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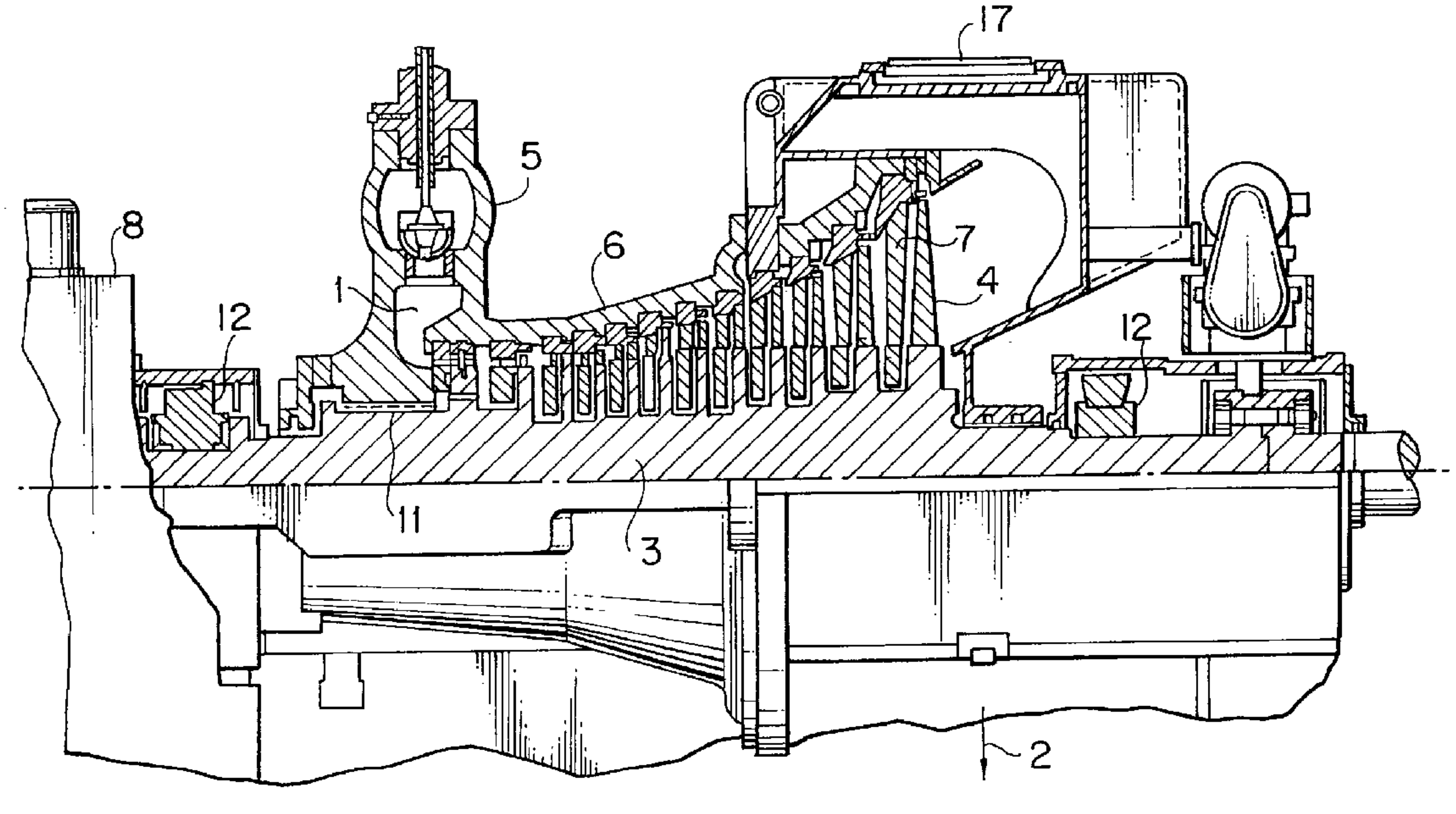

(57) **Abrégé/Abstract**:
A steam turbine that includes a rotor provided with a mono-block rotor shaft. Multi-stage blades are fixed to the rotor shaft from a high pressure side. The steam inlet temperature of the first stage blades is not less than 530°C to a low pressure side. Final stage blades are provided at the low pressure side having a length not less than 40 inches for a shaft rotated at 3000 rpm or a length not less than 33.5 inches for a shaft rotating at 3600 rpm. The final stage blades are illustratively made from a Ti-based alloy.

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ABSTRACT

A steam turbine that includes a rotor provided with a mono-block rotor shaft. Multi-stage blades are fixed to the rotor shaft from a high pressure side. The steam inlet temperature of the first stage blades is not less than 530°C to a low pressure side. Final stage blades are provided at the low pressure side having a length not less than 40 inches for a shaft rotated at 3000 rpm or a length not less than 33.5 inches for a shaft rotating at 3600 rpm. The final stage blades are illustratively made from a Ti-based alloy.

A POWER GENERATION SYSTEM

RELATED APPLICATION

This application is a division of co-pending Canadian Patent Application Serial No. 2,169,779 filed on February 19, 1996, which is a division of Canadian Patent Application Serial No. 2,009,120 filed February 1, 1990.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a combined power generator system comprising a generator driven by both a steam turbine and a gas turbine.

SUMMARY OF THE INVENTION

In accordance with one aspect of the present invention there is provided a steam turbine having a rotor provided with a mono-block rotor shaft, multi-stage blades fixed on the mono-block rotor shaft from a high pressure side at which a steam inlet temperature of first stage blades is not less than 530°C to a low pressure side at which are provided final stage blades having a length not less than 40 inches for a shaft rotated at 3000 rpm or a length not less than 33.5 inches for a shaft rotated at 3600 rpm, said final stage blades comprising a Ti-based alloy.

In accordance with another aspect of the present invention there is provided a steam turbine having a rotor provided with a mono-block rotor shaft, multi-stage blades fixed on the mono-block rotor shaft from a high pressure side at which a steam inlet temperature of first stage blades is not less than 566°C to a low pressure side at which are provided final stage blades having a length not less than 30 inches and comprising a Ti-based alloy.

In accordance with yet another aspect of the present invention there is provided a steam turbine having a rotor provided with a mono-block rotor shaft, multi-stage blades fixed on the mono-block rotor shaft from a high pressure side at which a steam inlet temperature of first stage blades is not less than 566°C to a low pressure side at which are provided final stage blades having a length not less than 30 inches and comprising a martensitic steel containing 10 to 13 wt.% Cr.

In accordance with still yet another aspect of the present invention there is provided a steam turbine having a rotor provided with a mono-block rotor shaft, multi-stage blades fixed on the mono-block rotor shaft from a high pressure side at which a steam inlet temperature of first stage blades is not less than 530°C to a low pressure side at which are provided final stage blades having a length not less than 40 inches for a shaft rotated at 3000 rpm or a length not less than 33.5 inches for a shaft rotated at 3600 rpm.

BRIEF DESCRIPTION OF THE INVENTION

Figures 1, 8 and 9 are partial cross sectional views of a steam turbine using a rotor shaft integrating high and low pressure portions;

Figure 2 is a graph showing a relationship between a ratio (V + Mo)/(Ni + Cr), and creep rupture strength and impact value;

Figure 3 is a graph showing a relationship between creep rupture strength and oxygen;

Figure 4 is a graph showing a relationship between creep rupture strength and Ni; and

Figure 5 to Figure 7 are graphs showing relationships between a V-shaped notch impact value, and Ni, Mn, Si + Mn, a ratio Mn/Ni, and a ratio (Si + Mn)/Ni.

PREFERRED EMBODIMENTS OF THE INVENTION

EXAMPLE 1

A turbine rotor is described below with reference to examples. Table 1 shows chemical compositions of typical specimens subjected to toughness and creep rupture tests. The specimens were obtained in such a manner that they were melted in a high frequency melting furnace, made to an ingot, and hot forged to a size of 30 mm square at a temperature from 850 to 1150°c. The specimens Nos. 1, 3 and 7 to 11 are materials according to the present invention. The specimens Nos. 2, 4 to 6 were prepared for the comparison with the invented materials. The specimen No. 5 is a material corresponding to ASTM A470 Class 8 and the specimen No. 6 is a material corresponding to ASTM A470 Class 7. These specimens were quenched in such a manner that they were made to have austenitic structure by being heated to 950°C in accordance with a simulation of the conditions of the center of a rotor shaft integrating high and low pressure portions of a steam turbine, and then cooled at a speed of 100°C/h. Next, they were annealed by being heated at 665°C for 40 hours and cooled in a furnace. Cr-Mo-V steels according to the present invention included no ferrite phase and were made to have a bainite structure as a whole.

An austenitizing temperature of the invented steels must be 900 to 1000°C. When the temperature is less than 900°C, creep rapture strength is lowered, although superior toughness can be obtained. When the temperature exceeds 1000°C, toughness is lowered, although superior creep rapture strength can be obtained. An annealing temperature must be 630 to 700°C. If the temperature is less than 630°C, superior toughness cannot be obtained, and when it exceeds 700°C, superior creep strength cannot be obtained.

Table 2 shows the results of a tensile strength test, impact test, and creep rupture test. Toughness is shown by Charpy impact absorbing energy of a V-shaped notch tested at 20°C. Creep rupture strength is determined by Larason Mirror method and shown by a strength obtained when a specimen was heated at 538°C for 100,000 hours. As apparent from Table 2, the invented materials have a tensile strength not less than 88 kgf/mm^2 at a room temperature, a 0.2% yield strength not less than 70 kgf/mm^2, an FATT not more than 40°C, an impact absorbing energy not less than 2.5 kgf-m both before they were heated and after they had been heated, and a creep rapture strength not less than about 11 kg/mm^2, and thus they are very useful for a turbine rotor integrating high and low pressure portions. In particular, a material having a strength not less than 15 kg/mm^2 is preferable to plant long blades of 33.5 inches.

Table 1

Specimen No.	Composition (wt%)										$\frac{V+Mo}{Ni+Cr}$	Mn/Ni	$\frac{Si+Mn}{Ni}$
	C	Si	Mn	P	S	Ni	Cr	Mo	V				
1	0.29	0.08	0.18	0.012	0.012	1.85	1.20	1.21	0.22	-	0.47	0.097	0.141
2	0.24	0.06	0.07	0.007	0.010	1.73	1.38	1.38	0.27	-	0.53	0.040	0.075
3	0.27	0.04	0.15	0.007	0.009	1.52	1.09	1.51	0.26	-	0.68	0.099	0.125
4	0.30	0.06	0.19	0.008	0.011	0.56	1.04	1.31	0.26	-	0.98	0.339	0.446
5	0.33	0.27	0.77	0.007	0.010	0.34	1.06	1.28	0.27	-	1.11	2.265	3.059
6	0.23	0.05	0.30	0.009	0.012	3.56	1.66	0.40	0.12	-	0.10	0.084	0.098
7	0.31	0.07	0.15	0.007	0.009	2.00	1.15	1.32	0.22	-	0.49	0.075	0.110
8	0.26	0.06	0.17	0.007	0.008	1.86	1.09	1.41	0.24	La+Ce 0.20	0.56	0.091	0.124
9	0.25	0.07	0.17	0.010	0.010	1.72	1.40	1.42	0.24	Ca 0.005	0.53	0.099	0.140
10	0.24	0.05	0.13	0.009	0.007	1.73	1.25	1.39	0.25	Zr 0.04	0.55	0.075	0.104
11	0.26	0.03	0.09	0.008	0.009	1.71	1.23	1.45	0.23	Al 0.01	0.57	0.052	0.070
12	0.29	0.09	0.23	0.013	0.009	1.70	1.06	1.32	0.25	-	0.57	0.135	0.188
13	0.29	0.21	0.33	0.012	0.007	1.74	1.04	1.20	0.23	-	0.51	0.190	0.310
14	0.31	0.25	0.90	0.010	0.007	1.86	1.06	1.29	0.22	-	0.52	0.484	0.618

Table 2

Value in parenthesis: after heated at 500°C for 3000 h

Specimen No.	Tensile strength (kg/mm^2)	0.02% yield strength (kg/mm^2)	Elongation (%)	Contraction of area (%)	Impact absorbing energy (kg-m)	50% FATT (°C)	538°C Creep rapture strength (kgf/mm2)
1	92.4	72.5	21.7	63.7	3.5 (3.3)	30	12.5
2	92.5	72.6	21.3	62.8	3.3 (3.0)	39	15.6
3	90.8	71.4	22.5	64.0	2.8 (2.7)	38	18.4
4	90.8	71.9	20.4	61.5	1.2	119	15.5
5	88.1	69.2	20.1	60.8	1.3	120	14.6
6	72.4	60.1	25.2	75.2	12.0	-20	5.8
7	89.9	70.3	22.3	64.5	3.6 (3.3)	29	10.8
8	90.8	70.7	21.9	63.9	4.2	21	14.8
9	91.0	71.4	21.7	63.5	3.9	25	15.1
10	92.0	72.2	20.9	62.2	3.7	34	15.6
11	90.6	71.1	21.5	61.8	3.7	36	15.5
12	-	-	-	-	3.0 (2.4)	-	-
13	-	-	-	-	3.4 (2.4)	-	-
14	-	-	-	-	3.6 (2.3)	-	-

Fig. 2 shows a relationship between a ratio of a sum of V and Mo acting as carbide creating elements to a sum of Ni and Cr acting as quenching ability improving elements, and creep rupture strength and impact absorbing energy. The creep rupture strength is increased as the component ratio (V + Mo)/(Ni + Cr) is increased until it becomes about 0.7. It is found that the impact absorbing energy is lowered as the component ratio is increased. It is found that the toughness (vE20 ≧ 2.5 kgf/m) and the creep rupture strength (6R ≧ 11 kgf/mm^2) necessary as the characteristics of a material forming the turbine rotor integrating high and low pressure portions are obtained when (V + Mo)/(Ni + Cr) = 0.45 to 0.7. Further, to examine the brittle characteristics of the invented material No. 2 and the comparative material Nos. 5 (corresponding to a material currently used to a high pressure rotor) and 6 (corresponding to a material currently used to a low pressure rotor), an impact test was effected to specimens before subjected to a brittle treatment for 3000 h at 500°C and those after subjected to the treatment and a 50% fracture appearance transition temperature (FATT) was examined. An FATT of the comparative material No. 5 was increased (made brittle) from 119°C to 135°C (△FATT = 16°C), an FATT of the material No. 6 was increased from -20°C to 18°C (△FATT = 38°C) by the brittle treatment, whereas it was also confirmed that an FATT of the invented material No. 3 remained at 38°C before and after the brittle treatment and thus it was confirmed that this material was not made brittle.

The specimens Nos. 8 to 11 of the invented materials added with rare earth elements (La - Ce), Ca, Zr, and Al, respectively, have toughness improved by these rare earth elements. In particular, the addition of the rare earth elements is effective to improve the toughness. A material added with Y in addition to La - Ce was also examined and it was confirmed that Y was very effective to improve the toughness.

Table 3 shows the chemical compositions and creep rapture strength of the specimens prepared to examine an influence of oxygen to creep rapture strength of the invented materials. A method of melting and forging these specimens were the same as that of the above-mentioned specimens Nos. 1 to 11.

Table 3

Specimen No.	Composition (wt%)									
	C	Si	Mn	P	S	Ni	Cr	Mo	V	O
15	0.26	0.05	0.08	0.008	0.011	1.71	1.24	1.37	0.25	0.0004
16	0.23	0.04	0.10	0.009	0.011	1.60	1.24	1.37	0.25	0.0014
17	0.25	0.05	0.09	0.010	0.012	1.61	1.25	1.36	0.24	0.0019
18	0.24	0.05	0.12	0.008	0.010	1.65	1.20	1.38	0.24	0.0030
19	0.25	0.04	0.11	0.009	0.010	1.69	1.29	1.29	0.23	0.0071
20	0.23	0.06	0.09	0.010	0.012	1.72	1.30	1.32	0.25	0.0087

The specimens were quenched in such a manner that they were austenitized by being heated to 950°C and then by being cooled at a speed of 100°C/h. Next, they were annealed by being heated at 660°C for 40 hours. Table 4 shows 538°C creep rapture strength in the same manner as that shown in Table 2. Figure 3 is a graph showing a relationship between creep rupture strength and oxygen. It is found that a superior creep rupture strength not less than about 12 kgf/mm^2 can be obtained by making O_2 to a level not more than 100 ppm, further, a superior creep rupture strength not less than 15 kgf/mm^2 can be obtained by making O_2 level thereof be not more than 80 ppm, and furthermore, a superior creep rupture strength not less than 18 kgf/mm^2 can be obtained by making O_2 level thereof be not more than 40 ppm.

Table 4

Specimen No.	$\frac{Mn}{Ni}$	$\frac{Si+Mn}{Ni}$	$\frac{V+Mo}{Ni+Cr}$	Creep rupture strength (kgf/mm^2)
15	0.047	0.076	0.55	19.9
16	0.063	0.088	0.57	21.0
17	0.056	0.087	0.56	20.3
18	0.073	0.103	0.57	18.5
19	0.065	0.089	0.51	15.6
20	0.052	0.087	0.52	14.3

Figure 4 is a graph showing a relationship between 538°C, 10^5 hour creep rupture strength and an amount of Ni. As shown in Figure 4, the creep rupture strength is abruptly lowered as an amount of Ni is increased. In particular, a creep rupture strength not less than about 11 kgf/mm^2 is exhibited when an amount of Ni is not more than about 2%, and in particular, a creep rupture strength not less than about 12 kgf/mm^2 is exhibited when an amount of Ni is not more than 1.9%.

Figure 5 is a graph showing a relationship between an impact value and an amount of Ni after the specimens have been heated at 500°C for 3,000 hours. As shown in Figure 5, the specimens of the present invention in which a ratio (Si + Mn)/Ni is not more than 0.18 or in which another ratio Mn/Ni is not more than 0.1 can bring about high impact value by the increase in an amount of Ni, but the comparative specimens Nos. 12 to 14 in which a ratio (Si + Mn)/Ni exceeds 0.18 or in which another ratio Mn/Ni exceeds 0.12 have a low impact value not more than 2.4 kgf-m, and thus an increase in the amount of Ni is little concerned with the impact value.

Likewise, Figure 6 is a graph showing a relationship between impact value after being subjected to heating embrittlement and an amount of Mn or an amount of Si + Mn of the specimens containing 1.6 to 1.9% of Ni. As shown in Figure 6, it is apparent that Mn or (Si + Mn) greatly influences the impact value at a particular amount of Ni. That is, the specimens have a very high impact value when an amount of Mn is not more than 0.2% or an amount of Si + Mn is not more than 0.25%.

Likewise, Figure 7 is a graph showing a relationship between an impact value and a ratio Mn/Ni or a ratio (Si + Mn)/Ni of the specimens containing 1.52 to 2.0% Ni. As shown in Figure 7, a high impact value not less than 2.5kgf-m is exhibited when a ratio Mn/Ni is not more than 0.12 or a ratio Si + Mn/Ni is not more than 0.18.

EXAMPLE 2

Table 5 shows typical chemical compositions (wt%) of specimens used in an experiment.

The specimens were obtained in such a manner that they were melted in a high frequency melting furnace, made to an ingot, and hot forged to a size of 30 mm square at a temperature from 850 to 1250°C. The specimens Nos. 21 and 22 were prepared for the comparison with the invented materials. The specimens Nos. 23 to 32 are rotor materials superior in toughness according to the present invention.

The specimens Nos. 23 to 32 were quenched in such a manner that they were austenitized being heated to 950°C in accordance with a simulation of the conditions of the center of a rotor shaft integrating high and low pressure portions of a steam turbine, and then cooled at a speed of 100°C/h. Next, they were annealed by being heated at 650°C for 50 hours and cooled in a furnace. Cr-Mo-V steel according to the present invention included no ferrite phase and was made to have a bainite structure as a whole.

An austenitizing temperature of the invented steels must be 900 to 1000°C. When the temperature was less than 900°C, creep rupture strength was lowered, although superior toughness can be obtained. When the temperature exceeded 1000°C, toughness was lowered, although superior creep rapture strength was obtained. An annealing temperature must be 630 to 700°C. If the temperature is less than 630°C superior toughness cannot be obtained, and when it exceeds 700°C, superior creep strength cannot be obtained.

Table 6 shows the results of a tensile strength test, impact test, and creep rupture test. Toughness is shown by Charpy impact absorbing energy of a V-shaped notch tested at 20°C and 50% fracture transition temperature (FATT).

The creep rupture test by a notch was effected using specimens each having a notch bottom radius of 66 mm, a notch outside diameter of 9 mm, and a V-shaped notch configuration of 45° (a radius of a notch bottom end) "r" is 0.16 mm).

Table 5

Specimen No.	Composition (wt%)												(ppm)	$\frac{V+Mo}{Ni+Cr}$	$\frac{Mn}{Ni}$
	C	Si	Mn	P	S	Ni	Cr	Mo	W	V	Nb	Others	O_2		
21	0.26	0.27	0.77	0.007	0.010	0.34	1.06	1.28	-	0.27	-	-	26	1.107	2.26
22	0.23	0.05	0.30	0.009	0.012	3.56	1.66	0.40	-	0.12	-	-	20	0.100	0.084
23	0.25	0.02	0.15	0.003	0.004	1.64	1.95	1.40	-	0.27	-	-	19	0.465	0.092
24	0.24	0.02	0.16	0.001	0.006	1.70	1.51	1.68	-	0.27	0.03	-	10	0.607	0.094
25	0.23	0.03	0.15	0.002	0.005	1.65	1.60	1.61	0.21	0.25	-	-	19	0.572	0.091
26	0.24	0.02	0.15	0.001	0.007	1.69	1.52	1.60	0.23	0.25	0.03	-	20	0.576	0.089
27	0.22	0.04	0.16	0.009	0.009	1.63	1.65	1.60	0.26	0.26	-	Ti 0.03 B 0.004	21	0.567	0.098
28	0.24	0.06	0.15	0.005	0.007	1.65	1.57	1.68	-	0.23	0.05	Ca 0.006	18	0.593	0.091
29	0.26	0.03	0.15	0.008	0.011	1.58	1.49	1.70	-	0.25	0.04	La 0.08 Ce 0.09	16	0.633	0.094
30	0.23	0.05	0.14	0.006	0.008	1.71	1.51	1.65	0.27	0.25	-	Al 0.006	16	0.590	0.082
31	0.26	0.08	0.13	0.007	0.006	1.80	1.50	1.73	-	0.24	-	Ta 0.06	17	0.597	0.072
32	0.25	0.04	0.13	0.009	0.009	1.46	1.61	1.63	0.14	0.25	-	Zr 0.31	15	0.612	0.089

Table 6

Specimen No.	Tensile strength (kg/mm^2)	Elongation (%)	Contraction of area (%)	Impact absorbing energy (kg-m)	50% FATT (°C)	538°C Creep rupture strength (kgf/mm^2)
21	88.1	20.1	60.8	1.3	120	14.0
22	72.4	25.2	75.2	12.0	-20	6.5
23	88.9	21.4	70.7	8.7	35	17.5
24	89.0	21.9	71.3	9.5	28	18.9
25	88.1	23.1	73.0	5.8	39	19.2
26	88.3	21.8	72.3	7.2	34	18.3
27	89.5	21.5	71.4	10.6	5	19.1
28	88.2	22.2	72.5	11.7	-2	18.8
29	88.5	22.7	72.8	13.7	-9	19.2
30	91.8	20.0	70.2	10.7	3	18.4
31	91.3	20.1	70.2	11.8	-3	19.3
32	90.8	20.6	70.6	10.8	0	18.5

Creep rupture strength is determined by a Larson Mirror method and shown by strength obtained when a specimen was heated at 538°C for 10^5 hours. As apparent from Table 6, the invented materials have a tensile strength not less than 88 kgf/mm^2 at a room temperature, an impact absorbing energy not less than 5 kgf/mm^2, a 50% FATT not more than 40°C, and a creep rupture strength of 17 kgf/mm^2, and thus they are very useful for a turbine rotor integrating high and low pressure portions.

These invented steels have greatly improved toughness as compared with that of the material (specimen No. 21) corresponding to a material currently used to a high pressure rotor (having a high impact absorbing energy and a low FATT). Further, they have a 538°C, 10^5 hour notch creep rupture strength superior to that of the material (specimen No. 22) corresponding to a material currently used to a low pressure rotor.

In the relationship between a ratio of a sum of V and Mo as carbide creating elements to a sum of Ni and Cr as quenching ability improving elements, and creep rapture strength and impact absorbing energy, the creep rupture strength is increased as the component ratio (V + Mo)/(Ni + Cr) is increased until it becomes about 0.7. The impact absorbing energy is lowered as the component ratio is increased. The toughness (vE20 > 2.5 kgf-m) and the creep rupture strength (R > 11 kgf/mm^2) necessary as the turbine rotor integrating high and low pressure portions are obtained when (V + Mo)/(Ni + Cr) is made to be in the range of 0.45 to 0.7. Further, to examine brittle characteristics of the invented materials and the comparative material No. 21 (corresponding to a material currently used to a high pressure rotor) and the comparative material No. 22 (corresponding to a material currently used to a low pressure rotor), an impact test was effected to specimens before subjected to a brittle treatment at 500°C for 3000 h and those after subjected to the treatment and a 50% fracture transition temperature (FATT) was examined. As a result, an FATT of the comparative material No. 21 was increased (made brittle) from 119°C to 135°C (ΔFATT = 16°C), an FATT of the material, No. 2 was increased from -20°C to 18°C (ΔFATT = 38°C) by the brittle treatment, whereas it was also confirmed that an FATT of the invented materials were 39°C both before and after subjected to the brittle treatment and thus it was confirmed that they were not made brittle.

The specimens Nos. 27 to 32 of the invented materials added with rare earth elements (La - Ce), Ca, Zr, and Al, respectively, have toughness improved thereby. In particular, an addition of the rare earth elements is effective to improve the toughness. A material added with Y in addition to La - Ce was also examined and it was confirmed that Y was very effective to improve the toughness.

As a result of an examination of an influence of oxygen to creep rupture strength of the invented materials, it is found that a superior strength not less than about 12 kgf/mm^2 can be obtained by making O_2 to be in a level not more than 100 ppm, further, a superior strength not less than 15 kgf/mm^2 can be obtained at a level thereof not more than 800 ppm, and, furthermore, a superior strength not less than 18 kgf/mm^2 can be obtained at a level thereof not more than 400 ppm.

As a result of an examination of the relationship between 538°C, 10^5 hour creep rupture strength and an amount of Ni, it is found that the creep rapture strength is abruptly lowered as an amount of Ni is increased. In particular, a strength not less than about 11 kgf/mm^2 is exhibited when an amount of Ni is not more than about 2%, and in particular, a strength not less than about 12 kgf/mm^2 is exhibited when an amount of Ni is not more than 1.9%.

Further, as a result of an examination of a relationship between impact value and an amount of Ni after the specimens have been heated at 500°C for 3000 hours, the specimens according to the present invention in which the ratio (Si + Mn)/Ni is not more than 0.18 bring about high impact values by the increase in an amount of Ni, but the comparative specimens in which the ratio (Si + Mn)/Ni exceeds 0.18 have a low impact value not more than 2.4 kgf/mm^2, and thus an increase in the amount of Ni is little concerned with the impacts value.

As a result of an examination of a relationship between impact value and an amount of Mn or an amount of Si + Mn of the specimens containing 1.6 to 1.9% of Ni, it is found that Mn or Si + Mn greatly influences the impact value at a particular amount of Ni, and the specimens have a very high impact value when an amount of Mn is not more than 0.2% or an amount of Si + Mn is in a range from 0.07 to 0.25%.

As a result of an examination of a relationship between impact value and a ratio Mn/Ni or a ratio (Si + Mn)/Ni of the specimens containing 1.52 to 2.0% of Ni, a high impact value not less than 2.5 kgf/mm^2 is exhibited when the ratio Mn/Ni is not more than 0.12 or the ratio (Si + Mn)/Ni is in a range from 0.04 to 0.18.

EXAMPLE 3

Figure 1 shows a partial cross sectional view of a steam turbine integrating high and low pressure portions. A conventional steam turbine consumes high pressure and temperature steam of 80 atg and 480°C at the main steam inlet thereof and low temperature and pressure steam of 722 mmHg and 33°C at the exhaust portion thereof by a single rotor thereof, whereas the steam turbine integrating high and low pressure portions of the invention can increase an output of a single turbine by increasing a pressure and temperature of steam at the main steam inlet thereof to 100 atg and 536°C, respectively. To increase an output of the single turbine, it is necessary to increase a blade length of movable blades at a final stage and to increase a flow rate of steam. For example, when a blade length of the movable blade at a final stage is increased from 26 inches to 33.5 inches, an ring-shaped band area is increased by about 1.7 times. Consequently, a conventional output of 100 MW is increased to 170 MW, and further when a blade length is increase to 40 inches, an output per a single turbine can be increased by 2 times or more.

When a Cr-Mo-V steel containing 0.5% of Ni is used for a rotor integrating high and low pressure portions as a material of the rotor shaft having blades of a length not less than 33.5 inches, this rotor material can sufficiently withstand an increase in a steam pressure and temperature at the main stream inlet thereof, because this steel is superior in high temperature strength and creep characteristics to be thereby used at a high temperature region. In the case of a long blade of 26 inches, however, tangential stress in a low temperature region, in particular, tangential stress occurring at the center hole of the turbine rotor at a final stage movable blade portion is about 0.95 in a stress ratio (operating stress/allowable stress) when the rotor is rotated at a rated speed, and in the case of a long blade of 33.5 inches, the tangential stress is about 1.1 in the stress ratio, so that the above steel is intolerable to this application.

On the other hand, when 3.5% Ni-Cr-Mo-V steel is used as a rotor material, the above stress ratio thereof is about 0.96 even when long blades of 33.5 inches are used, because this material has toughness in the low temperature region, and tensile strength and yield strength which are 14% higher than those of the Cr-Mo-V steel. However, long blades of 40 inches are used, the above stress ratio is 1.07, and thus this rotor material is intolerable to this application. Since this material has creep rupture stress in the high temperature region which is about 0.3 times that of the CR-Mo-V steel and thus it is intolerable to this application due to lack of high temperature strength.

To increase an output as described above, it is necessary to provide a rotor mateial which simultaneously has both superior characteristics of the Cr-Mo-V steel in a high temperature region and superior characteristics of the Ni-Cr-Mo-V steel in a low temperature region.

When a long blade of a class from 30 to 40 inches is used, a material ahving a tensile strength not less than 88 kgf/mm^2 is necessary, because conventional Ni-Cr-Mo-V steel (ASTM A470 Class 7) has the stress ratio of 1.07, as described above.

Further, a material of a steam turbine rotor integrating high and low pressure portions on, which long blades not less than 30 inches are attached must have a 538°C, 10^5 h creep rapture strength not less than 15 kgf/mm^2 from a view point of securing safety against high temperature breakdown on a high pressure side, and an impact absorbing energy not less than 2.5 kgf-m (3 kg-m/cm^2) from a view point of securing safety against breakdown due to brittleness on a low pressure side.

From the above view point, in the invention there was obtained heat resisting steels which can satisfy the above requirements and which increase an output per a single turbine.

The steam turbine includes thirteen stages of blades 4 planted on a rotor shaft 3 integrating high and low pressure portions, and steam having a high temperature and pressure of 538°C and 88 atg, respectively, is supplied from a steam inlet 1 through a steam control valve 5. The steam flows in one direction from the inlet 1 with the temperature and pressure thereof being decreased to 33°C and 722 mmHg, respectively and then discharged from an outlet 2 through final stage blades 4. Since the rotor shaft integrating high and low pressure portions 3 according to the present invention is exposed to a steam temperature ranging from 538°C to 33°C, forged steel composed of Ni-Cr-Mo-V low alloy steel having the characteristics described inthe example 1 is used. The portions of the rotor shaft 3 where the blades 4 are planted are formed to a disk shape by integrally machining the rotor shaft 3. The shorer the blade is, the longer the disk portion, whereby the vibration thereof is reduced.

The rotor shaft 3 was manufactured in such a manner that cast ingot having the alloy compositions of the specimen No. 16 shown in the example 1 and the specimen No. 24 shown in the example 2, respectively was electro-slug remelted, forged to a shaft having a diameter of 1.2 m, heated at 950°C for 10 hours, and then the shaft was cooled at a cooling speed of 100°C/h by spraying water while it is rotated. Next, the shaft was annealed by being heated at 665°C for 40 hours. A test piece cut from the center of the rotor shaft was subjected to a creep test, an impact test of a V-shaped notch (a cross sectional area of the specimen: 0.8 cm^2) before the specimen was heated and after it had been heated (after it had been heated at 500°C for 300 hours), and a tensile strength test, and values substantially similar to those of the examples 1 and 2 were obtained.

Each portion of the present examples are fabricated from a material having the following composition.

(1) Blade

Blades composed of three stages on a high temperature and pressure side have a length of about 40 mm in an axial direction and are fabricated from forged martensitic steel consisting, by weight, of 0.20 to

0.30% C, 10 - 13% Cr, 0.5 to 1.5% Mo, 0.5 to 1.5% W, 0.1 to 0.3% V, not more than 0.5% Si, not more than 1% Mn, and the balance Fe and incidental impurities.

Blades at an intermediate portion, of which length is gradually made longer as they approach a low pressure side, are fabricated from forged martensitic steel consisting, by weight, of 0.05 to 0.15% C, not more than 1% Mn, not more than 0.5% Si, 10 to 13% Cr, not more than 0.5% Mo, not more than 0.5% Ni, and the balance Fe and incidental impurities.

Blades having a length of 33.5 inches at a final stage, ninety pieces of which were planted around one circumference of a rotor were fabricated from forged martensitic steel consisting, by weight, of 0.08 to 0.15% C, not more than 1% Mn, not more than 0.5% Si, 10 to 13% Cr, 1.5 to 3.5% Ni, 1 to 2% Mo, 0.2 to 0.5% V, 0.02 to 0.08% N, and the balance Fe and incidental impurities. An erosion-preventing shield plate fabricated from a stellite plate was welded to the leading edge of the final stage at the terminal end thereof. Further, a partial quenching treatment was effected regarding portions other than the shield plate. Furthermore, a blade having a length not less than 40 inches may be fabricated from Ti alloy containing 5 to 7% Al and 3 to 5% V.

Each of 4 to 5 pieces of these blades in the respective stages was fixed to a shroud plate through tenons provided at the extreme end thereof and caulked to the shroud plate made of the same material as the blades.

The 12% Cr steel shown above was used to provide a blade which was rotated at 3000 rpm even in a case of its length of 40 inches. Although Ti alloy was used when a blade having a length of 40 inches was rotated at 3600 rpm, the 12% Cr steel was used to provide a blade having a length up to 33. 5 inches and being rotated at 3600 rpm.

(2) Stationary blades 7 provided in the first to third stages at the high pressure side were fabricated from martensitic steel having the same composition as those of the corresponding movable blades and stationary blades other than those of the first to third stages were fabricated from martensitic steel having the same composition as those of the movable blades at the intermediate portion.

(3) A casing 6 was fabricated from Cr-Mo-V cast steel comprising by weight 0.15 to 0.3% C, not more than 0.5% Si, not more than 1% Mn, 1 to 2% Cr, 0.5 to 1.5% Mo, 0.05 to 0.2% V, and not more than 0.1% Ti.

Designated at 8 is a generator capable of generating an output of 100,000 to 200,000 KW. In the present examples, a distance between bearings 12 of the rotor shaft was about 520 cm, an outside diameter of a final blade was 316 cm, and a ratio of the distance between bearings to the outside diameter was 1.65. The generator had a generating capacity of 100,000 KW. A distance between the bearings was 0.52 m per 10,000 KW.

Further, in the present examples, when a blade of 40 inches was used at a final stage, an outside diameter thereof was 365 cm, and thus a ratio of a distance between bearings to this outside diameter was 1.43, whereby an output of 200,000 KW was generated with a distance between the bearings being 0.26 m per 10,000 KW.

In these cases, a ratio of an outside diameter of a portion of the rotor shaft where the blades were planted to a length of the final stage blade is 1.70 for a blade of 33.5 inches and 1.71 for a blade of 40 inches.

In the present examples, steam having a temperature of 566°C was applicable, and pressures thereof of 121, 169, or 224 atg were also applicable.

EXAMPLE 4

Figure 8 is a partially taken-away sectional view of an arrangement of a reheating type steam turbine integrating high and low pressure portions. In this steam turbine, steam of 538°C and 126 atg was supplied from an inlet 1 and discharged from an outlet 9 through a high pressure portion of a rotor 3 as steam of 367°C and 38 atg, and further steam having been heated to 538°C and to a pressure of 35 atg was supplied from an inlet 10, flowed to a low pressure portion of the rotor

3 through an intermediate pressure portion thereof, and discharged from an outlet 2 as steam having a temperature of about 46°C and a pressure of 0.1 atg. A part of the steam discharged from the outlet 9 is used as a heat source for the other purpose and then again supplied to the turbine from the inlet 10 as a heat source therefor. If the rotor for the steam turbine integrating high and low pressure portions is fabricated from the material of the specimen No. 5 of the example 1, the vicinity of the steam inlet 1, i.e., a portion a will have sufficient high temperature strength, however, since the center of the rotor 3 will have a high ductility-brittle transition temperature of 80 to 120°C, there will be caused such drawback that, when the vicinity of the steam outlet 2, i.e., a portion b has a temperature of 50°C, the turbine is not sufficiently ensured with respect to safety against brittle fracture. On the other hand, if the rotor 3 is fabricated from the material of the specimen No. 6, safety against brittle fracture thereof at the vicinity of the steam outlet 2, i.e., the portion b will be sufficiently ensured, since a ductility-brittle transition temperature at the center of the rotor 3 is lower than a room temperature, however, since the vicinity of the steam inlet 1, i.e., the portion a will have insufficient high temperature strength and since the alloy constituting the rotor 3 contains a large amount of Ni, there will be such a drawback that the rotor 3 is apt to become brittle when

it is used (operated) at a high temperature for a long time. More specifically, even if any one of the materials of the specimens Nos. 5 and 6 is used, the steam turbine rotor integrating high and low pressure portions made of the material composed of the specimens No. 5 or 6 has a certain disadvantage, and thus it cannot be practically used. Note that, in Figure 8, 4 designates a movable blade, 7 designates a stationary blade, and 6 designates a casing, respectively. A high pressure portion was composed of five stages and a low pressure portion was composed of six stages.

In this example, the rotor shaft 3, the movable blades 4, the stationary blades 7, and the casing 6 were formed of the same materials as those of the above-mentioned example 3. The movable blade at a final stage had a length not less than 33.5 inches and was able to generate an output of 120,000 KW. Similar to the example 3, 12% Cr steel or Ti alloy steel is used for this blade having length of not less than 33.5 inches. A distance between bearings 12 was about 454 cm, a final stage blade of 33.5 inches in length had a diameter of 316 cm and a ratio of the distance between the bearings to this outside diameter was 1.72. When a final stage blade of 40 inches in length was used, an output of 200,000 KW was generated. The blade portion thereof had a diameter of 365 cm and a ratio of a distance between bearings to this diameter was 1.49. A distance between the bearings per a generated output of

10,000 KW in the former of 33.5 inches was 0.45 m and that in the latter of 40 inches was 0.27 m. The above mentioned steam temperature and pressures were also applicable to this example.

EXAMPLE 5

The rotor shaft integrating high and low pressure portions was also able to be applied to a single flow type steam turbine in which a part of steam of an intermediate pressure portion of a rotor shaft was used as a heat source for a heater and the like. The materials used in the example 3 were used regarding the rotor shaft, movable blades, stationary blades and casing of this example.

EXAMPLE 6

The steam turbines described in the examples 3 to 5 were directly connected to a generator, and a gas turbine was directly connected to the generator. A steam turbine of this example was applied to a combined generator system, wherein steam was generated by a waste-heat recovery boiler using exhaust combustion gas occurring in the gas turbine and the steam turbine was rotated by the steam. The gas turbine generated an output of about 40,000 KW and the steam turbine generated an output of about 60,000 KW, and thus this combined generator system generated a total output of

100,000 KW. Since the steam turbine of this example was made compact, it was manufactured at a cost lower than that of a conventional large stem turbine supposing that they have the same generating capacity and it has an advantage of being economically operated when an output to be generated fluctuates.

In the gas turbine, air compressed by a compressor was fed in a burner to produce a combustion gas having a high temperature not less than 1100°C and a disc on which blades were planted was rotated by the combustion gas. The disc was formed of three stages, wherein a movable blade was fabricated from Ni base cast alloy containing by weight 0.04 to 0.1% C, 12 to 16% Cr, 3 to 5% Al, 3 to 5% Ti, 2 to 5% Mo, and 2 to 5% Ni and a stationary blade was fabricated from Co base cast alloy containing by weight 0.25 to 0.45 C, 20 to 30% Cr, 2 to 5% at least one selected from the group consisting of Mo and W, and 0.1 to 0.5% at least one selected from the group consisting of Ti and Nb. A burner liner was fabricated from FE-Ni-Cr austenitic alloy containing by weight 0.05 to 0.15% C, 20 to 30% Cr, 30 to 45% Ni, 0.1 to 0.5% at least one selected from the group consisting of Ti and Nb, and 2 to 7% at least one selected from the group consisting of Mo and W. A heat shielding coating layer made of a Y_2O_2 stabilizing zirconia sprayed onto the outer surface of the liner was provided to the flame side of the liner. Between the Fe-Ni-Cr austenitic alloy and the zirconia layer was disposed a MCrAlY alloy layer consisting, by weight, of 2 to 5% Al, 20 to 30% Cr, 0.1 to 1% Y, and at least one selected from the group consisting of Fe, Ni and Co, that is, M is at least one selected from the group consisting of Fe, Ni and Co.

An Al-diffused coating layer was provided on the movable and stationary blades shown above.

A material of the turbine disc was fabricated from a martensitic forged steel containing by weight 0.15 to 0.25% C, not more than 0.5% Si, not more than 0.5% Mn, 1 to 2% Ni, 10 to 13% Cr, 0.02 to 0.1% at least one selected from the group consisting of Nb and Ta, 0.03 to 0.1% N, and 1.0 to 2.0% Mo; a turbine spacer, distant piece and compressor disc at a final stage being fabricated from the same martensitic steel, respectively.

EXAMPLE 7

Figure 9 is a partially sectional view of a steam turbine integrating high and low pressure portions. A rotor shaft integrating high and low pressure portions 3 used in this example was fabricated from the Ni-Cr-Mo-V steel having the bainite structure as a whole described in the example 3. The left side is a high pressure side and the right side is a low pressure side in Figure 9, and a final stage blade had a length of 33.5 or 40 inches. Blades on the left high pressure side were made of the same material as that described in the example 3 and final stage blades were made of the same material as that described in the Example 3. Steam of this example had a temperature of 538°C and a pressure of 102 kg/cm^2 at an inlet and had an temperature no more than 46°C and a pressure not more than an atmospheric pressure at an outlet, which steam was supplied to a condenser as shown by numeral 2. A material of the rotor shaft of this example had an FATT not more than 40°C, a V-shaped notch impact value at a room temperature not less than 4.8 kgf-mm^2 (a cross sectional area: not less than 0.8 cm^2), a tensile strength at a room temperature not less than 81 kgf/mm^2, a 0.2 yield strength not less than 63 kgf/mm^2, an elongation not less than 16%, a contraction of area not less than 45 percent, and a 538°C, 10^5 hour creep rupture strength not less than 11 kgf/mm^2. Steam was supplied from an inlet 14, discharged from an outlet 15 through high pressure side blades, again supplied to a reheater 13, and supplied to a low pressure side as high temperature steam of 538°C and 35 atg. Designated at 12 are bearings disposed at the opposite sides of the rotor shaft 3, and a distance between bearings was about 6 m. The rotor of this example rotated at 3600 rpm and generated an output of 120,000 KW. Blades 4 were composed of six stages on the high pressure side and ten stages on the low pressure side. In this example, a distance between bearings was 0.5 m per a generated output of 10,000 KW, and thus the distance was about 40%

shorter than a conventional distance of 1.1 m.

Further, in this example, a final stage blade of 33.5 inches had a diameter of 316 cm and thus a ratio of a distance between the bearings to this outside diameter was 2.22. In another case, a final stage blade of 40 inches having a diameter of 365 cm was used, a ratio of the distance between the bearings to the diameter being 1.92, which enables an output of 200,000 KW to be generated. As a result, a distance between the bearings per a generated output of 10,000 KW was 0.3 m in this another case, whereby the steam turbine was able to be made very compact.

CLAIMS:

1. A steam turbine having a rotor provided with a mono-block rotor shaft, multi-stage blades fixed on the mono-block rotor shaft from a high pressure side at which a steam inlet temperature of first stage blades is not less than 530°C to a low pressure side at which are provided final stage blades having a length not less than 40 inches for a shaft rotated at 3000 rpm or a length not less than 33.5 inches for a shaft rotated at 3600 rpm, said final stage blades comprising a Ti-based alloy.

2. A steam turbine according to claim 1, wherein blades from the first stage blades to at least a third stage at the high pressure side comprise a martensitic steel containing, by weight, 0.20 to 0.30% C, not more than 0.5% Si, not more than 1% Mn, 10 to 13% Cr, 0.5 to 1.5% Mo, 0.5 to 1.5% W, and 0.1 to 0.35% V.

3. A steam turbine according to claim 2, wherein blades at an intermediate portion between said third stage comprise a martensitic steel containing, by weight, 0.05 to 0.15% C, not more than 0.5% Si, not more than 1% Mn, 10 to 13% Cr, not more than 0.5% Ni, and not more than 0.5% Mo.

4. A high and low pressure sides-integrating steam turbine, comprising a rotor provided with a mono-block rotor shaft and multi-stage blades fixed on the mono-block rotor shaft from a high pressure side to a low pressure side of the turbine at which are provided final stage blades having a length not less than 40 inches for a shaft rotated at 3000 rpm or a length not less than 33.5 inches for a shaft rotated at 3600 rpm, said final stage blades comprising a Ti-based alloy, and a casing covering the rotor, said rotor shaft being formed of a mono-block shaft from the high pressure side at which steam having a temperature not less than 530°C is introduced onto the first stage blades, said steam turbine further comprising a high temperature and high pressure turbine portion, and a high temperature and intermediate pressure to low temperature and low pressure turbine portion in which a high temperature and intermediate pressure state is shifted to a low pressure state, and wherein steam flowing out of the high temperature and high pressure turbine portion is re-heated and is introduced in the high temperature and intermediate pressure side of the high temperature and intermediate pressure to low temperature and low pressure turbine portion.

5. A steam turbine having a rotor provided with a mono-block rotor shaft, multi-stage blades fixed on the mono-block rotor shaft from a high pressure side at which a steam inlet temperature of first stage blades is not less than 566°C to a low pressure side at which are provided final stage blades having a length not less than 30 inches and comprising a Ti-based alloy.

6. A steam turbine according to claim 5, wherein said mono-block rotor shaft is supported by bearings, and wherein said Ti-based alloy contains, by weight, 5 to 7% Al and 3 to 5% V.

7. A steam turbine having a rotor provided with a mono-block rotor shaft, multi-stage blades fixed on the mono-block rotor shaft from a high pressure side at which a steam inlet temperature of first stage blades is not less than 566°C to a low pressure side at which are provided final stage blades having a length not less than 30 inches and comprising a martensitic steel containing 10 to 13 wt.% Cr.

8. A steam turbine according to claim 7, wherein said martensitic steel contains, by weight, 0.08 to 0.15% C, not more than 0.5% Si, not more than 1% Mn, 10 to 13% Cr, 1.5 to 3.5% Ni, 1 to 2% Mo, 0.2 to 0.5% V, and 0.02 to 0.08% N.

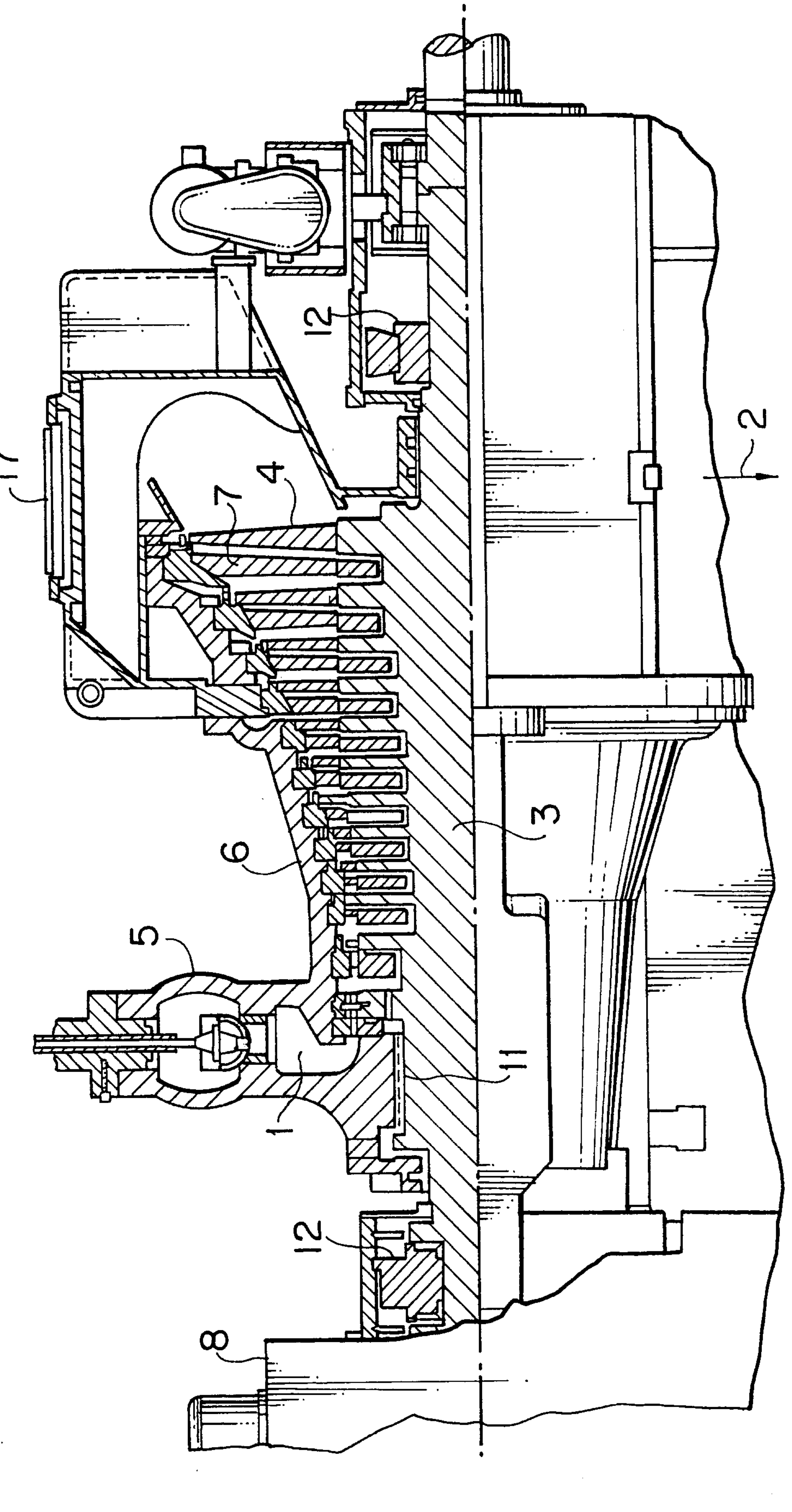
9. A high and low pressure sides-integrating steam turbine, comprising a rotor provided with a mono-block rotor shaft and multi-stage blades fixed on the mono-block rotor shaft from a high pressure side to a low pressure side of the turbine, and a casing covering the rotor, said rotor shaft being a mono-block type and being formed of a mono-block shaft from the high pressure side at which steam having a temperature not less than 566°C is introduced onto the first stage blades, said steam turbine further comprising a high temperature and high pressure turbine portion, and a high temperature and intermediate pressure to low temperature and low pressure turbine portion in which a high temperature and intermediate pressure state is shifted to a low pressure state, and wherein steam flowing out of the high temperature and high pressure turbine portion is re-heated and is introduced in the high temperature and intermediate pressure side of the high temperature and intermediate pressure to low temperature and low pressure turbine portion.

10. A steam turbine having a rotor provided with a mono-block rotor shaft, multi-stage blades fixed on the mono-block rotor shaft from a high pressure side at which a steam inlet temperature of first stage blades is not less than 530°C to a low pressure side at which are provided final stage blades having a length not less

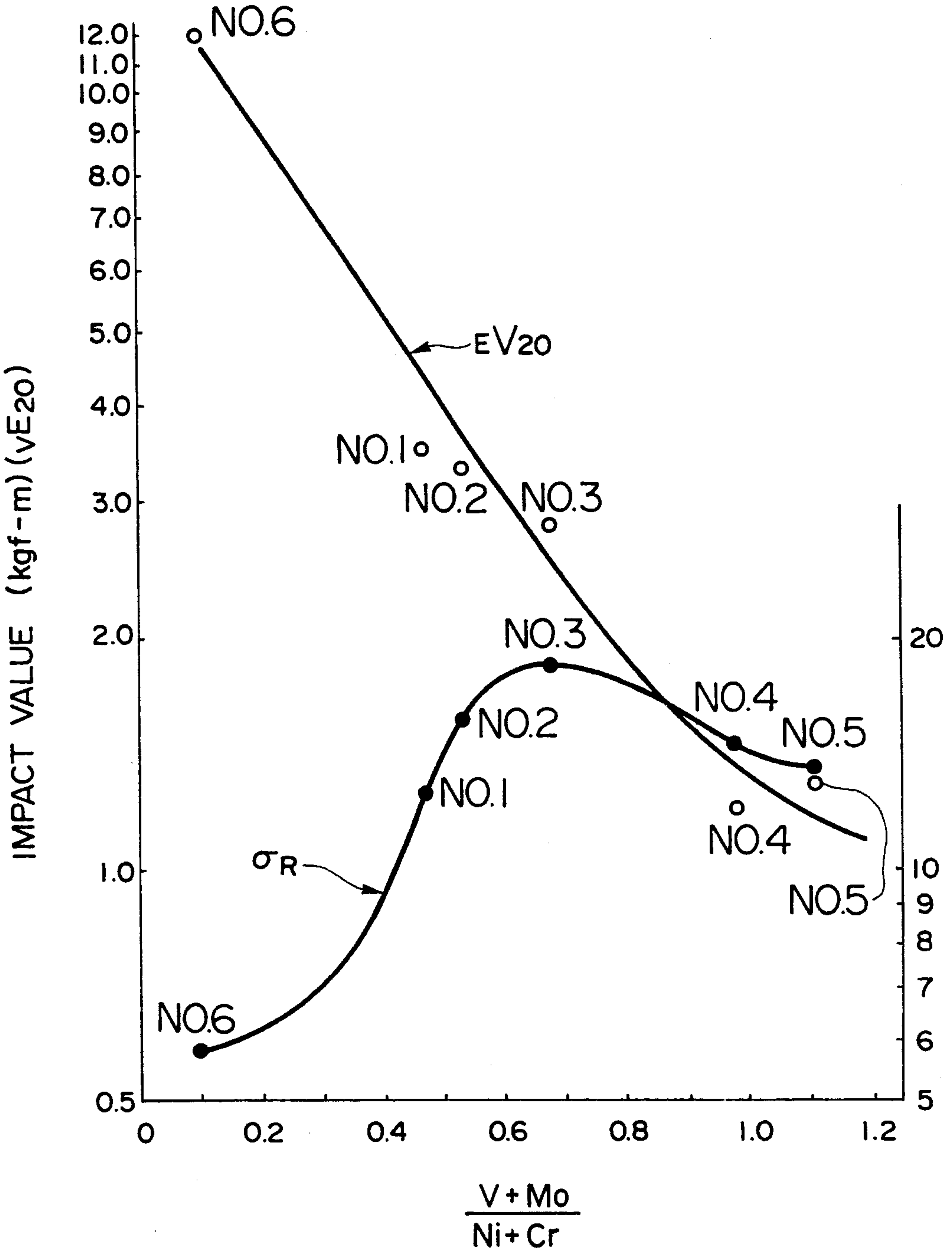
than 40 inches for a shaft rotated at 3000 rpm or a length not less than 33.5 inches for a shaft rotated at 3600 rpm.

11. A high and low pressure sides-integrating steam turbine, comprising a rotor provided with a mono-block rotor shaft and multi-stage blades fixed on the mono-block rotor shaft from a high pressure side to a low pressure side of the turbine at which are provided final stage blades having a length not less than 40 inches for a shaft rotated at 3000 rpm or a length not less than 33.5 inches for a shaft rotated at 3600 rpm, and a casing covering the rotor, said rotor shaft being formed of a mono-block shaft from the high pressure side at which steam having a temperature not less than 530°C is introduced onto the first stage blades, said steam turbine further comprising a high temperature and high pressure turbine portion, and a high temperature and intermediate pressure to low temperature and low pressure turbine portion in which a high temperature and intermediate pressure state is shifted to a low pressure state, and wherein steam flowing out of the high temperature and high pressure turbine portion is re-heated and is introduced in the high temperature and intermediate pressure side of the high temperature and intermediate pressure to low temperature and low pressure turbine portion.

FIG. I



F I G. 2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4.0
3.0
2.0
1.0
0.5
20
10
9
8
7
6
5
0
0.2
0.4
0.6
0.8
1.0
1.2
NO.6
NO.1
NO.2
NO.3
NO.4
NO.5
EV20
σR
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NO.2
NO.1
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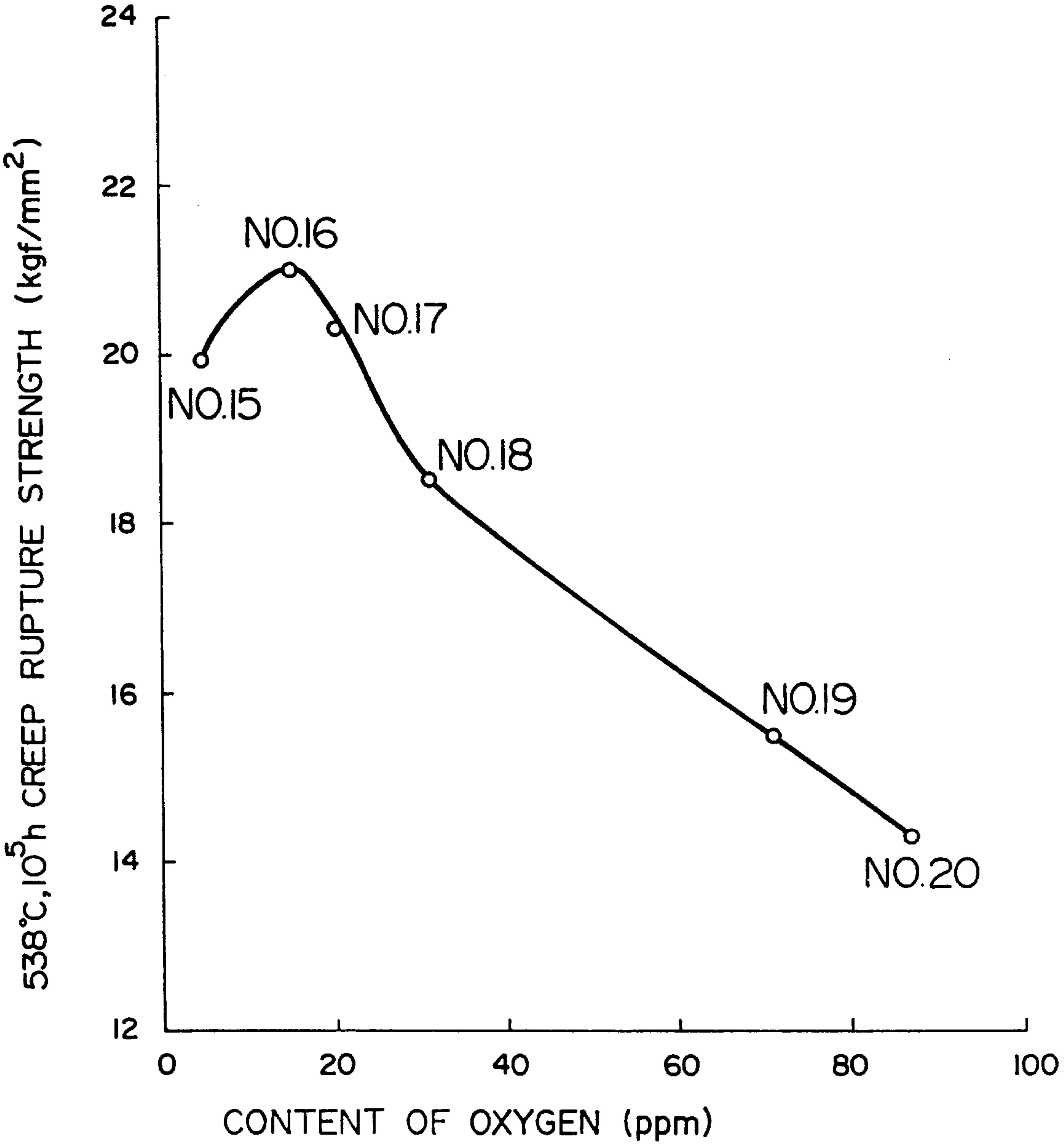
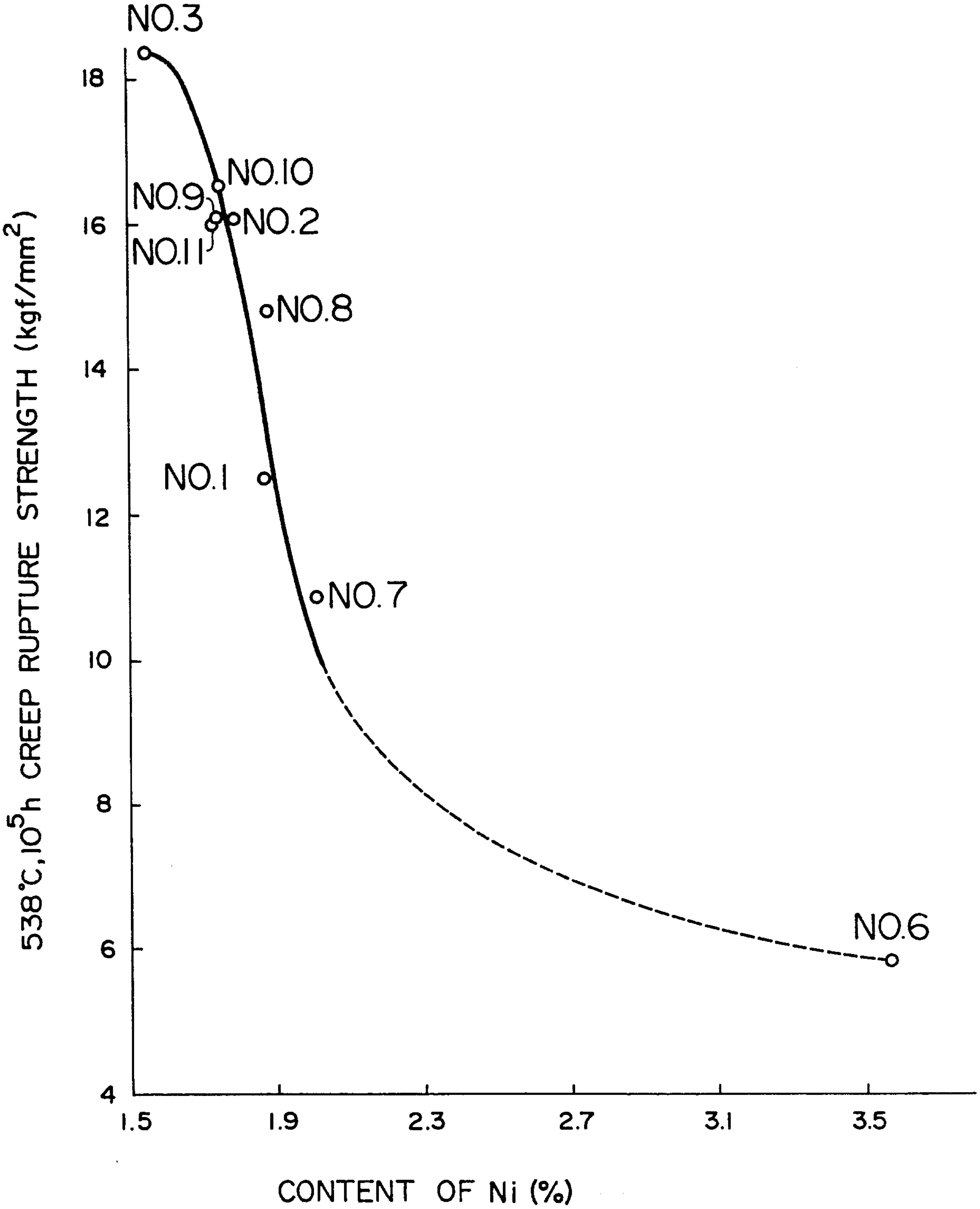
NO.5
V+Mo / Ni+Cr

F I G. 3


538°C, 10⁵h CREEP RUPTURE STRENGTH (kgf/mm²)
CONTENT OF OXYGEN (ppm)
24
22
20
18
16
14
12
0
20
40
60
80
100
NO.15
NO.16
NO.17
NO.18
NO.19
NO.20

F I G. 4


NO.3
NO.10
NO.9
NO.2
NO.11
NO.8
NO.1
NO.7
NO.6
538°C, 10^5h CREEP RUPTURE STRENGTH (kgf/mm^2)
18
16
14
12
10
8
6
4
1.5
1.9
2.3
2.7
3.1
3.5
CONTENT OF Ni (%)

F I G. 5

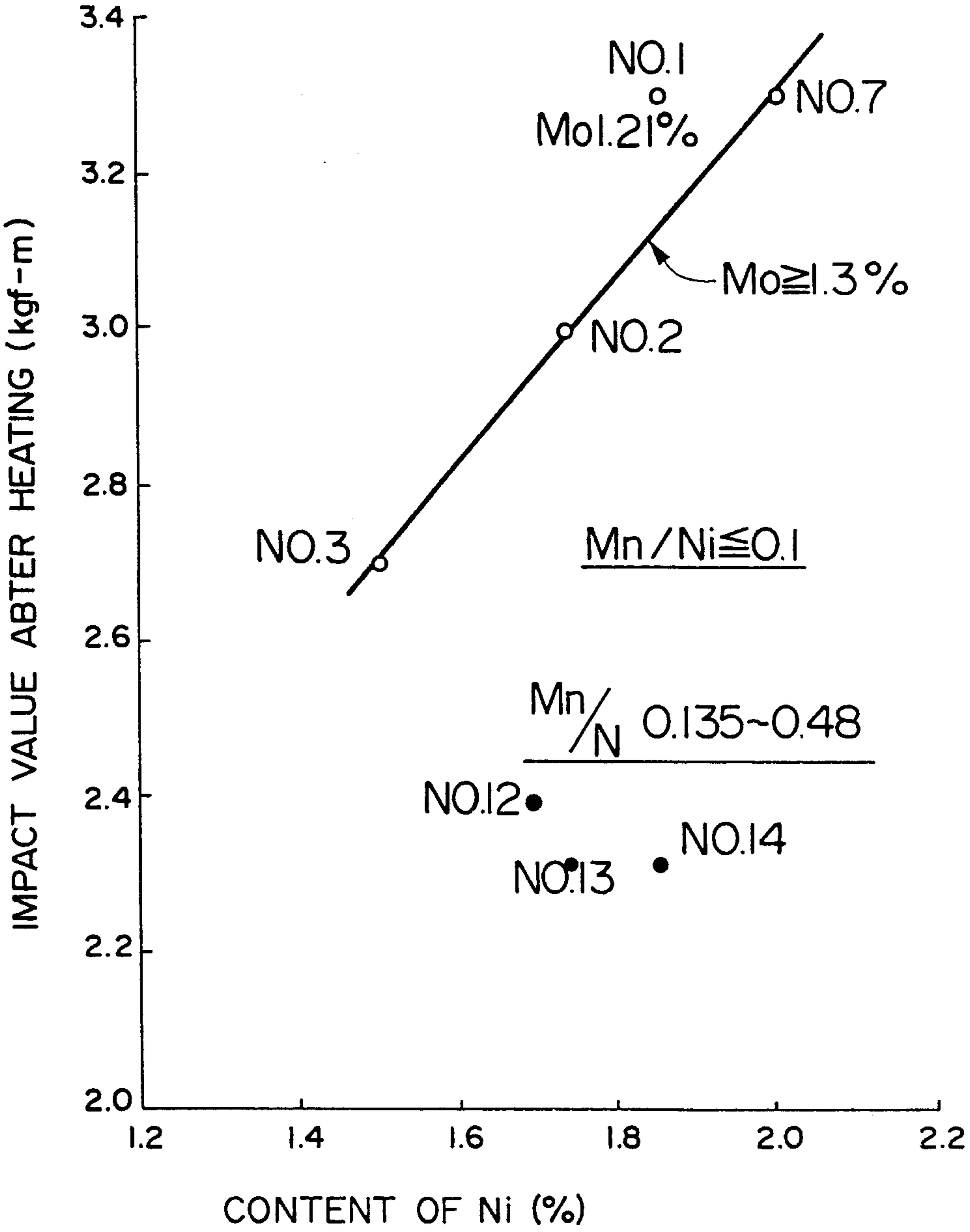
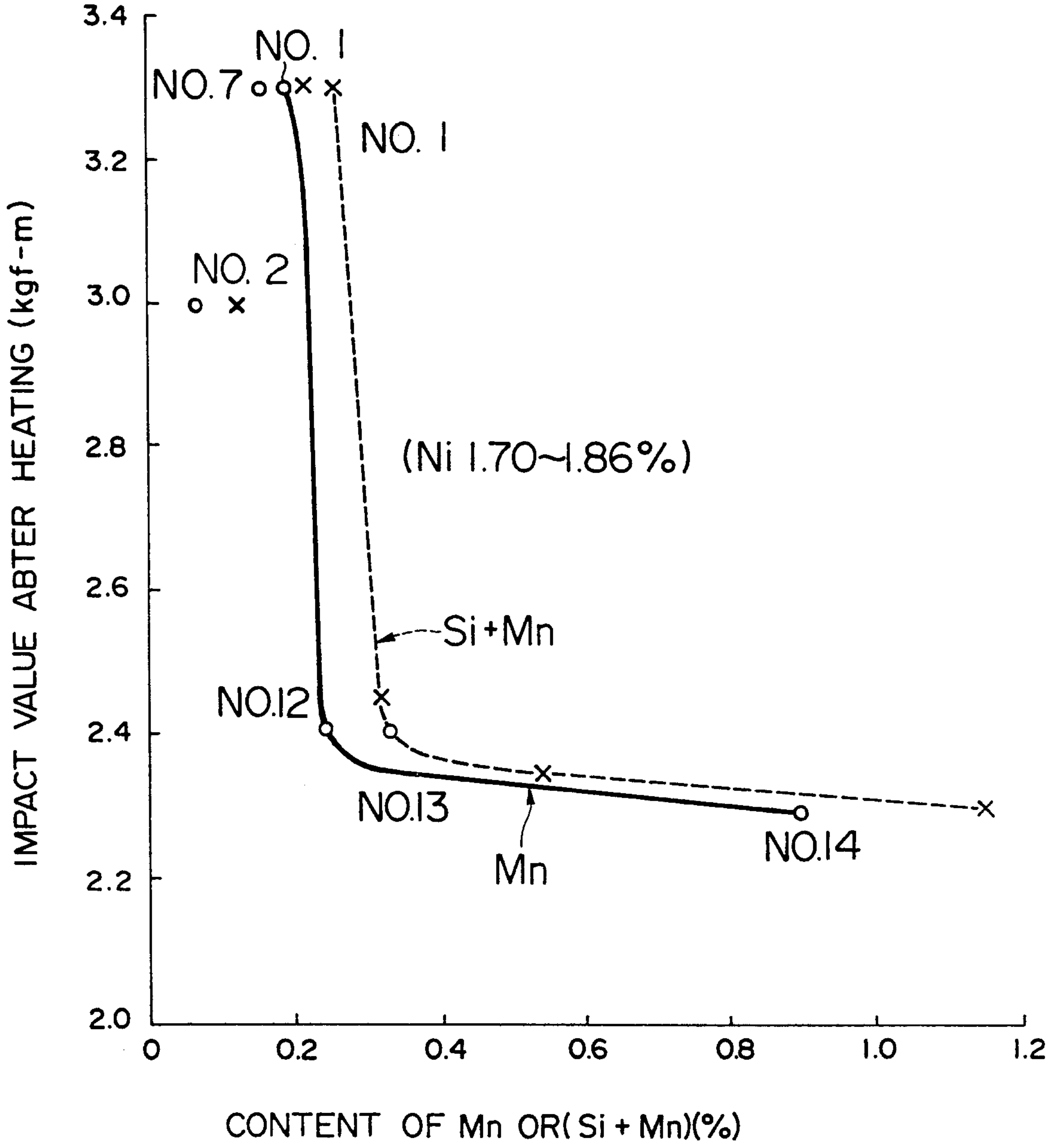
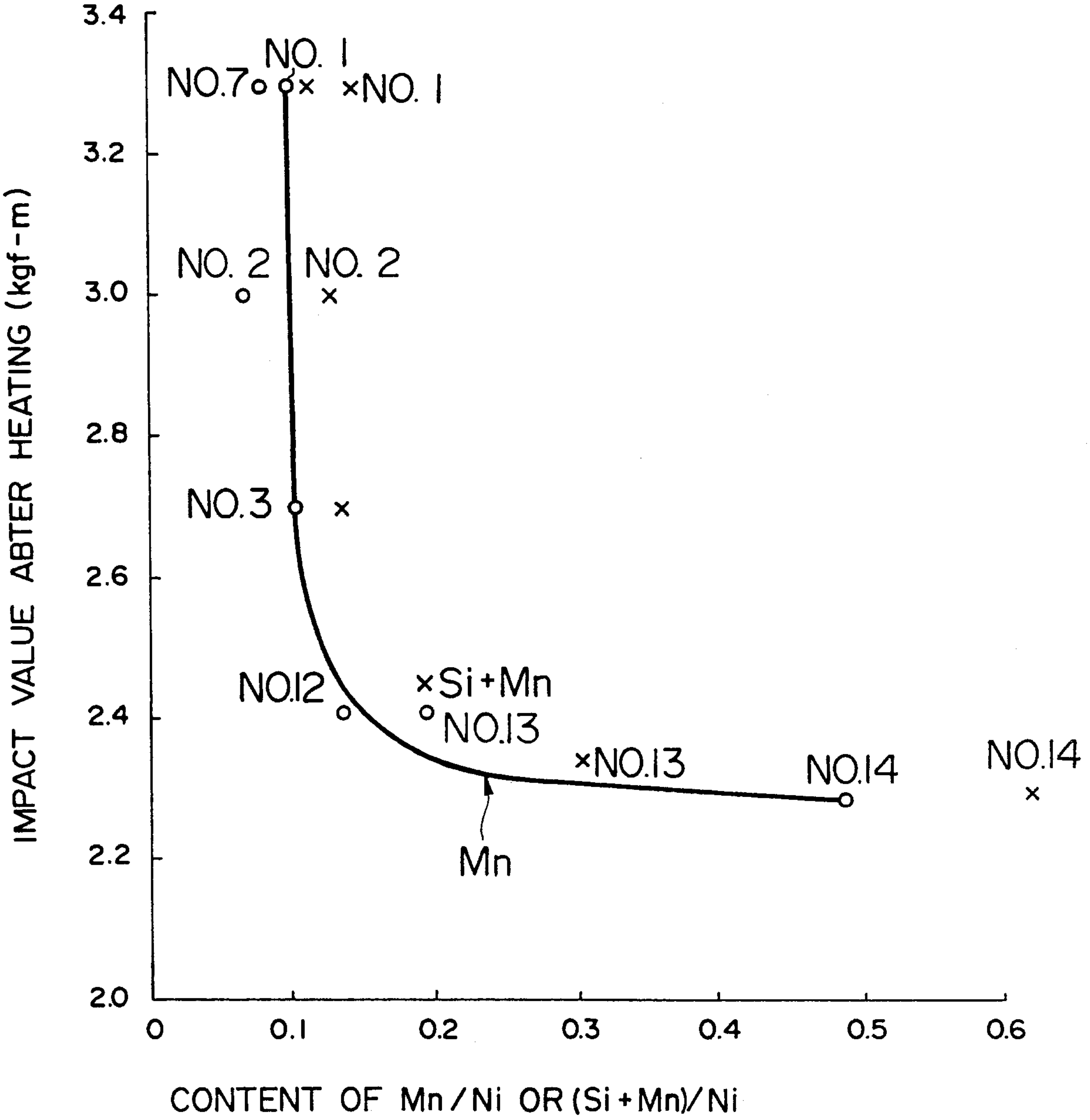

IMPACT VALUE ABTER HEATING (kgf-m)
CONTENT OF Ni (%)
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.2
1.4
1.6
1.8
2.0
2.2
NO.1
Mo1.21%
NO.7
Mo≧1.3%
NO.2
NO.3
Mn/Ni≦0.1
Mn/N 0.135~0.48
NO.12
NO.13
NO.14

FIG. 6


3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
0
0.2
0.4
0.6
0.8
1.0
1.2
IMPACT VALUE ABTER HEATING (kgf-m)
CONTENT OF Mn OR(Si + Mn)(%)
NO. 1
NO.7
NO. 1
NO. 2
(Ni 1.70~1.86%)
Si+Mn
NO.12
NO.13
Mn
NO.14

F I G. 7


IMPACT VALUE ABTER HEATING (kgf-m)
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3.2
3.0
2.8
2.6
2.4
2.2
2.0
0
0.1
0.2
0.3
0.4
0.5
0.6
CONTENT OF Mn/Ni OR (Si+Mn)/Ni
NO. 1
NO.7
×NO. 1
NO. 2
NO. 2
NO.3
NO.12
×Si+Mn
NO.13
×NO.13
NO.14
NO.14
Mn

FIG.8

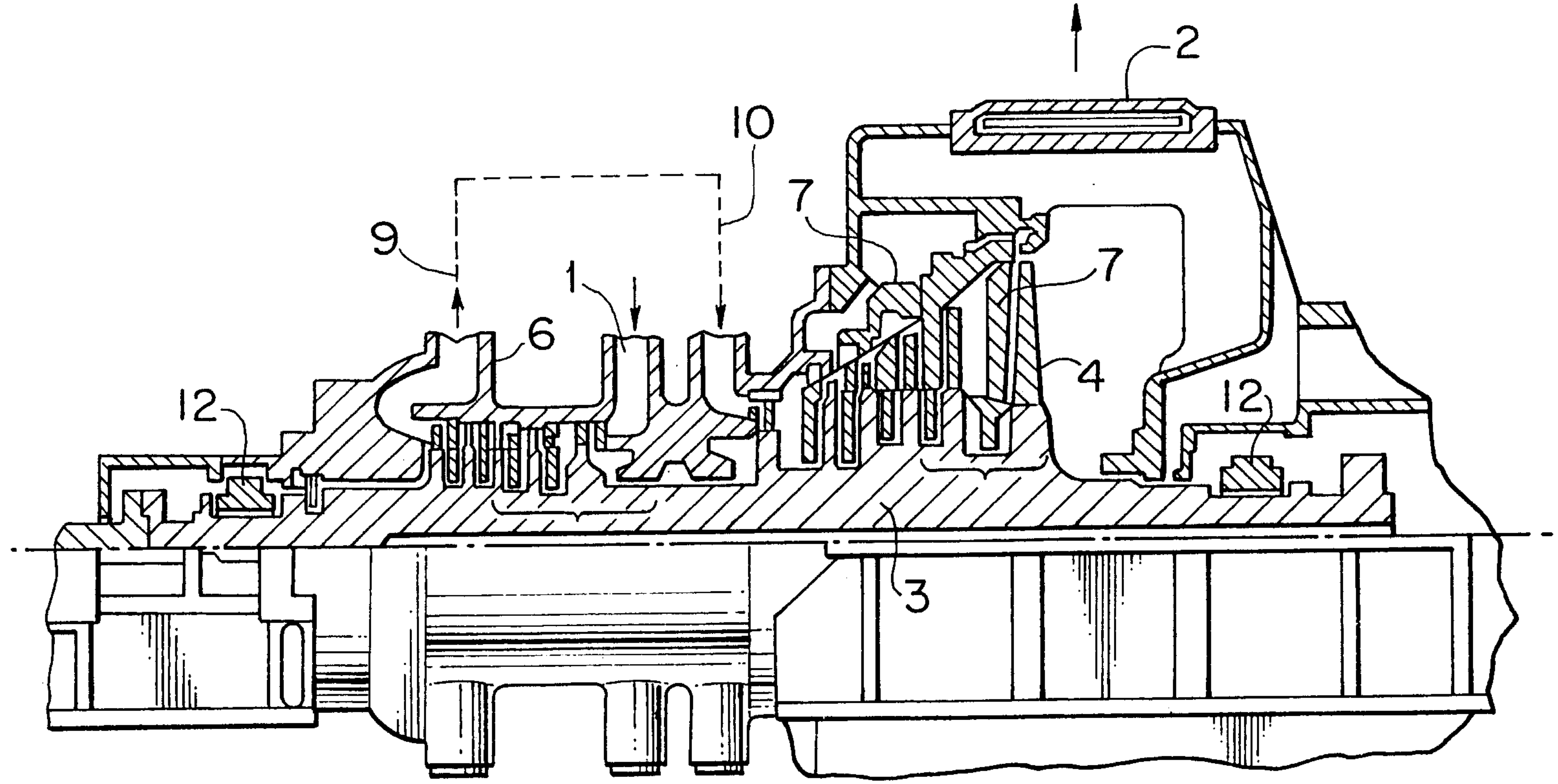
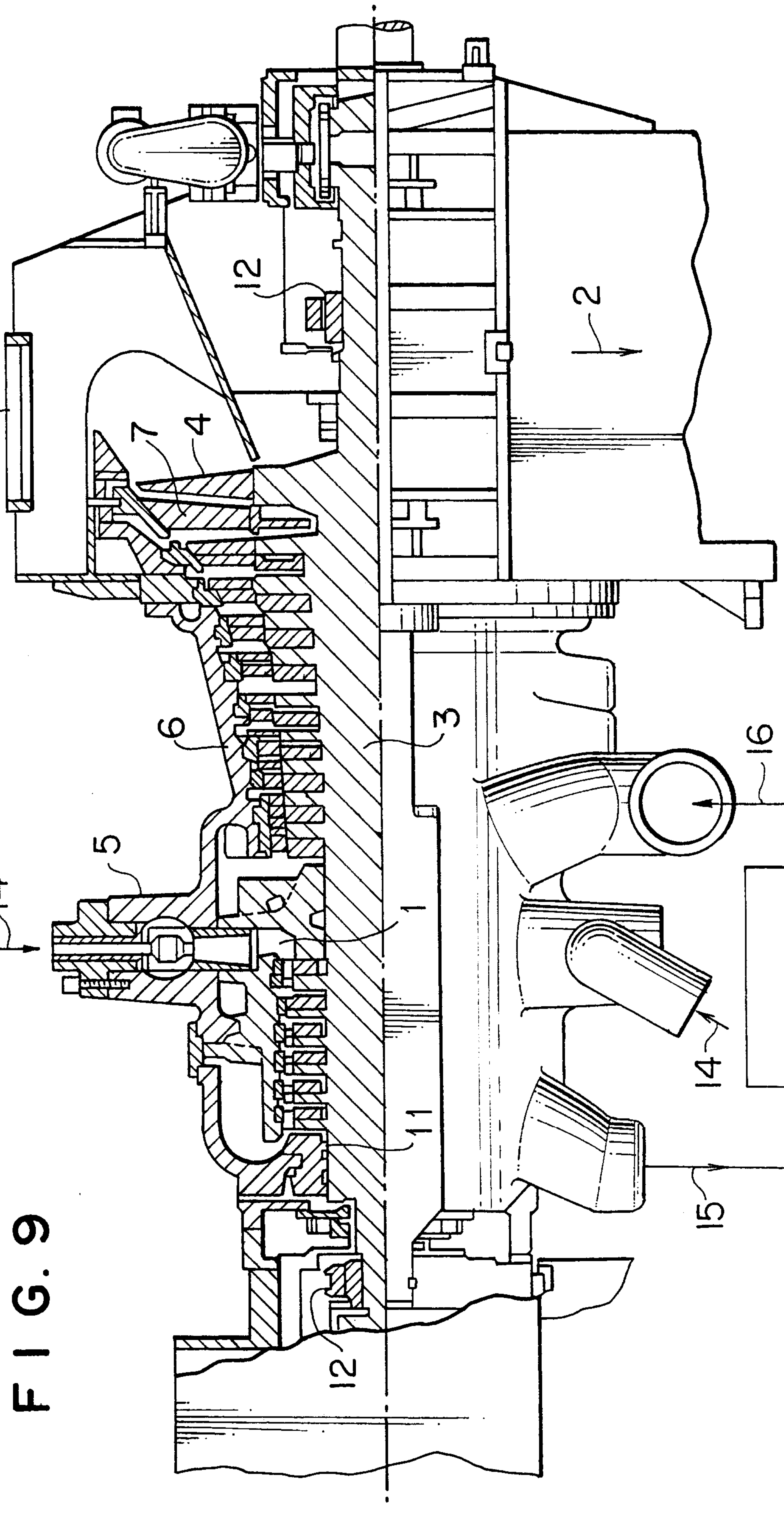
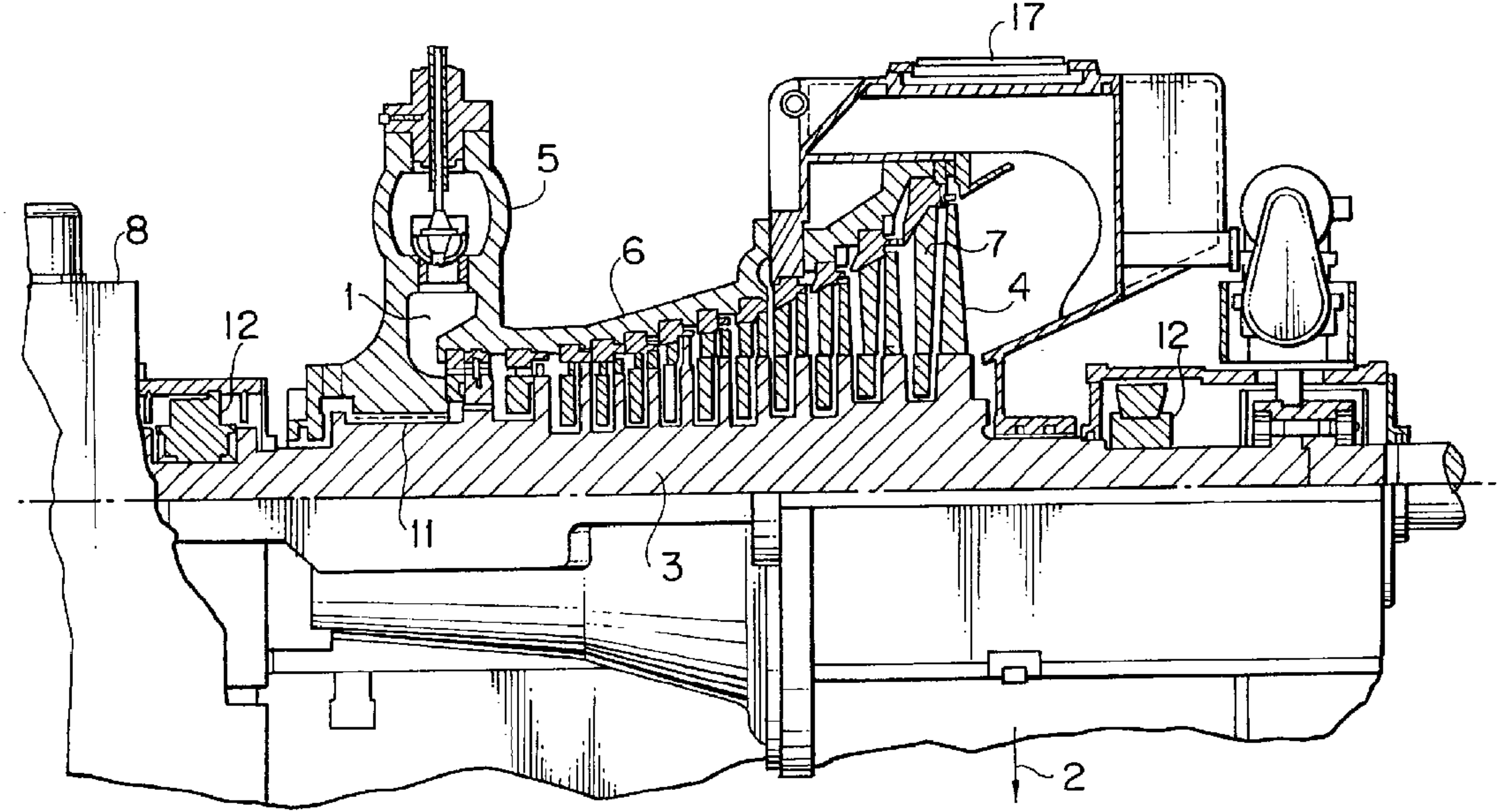


FIG. 9




17
5
8
6
7
1
4
12
12
11
3
2