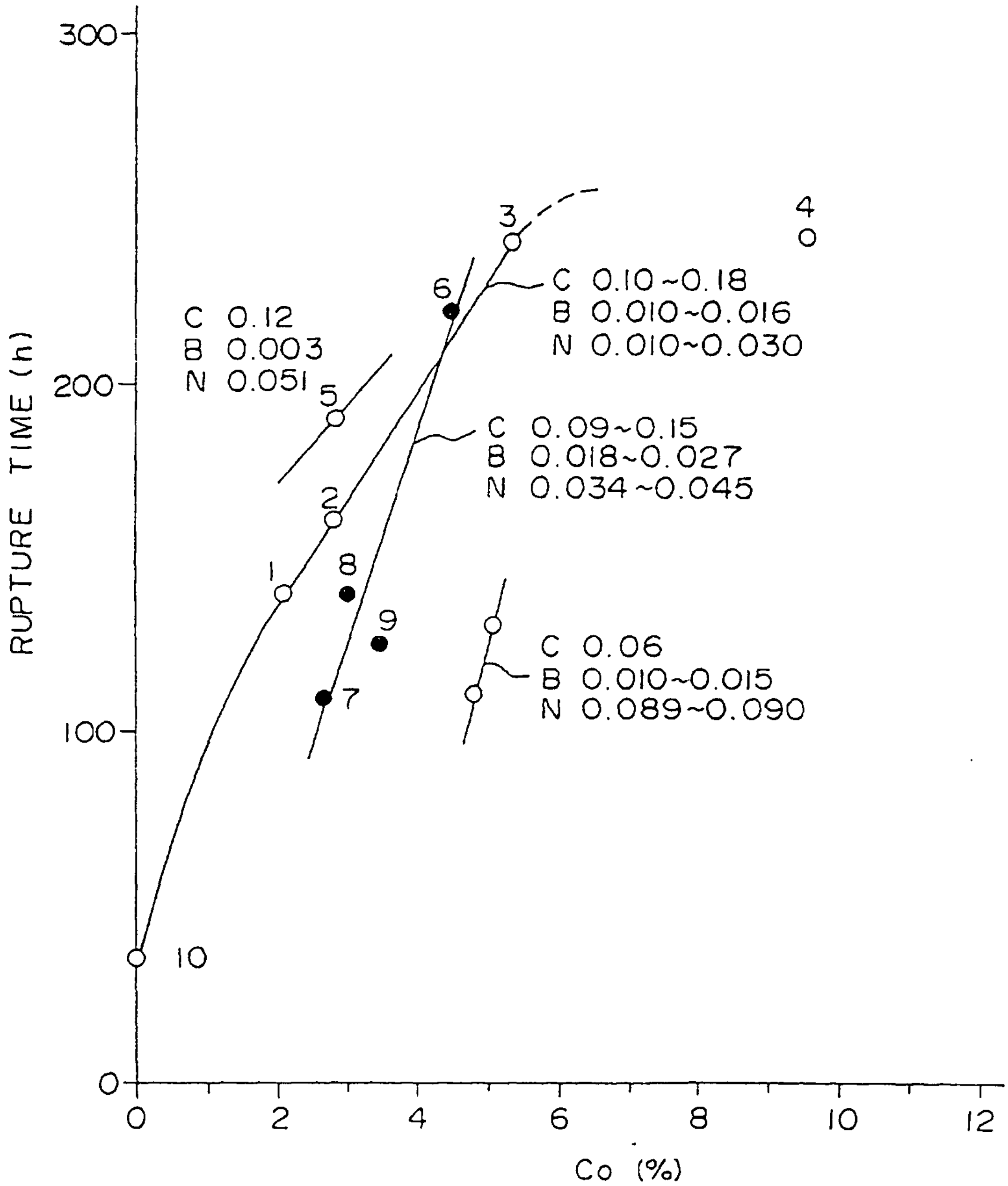

RUPTURE TIME (h)
300
200
100
0
0
2
4
6
8
10
12
Co (%)
1
2
3
4
5
6
7
8
9
10
C 0.12
B 0.003
N 0.051
C 0.10~0.18
B 0.010~0.016
N 0.010~0.030
C 0.09~0.15
B 0.018~0.027
N 0.034~0.045
C 0.06
B 0.010~0.015
N 0.089~0.090

FIG. 9

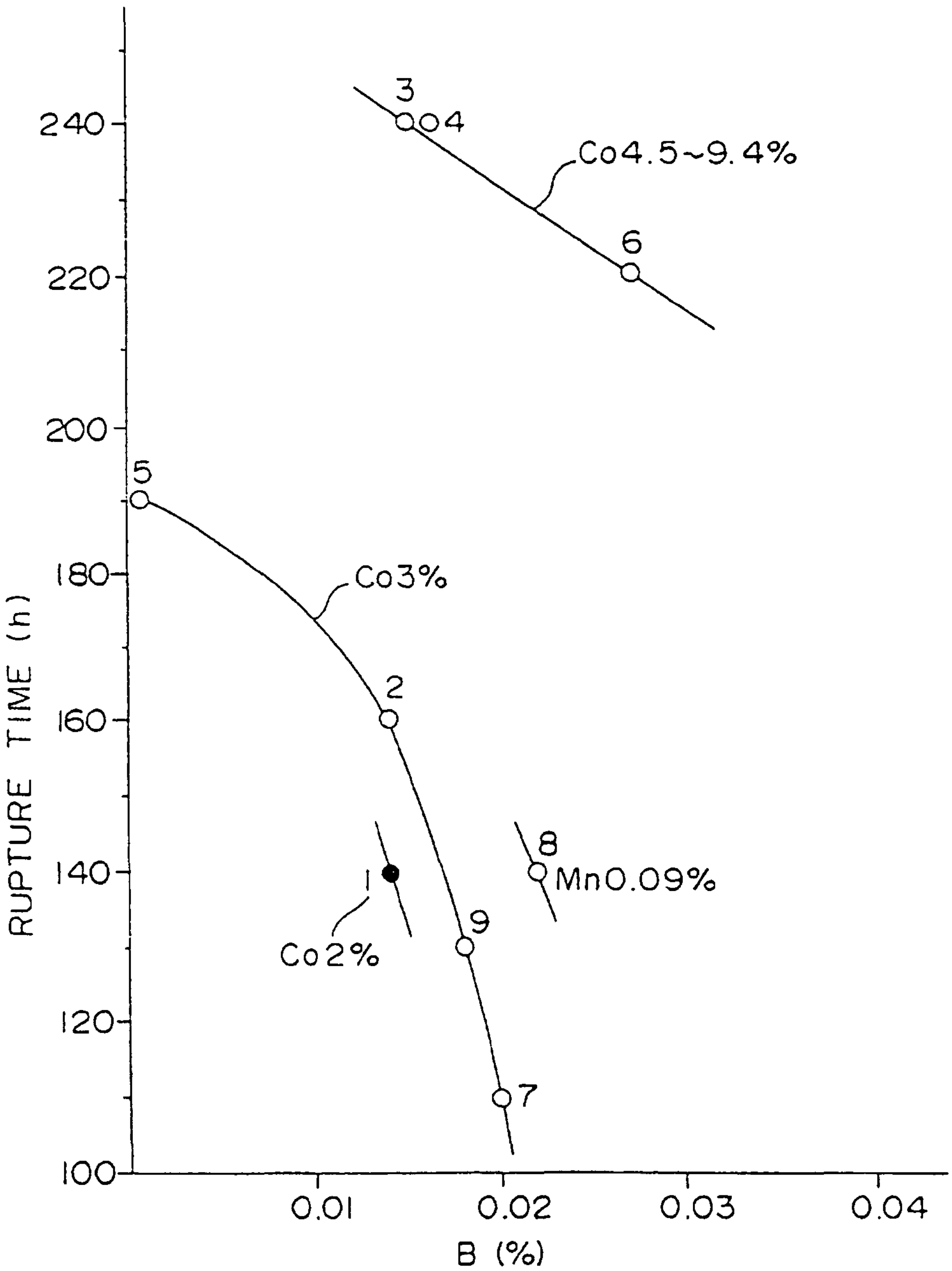

RUPTURE TIME (h)
240
220
200
180
160
140
120
100
0.01
0.02
0.03
0.04
B (%)
3
4
Co4.5~9.4%
6
5
Co3%
2
8
Mn0.09%
1
Co2%
9
7

FIG. 10

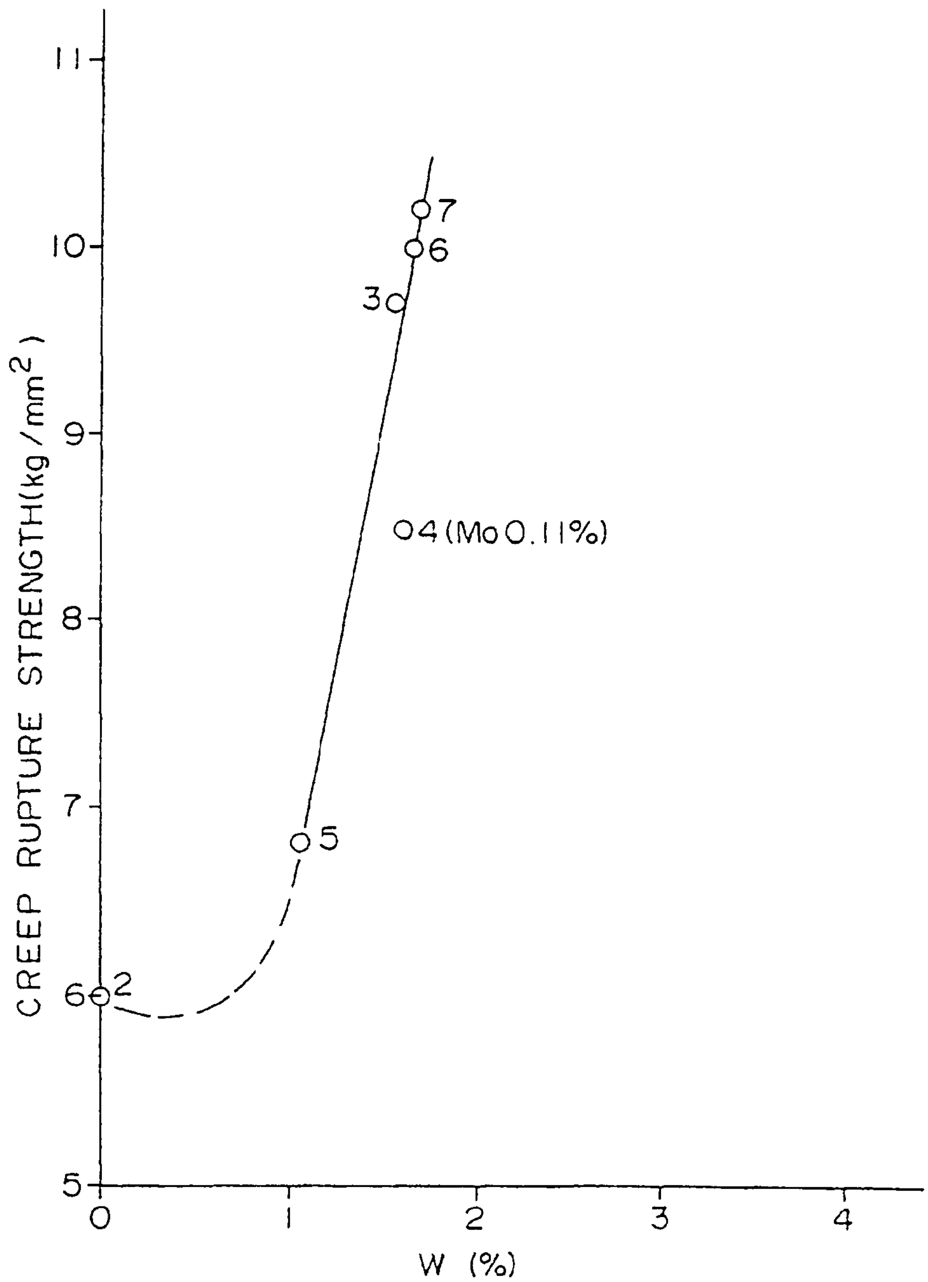

CREEP RUPTURE STRENGTH(kg/mm^2)
W (%)
11
10
9
8
7
6
5
0
1
2
3
4
2
3
4 (Mo 0.11%)
5
6
7

FIG. 11

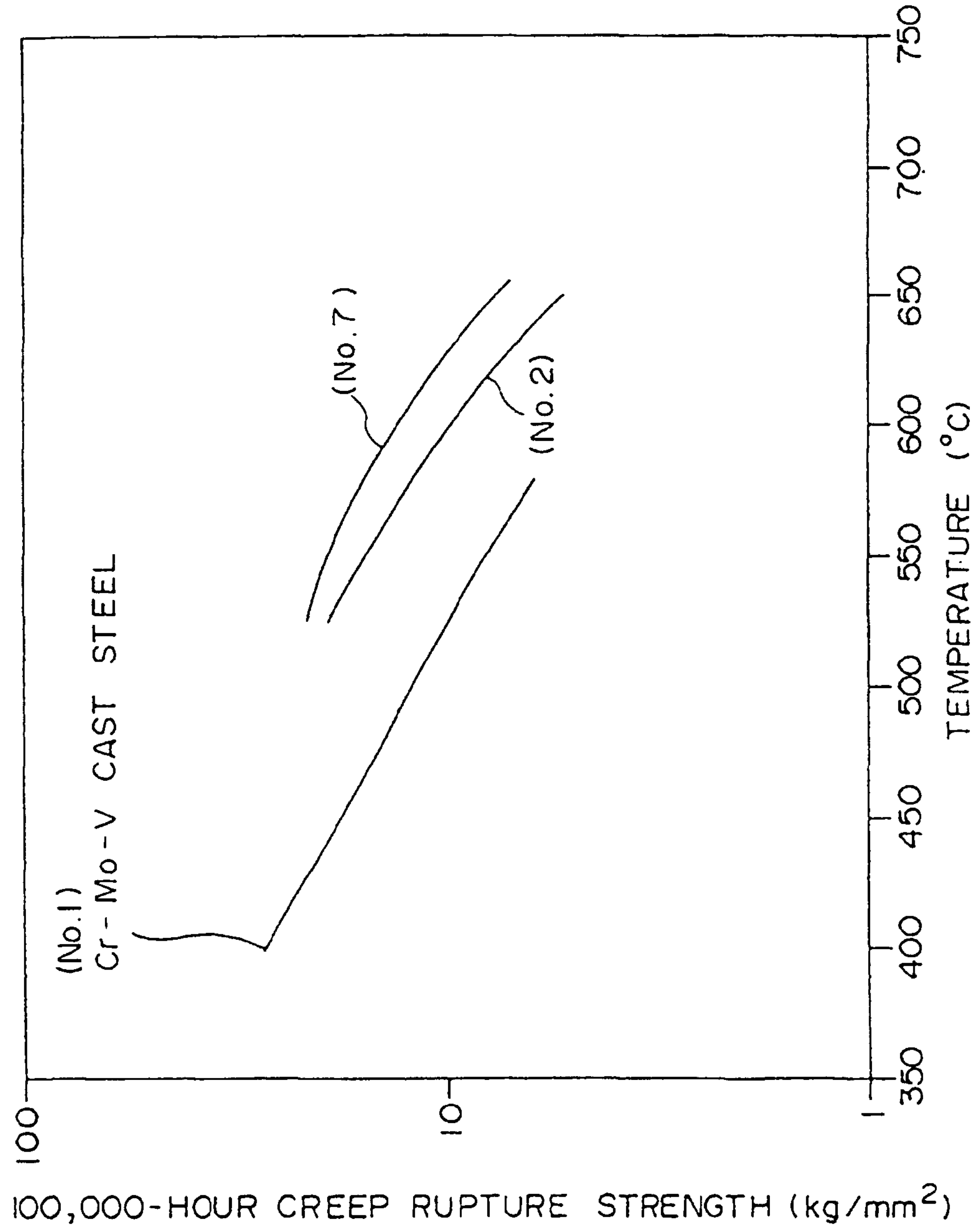

(No.1)
Cr-Mo-V CAST STEEL
(No.7)
(No.2)
100
10
1
350
400
450
500
550
600
650
700
750
TEMPERATURE (°C)
100,000-HOUR CREEP RUPTURE STRENGTH (kg/mm2)

FIG. 12

TABLE I

PLANT OUTPUT		1050MW
OPERATING METHOD		CONSTANT-PRESSURE TYPE
BOILER SPECIFICATIONS	TYPE	RADIATION-REHEATING TYPE ONCE-THROUGH BOILER OF ULTRA-SUPERCRITICAL PRESSURE
	EVAPORATION RATE	3170t/h
	STEAM PRESSURE	24.12MPa[G]
	STEAM TEMPERATURE	630°C/630°C
PERFORMANCE	COMBUSTION QUALITY	
	NOx	120ppm
	COMBUSTIBLES IN REFUSE	3.2%
	LOAD CHANGE SPEED (50 ⟷ 100%)	4%/min
	MINIMUM LOAD	33% ECR (COAL)

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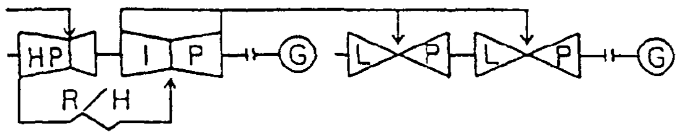
TABLE 2

TURBINE TYPE	CC4F-43
REVOLUTIONS PER MINUTE	3600/1800r/min
STEAM CONDITIONS	24.1MPa-625°C/625°C
TURBINE CONFIGURATION	
CONSTRUCTION OF FIRST-STAGE BLADE	DOUBLE-FLOW, DOUBLE-TENON TYPE TANGENTIAL ENTRY DOVETAIL BLADE
FINAL-STAGE BLADE	BLADE OF TITANIUM ALLOY BEING 43 INCHES LONG
OVERALL LENGTHS OF TURBINES	HP-IP:13.2m, LP-LP:22.7m
BODY OF MAIN-STEAM STOP VALVE, BODY OF STEAM CONTROL VALVE	HIGH-STRENGTH 12Cr FORGED STEEL
HIGH-PRESSURE ROTOR	HIGH-STRENGTH 12Cr FORGED STEEL
INTERMEDIATE-PRESSURE ROTOR	HIGH-STRENGTH 12Cr FORGED STEEL
LOW-PRESSURE ROTOR	SUPERCLEAN TYPE, 3.5Ni-Cr-Mo-V FORGED STEEL
MOVING BLADE AT HIGH TEMPERATURE PART	FIRST STAGE, HIGH-STRENGTH 12Cr FORGED STEEL
HIGH-PRESSURE INNER CASING	HIGH-STRENGTH 9Cr CAST STEEL
HIGH-PRESSURE OUTER CASING	HIGH-STRENGTH Cr-Mo-V-B CAST STEEL
INTERMEDIATE-PRESSURE INNER CASING	HIGH-STRENGTH 9Cr CAST STEEL
INTERMEDIATE-PRESSURE OUTPUT CASING	HIGH-STRENGTH Cr-Mo-V-B CAST STEEL
THERMAL EFFICIENCY (FOR RATED OUTPUT, AT GENERATING END)	47.1%

(CC4F-43:CROSS-COMPOUND TYPE 4-FLOW EXHAUST, USING BLADE 43 INCHES LONG, HP:HIGH-PRESSURE PORTION, IP:INTERMEDIATE-PRESSURE PORTION, LP:LOW-PRESSURE)

FIG. 14

TABLE 3

(wt.%) psi l-14

NAMES OF PRINCIPAL COMPONENTS		C	Si	Mn	Ni	Cr	Mo	W	V	Nb	N	Co	B	OTHER	Cr EQUIVALENT	NOTES
HIGH-PRESSURE PORTION AND INTERMEDIATE-PRESSURE PORTION	ROTOR	0.11	0.03	0.52	0.49	10.98	0.19	2.60	0.21	0.07	0.019	2.70	0.015	–	5.11 (≦9.5)	FORGED STEEL
	BLADE (FIRST STAGE)	0.10	0.04	0.47	0.51	11.01	0.15	2.62	0.19	0.08	0.020	2.81	0.016	–	5.07 (≦10)	〃
	NOZZLE (FIRST STAGE)	0.09	0.04	0.55	0.59	10.50	0.14	2.54	0.18	0.06	0.015	2.67	0.013	–	4.54 (〃)	〃
	INNER CASING	0.12	0.19	0.50	0.68	8.95	0.60	1.68	0.18	0.06	0.040	–	0.002	–	7.57	CAST STEEL
	OUTER CASING	0.12	0.21	0.32	0.25	1.51	1.22	–	0.22	–	–	–	0.005	Ti0.05	–	〃
	TIGHTENING BOLT FOR INNER CASING	0.11	0.10	0.50	0.60	10.82	0.23	2.80	0.23	0.08	0.021	3.00	0.020	–	4.72	FORGED STEEL
LOW-PRESSURE PORTION	ROTOR	0.25	0.03	0.04	3.68	1.75	0.36	–	0.13	–	–	–	–	–	–	FORGED STEEL
	BLADE	0.11	0.20	0.53	0.39	12.07	0.07	–	–	–	–	–	–	–	–	〃
	NOZZLE	0.12	0.18	0.50	0.43	12.13	0.10	–	–	–	–	–	–	–	–	〃
	INNER CASING	0.25	0.51	–	–	–	–	–	–	–	–	–	–	–	–	CAST STEEL
	OUTER CASING	0.24	0.50	–	–	–	–	–	–	–	–	–	–	–	–	〃
CASING OF MAIN-STEAM STOP VALVE		0.10	0.19	0.48	0.65	8.96	0.60	1.62	0.20	0.05	0.042	–	0.002	–	8.56	CAST STEEL
CASING OF STEAM CONTROL VALVE		0.12	0.21	0.52	0.63	9.00	0.63	1.70	0.17	0.06	0.039	–	0.001	–	7.97	〃

		B+N	N/B	B/Co	Co/Mo	Co/Nb	W/Mo	Mo/Cr
HIGH-PRESSURE PORTION AND INTERMEDIATE-PRESSURE PORTION	ROTOR	0.034	1.27	0.0056	14.2	38.6	13.7	0.0173
	BLADE	0.036	1.25	0.0057	18.7	35.1	17.5	0.0136
	NOZZLE	0.028	1.15	0.0049	19.1	44.5	18.1	0.0133
	INNER CASING	–	–	–	–	–	2.80	0.0670

FIG. 15

TABLE 4

psil-14

NAMES OF PRINCIPAL COMPONENTS		TENSILE STRENGTH (kg/mm²)	0.2% PROOF STRESS (kg/mm²)	ELONGATION (%)	CONTRACTION OF AREA (%)	IMPACT VALUE (kg-m)	FATT (%)	10^5-h CREEP RUPTURE STRENGTH (kg/mm²) 625°C	575°C	450°C	HSOF TREATMENT CONDITIONS
HIGH-PRESSURE PORTION AND INTERMEDIATE-PRESSURE PORTION	ROTOR	90.5	76.5	20.6	66.8	3.8	40	17.0	–	–	1050°C×15h WATER SPRAY QUENCHING, 570°C×20h FURNACE COOLING, 690°C×20h FURNACE COOLING
	BLADE (FIRST STAGE)	93.4	81.5	20.9	69.8	4.1	–	18.1	–	–	1075°C×1.5h OIL COOLING, 740°C×5h AIR COOLING
	NOZZLE (FIRST STAGE)	93.9	80.9	21.4	70.3	4.8	–	17.8	–	–	1050°C×1.5h OIL COOLING, 690°C×5h AIR COOLING
	INNER CASING	77.7	60.7	19.0	65.3	2.3	–	11.2	–	–	1050°C×8h AIR BLAST QUENCHING, 600°C×20h FURNACE COOLING, 730°C×10h FURNACE COOLING
	OUTER CASING	68.6	57.2	20.4	65.4	1.5	–	–	12.5	–	1050°C×8h AIR BLAST QUENCHING, 725°C×10h FURNACE COOLING
	TIGHTENING BOLT FOR INNER CASING	107.1	91.6	19.5	86.7	2.0	–	18.0	–	–	1075°C×2h OIL COOLING, 740°C×5h AIR COOLING
LOW-PRESSURE PORTION	ROTOR	91.6	80.6	22.0	70.1	19.1	-50	–	–	36	950°C×30h WATER SPRAY QUENCHING, 605°C×45h FURNACE COOLING
	BLADE	80.9	66.6	22.1	67.5	3.5	–	–	–	27	950°C×1.6h OIL COOLING, 650°C×5h AIR COOLING
	NOZZLE	79.8	65.7	22.4	69.6	3.8	–	–	–	26	950°C×1.5h OIL COOLING, 650°C×5h AIR COOLING
	INNER CASING	41.5	22.2	22.2	81.0	–	–	–	–	–	–
	OUTER CASING	41.1	20.3	24.5	80.5	–	–	–	–	–	–
CASING OF MAIN-STEAM STOP VALVE		77.0	61.0	18.6	65.0	2.5	–	11.2	–	–	1050°C×8h AIR BLAST QUENCHING, 600°C×20h FURNACE COOLING, 730°C×10h FURNACE COOLING
CASING OF STEAM CONTROL VALVE		77.5	61.6	18.2	64.8	2.4	–	11.0	–	–	1050°C×8h AIR BLAST QUENCHING, 600°C×20h FURNACE COOLING, 730°C×10h FURNACE COOLING

FIG. 16

TABLE 5

ID SYMBOL	C	Si	Mn	P	S	Ni	Cr	Mo	Fe
A	0.06	0.45	0.65	0.010	0.011	–	7.80	0.50	BALANCE
B	0.03	0.65	0.70	0.009	0.008	–	5.13	0.53	〃
C	0.03	0.79	0.56	0.009	0.012	0.01	2.34	1.04	〃
D	0.03	0.70	0.90	0.007	0.016	0.03	1.30	0.57	〃

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TABLE 6

SAMPLE NO.	1ST LAYER	2ND LAYER	3RD LAYER	4TH LAYER	5TH LAYER	6TH LAYER	7TH LAYER	8TH LAYER
1	A	B	C	C	C	C	C	C
2	B	C	D	D	D	D	D	D
3	A	B	C	D	D	D	D	D

(Letters A ~D are the identification symbols of welding rods employed.)

FIG. 18

TABLE 7

No.	C	Si	Mn	P	S	Ni	Cr	Mo	Co	Al	Ti	B	Fe	N
1	0.047	<0.01	<0.01	0.02	0.0006	36.5	18.06	2.92	19.10	0.19	2.80	0.005	Bal.	0.0017
2	0.13	0.02	<0.01	0.003	0.0008	Bal.	18.86	9.64	9.92	1.13	2.76	0.011	1.47	0.0014
3	0.12	0.02	<0.01	0.002	0.0003	Bal.	19.0	9.70	–	1.14	2.67	0.007	–	0.0015
4	0.03	<0.01	<0.01	0.002	0.0004	Bal.	12.0	9.93	5.03	0.63	2.67	0.007	3.6	0.0015
5	0.03	<0.01	<0.01	0.002	0.0004	Bal.	12.31	9.96	10.08	0.62	2.67	0.008	3.56	0.0015
6	0.03	<0.01	<0.01	0.002	0.0005	Bal.	12.32	15.04	–	0.62	2.66	0.006	3.55	0.0015
7	0.03	<0.01	<0.01	0.002	0.0004	Bal.	12.31	20.0	–	0.62	2.66	0.006	3.55	0.0015

FIG. 19

TABLE 8

No.	CHEMICAL CONSTITUENTS (wt.%)													CREEP RUPTURE TIME(h) 625°C-30kgf/mm²	
	C	Si	Mn	Ni	Cr	Mo	W	V	Nb	Co	N	B	Fe	ROTOR SHAFT	BLADE
1	0.11	0.01	0.50	0.54	10.72	0.15	2.61	0.20	0.09	2.15	0.025	0.014	Bal	140	278
2	0.11	0.01	0.50	0.50	10.98	0.15	2.59	0.21	0.09	2.87	0.025	0.014	〃	161	315
3	0.11	0.01	0.51	0.53	11.00	0.16	2.55	0.22	0.08	5.79	0.027	0.015	〃	241	508
4	0.11	0.01	0.48	0.49	11.03	0.18	2.60	0.19	0.08	9.43	0.030	0.016	〃	240	488
5	0.12	0.01	1.30	0.11	11.24	0.20	2.65	0.18	0.11	2.98	0.051	0.003	〃	192	392
6	0.13	0.01	0.15	0.89	11.35	0.09	2.91	0.27	0.10	4.50	0.045	0.027	〃	219	456
7	0.09	0.01	0.64	0.09	10.54	0.32	3.33	0.14	0.15	2.77	0.028	0.020	〃	111	225
8	0.15	0.01	0.09	0.33	12.63	0.27	2.46	0.16	0.08	3.01	0.035	0.022	〃	140	286
9	0.12	0.01	0.37	0.71	10.22	0.14	2.41	0.23	0.06	3.45	0.034	0.018	〃	126	258
10	0.11	0.01	0.51	0.50	10.78	0.15	2.58	0.21	0.14	—	0.026	0.013	〃	34	78
11	0.09	0.02	0.53	0.51	11.00	0.23	2.66	0.22	0.07	2.53	0.020	0.018	〃		
12	0.10	0.05	0.48	0.58	10.90	0.20	2.72	0.19	0.05	2.51	0.035	0.011	〃		
13	0.10	0.04	0.50	0.60	11.01	0.20	2.60	0.20	0.06	2.50	0.018	0.010	〃		

FIG.20

TABLE 9

No.	B+N	N/B	B/Co	Co/Mo	Co/Nb
1	0.039	1.79	0.0065	14.3	23.9
2	0.039	1.79	0.0049	19.1	31.9
3	0.042	1.80	−	−	−
4	0.046	1.89	−	−	−
5	0.054	17.0	0.0010	14.9	27.1
6	0.072	1.67	−	−	−
7	0.048	1.40	0.0072	8.7	18.5
8	0.057	1.59	0.0073	11.1	37.6
9	0.052	1.89	0.0052	24.6	57.5
10	0.039	2.00	−	−	−
11	0.038	1.11	0.0071	11.0	36.1
12	0.046	3.18	0.0044	12.6	50.2
13	0.028	1.80	0.0040	12.5	41.7

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TABLE 10

SAMPLE	C	Si	Mn	Ni	Cr	Mo	W	V	Nb	N	B	OTHER	Cr EQUIVALENT	W/MO	MO/CV
1	0.15	0.44	0.77	0.20	1.28	1.12	–	0.19	–	–	–	Ti 0.02	–	–	–
2	0.13	0.40	0.52	0.55	10.25	0.90	–	0.20	0.10	0.05	–	–	9.01	–	–
3	0.12	0.22	0.51	0.82	9.05	0.59	1.59	0.21	0.06	0.05	0.0031	–	7.13	2.70	0.065
4	0.13	0.20	0.50	0.61	8.97	0.11	1.60	0.19	0.07	0.05	0.0019	–	5.31	14.6	0.012
5	0.13	0.22	0.49	0.95	9.00	0.65	1.06	0.20	0.05	0.05	0.0015	–	5.48	1.63	0.072
6	0.12	0.20	0.48	0.61	9.00	0.62	1.66	0.19	0.07	0.03	0.0010	–	8.21	2.68	0.069
7	0.12	0.19	0.50	0.58	9.10	0.68	1.68	0.20	0.06	0.02	0.0015	–	8.66	2.47	0.075
8	0.12	0.15	0.50	0.60	9.51	0.51	1.75	0.20	0.06	0.04	0.0015	–	8.12	3.43	0.054
9	0.12	0.15	0.52	0.55	9.55	0.48	1.90	0.20	0.06	0.04	0.0016	–	–	3.96	0.050

FIG. 22

TABLE 11

SAMPLE	TENSILE STRENGTH (kg/mm)	ELONGATION (%)	CONTRACTION OF AREA (%)	ABSORBED IMPACT ENERGY (kg-m)	625°C, 10^5h CREEP RUPTURE STRENGTH (kg/mm^2)	WELDING CRACK
1	67.4	22.3	68.5	2.1	3	ABSENT
2	71.0	18.0	59.9	1.9	6	ABSENT
3	72.8	19.7	64.8	2.1	9.7	PRESENT
4	71.6	19.9	65.8	2.1	8.5	ABSENT
5	69.8	20.3	62.7	3.5	6.8	–
6	72.5	20.2	64.8	2.4	10	ABSENT
7	72.7	21.0	65.3	2.3	10.2	ABSENT