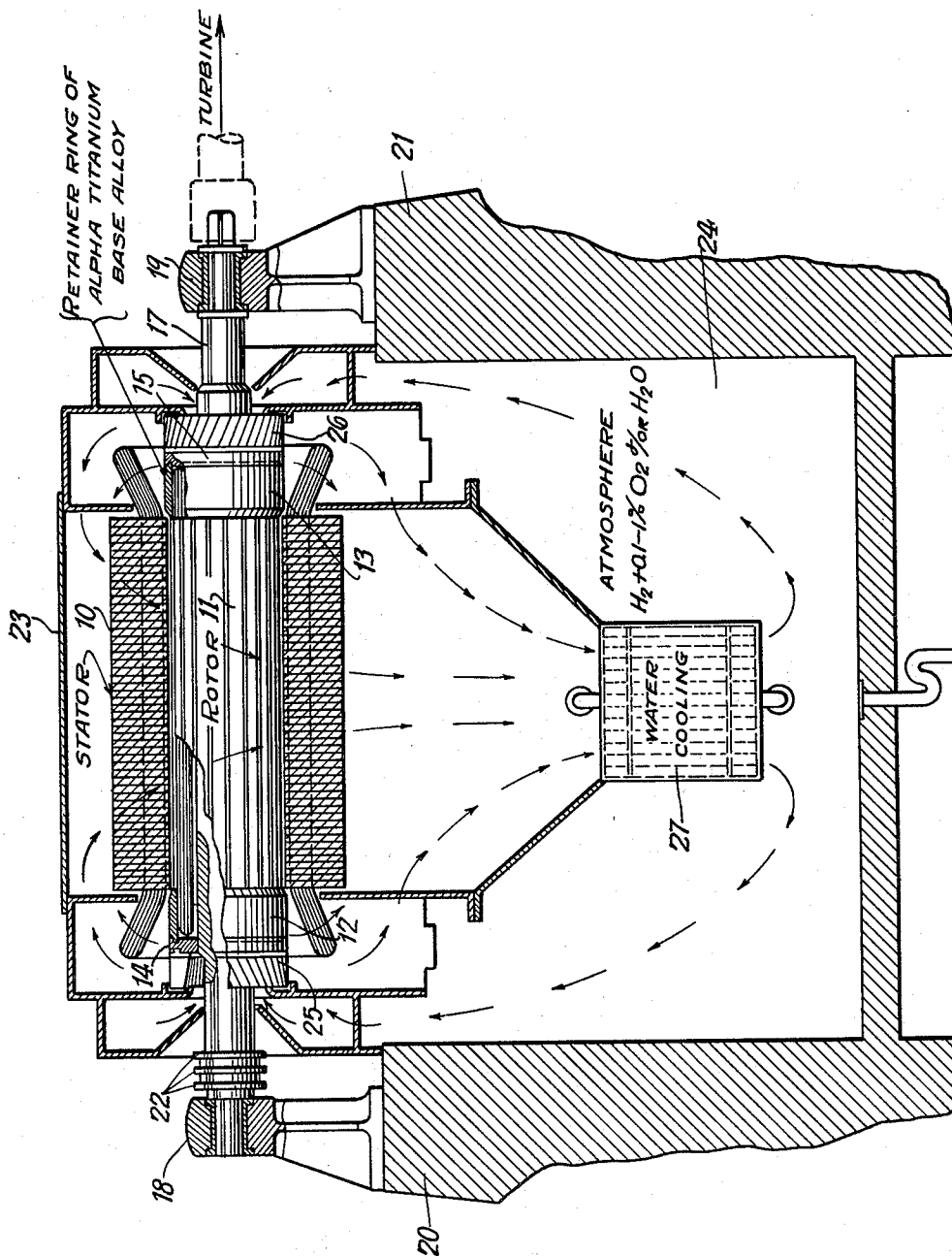


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FOR DYNAMOELECTRIC MACHINES
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TITANIUM ALLOY ARTICLES RESISTANT TO HYDROGEN ABSORPTION FOR DYNAMO-ELECTRIC MACHINES

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This invention pertains to articles made of titanium base alloys which are highly resistant to hydrogen absorption at temperatures up to about 400° C., and means for minimizing hydrogen absorption in articles made of titanium and titanium base alloys which are exposed in service to hydrogen or hydrogen-containing atmospheres at such elevated temperatures.

The invention finds special application in large electrical generators of the hydrogen cooled type, for constructing certain components of which such as the armature retainer and end rings and the like, there is a demand for a strong, ductile and non-magnetic material of high strength-to-weight ratio, which at the same time is resistant to absorption of the hydrogen atmosphere employed for cooling and which is not embrittled thereby over long periods of use.

The present invention provides in one of its aspects certain titanium base alloys which inherently meet the aforesaid requirements to a high degree, and which when made into articles such as armature retaining rings, end rings and the like, and appropriately surface treated, are highly resistant to hydrogen absorption at operating temperatures including overload conditions of such generators.

The invention provides in another of its aspects a modified type of hydrogen atmosphere containing a small fraction of oxygen and/or water vapor, for use in such generators for cooling purposes, and adapted substantially to inhibit appreciable hydrogen absorption by components thereof exposed to such atmosphere and made of titanium or titanium base alloys.

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are given a surface treatment, as by vacuum annealing and exposure to air prior to placing in service, their resistance to hydrogen absorption at elevated temperatures is greatly enhanced.

We have further discovered that if the hydrogen atmosphere to which such articles are exposed in service contains a small amount of oxygen and/or water vapor, in the range of about 0.1 to 1% by volume of oxygen and/or water vapor, preferably the former, that articles made of titanium and titanium base alloys, particularly those of the alpha or predominantly alpha type aforesaid, are rendered substantially immune to hydrogen absorption as a result of such exposure.

Our researches in the experimental hydrogenation of titanium alloys at temperatures up to 700-800° C., have clearly demonstrated that the rate of hydrogen absorption is a function of the alloys' crystallographic form and that it is markedly influenced by the purity of the hydrogen employed. We have found that the alpha, titanium base alloys are considerably more difficult to hydrogenate than those of the beta or alpha-beta types, and that for effectively hydrogenating the former, pure, dry hydrogen is required.

Large alternating current electrical generators, of the hydrogen atmosphere cooled type, are designed to operate normally below 200° C., but overloads can raise the temperature for short periods as high as 300° C., while arcing can result in brief, localized temperature excursions up to about 400° C. Therefore, if the inherent advantages of titanium base alloys as regards high strength-to-weight ratio and non-magnetic properties are to be successfully utilized for components as aforesaid in such generators, alloys of this type must be provided which are inherently resistant to hydrogen absorption or may be rendered so by suitable surface treatment, and/or which are employed under conditions such that absorption will not occur over prolonged periods of operation.

The present invention provides these features as will now be shown by reference to the test data given in Tables II-V below made on titanium and titanium base alloys of the compositions given in the following Table I:

TABLE I

Chemical Analyses of Titanium Alloys Tested

Alloy Designation	Composition Percent—Balance Titanium							
	Al	V	Mo	Cr	Sn	Zr	C	N
A70	—	—	—	—	—	—	0.04	0.015
A110AT	4.62	—	—	—	2.64	—	0.05	0.056
RC900	5.56	—	—	—	—	13.42	0.07	0.024
C120AV	5.91	4.51	—	—	—	—	0.03	0.016
C135AMo	5.41	—	3.60	—	—	—	0.03	0.019
B120VCA	2.8	12.21	—	10.8	—	—	0.02	0.013
12-4	—	—	1.12	—	1.4	—	—	—
8-1-1	7.86	1.00	1.02	—	—	—	0.031	0.019

1 Nominal.

The invention is based in part on our discovery that titanium base alloys of an all-alpha or predominantly alpha type, and preferably containing about 5 to 30% of one or more of the alpha promoters aluminum, tin and zirconium, but not to exceed about 23% tin, or 10% aluminum, and such as may also contain up to about 5% of one or more of the isomorphous beta promoters vanadium, columbium, molybdenum and tantalum, are not embrittled on prolonged exposure to hydrogen atmospheres at elevated temperatures up to about 400° C., and are moreover far more resistant to hydrogen absorption under such conditions than are the titanium base alloys of the mixed alpha-beta or all-beta types. We have further discovered that when articles made of these alloys

In the alloys of the above table, that designated A70 is commercial purity titanium containing only small amounts of contaminants, such as carbon, nitrogen and iron, as shown, and also a small amount of oxygen although no analysis was made for the oxygen content. The alloys A110AT and RC900 are of the all-alpha type while that designated C120AV is of the substantially all-alpha type owing to the relatively high alpha-solubility of the beta promoter vanadium. Alloy 8-1-1 is likewise of the substantially all-alpha type owing to the small contents of the beta promoters vanadium and molybdenum and the alpha-solubilities thereof. Alloy C135AMo is of the mixed alpha-beta type, while B120VCA and 12-4 are substantially all-beta alloys.

For purposes of conducting the tests set forth in Tables II-V presented and discussed below, the alloys shown in Table I were prepared by forging and rolling into strip and thereupon vacuum annealing for 4 hours at 1400° F. followed by rapid furnace cooling in the cold zone of the furnace. Standard microtensile specimens and stress samples were prepared, degreased, and placed in Pyrex vials 9.5" long by 0.5" in diameter. The vials were then evacuated and given the atmospheres listed in Tables II-V, inc., as discussed below. The hydrogen and argon gases used in these experiments were dried with "Drierite." After the tubes were flame sealed, they were placed in capped steel pipes (for safety) and exposed at the temperatures and times indicated in Tables II-V. Hydrogen determinations were made both before and after exposures.

The following Table II gives the hydrogen absorption in 30 days at 200° C. of a series of specimens prepared as above and exposed to atmospheres comprising, respectively, dry hydrogen and dry hydrogen to which variable amounts of oxygen, nitrogen and water, by volume, had been added as indicated in the table, the comparison in each instance being made with reference to the hydrogen content of a non-exposed specimen as shown in the table.

TABLE II
Hydrogen Absorption in 30 Days at 200° C.

Alloy	Surface Condition	Test Atmosphere ¹	H Analyses, p.p.m. ²
A70-----	as vacuum annealed....	(not exposed)....	7
		H ₂ only.....	9
		H ₂ +1% O ₂	9
		H ₂ +1% N ₂	8
		H ₂ +1.8% H ₂ O....	7
	vacuum annealed and anodized.	H ₂ only.....	8
A110AT-----	as vacuum annealed....	(not exposed)....	7
		H ₂ only.....	7
		H ₂ +1% O ₂	6
		H ₂ +1% N ₂	6
		H ₂ +1.6% H ₂ O....	4
	vacuum annealed and anodized.	H ₂ only.....	6

See footnotes at end of table.

TABLE II—Continued

Alloy	Surface Condition	Test Atmosphere ¹	H Analyses, p.p.m. ²
5 RC900-----	as vacuum annealed....	(not exposed)....	4
		H ₂ only.....	15
		H ₂ +1% O ₂	6
		H ₂ +1% N ₂	6
		H ₂ +1.6% H ₂ O....	5
	vacuum annealed and anodized.	H ₂ only.....	6
10 C135AMo-----	as vacuum annealed....	(not exposed)....	6
		H ₂ only.....	8
		H ₂ +1% O ₂	12
		H ₂ +1% N ₂	6
		H ₂ +1.6% H ₂ O....	6
	vacuum annealed and anodized.	H ₂ only.....	6
15 C120AV-----	as vacuum annealed....	(not exposed)....	4
		H ₂ only.....	4
		H ₂ +1% O ₂	4
		H ₂ +1% N ₂	5
		H ₂ +1% H ₂ O....	4
	vacuum annealed and anodized.	H ₂ only.....	8
20 B120VCA-----	as vacuum annealed....	(not exposed)....	12
		H ₂ only.....	12
	vacuum annealed and air oxidized.	H ₂ only.....	7
25 12-4-----	as vacuum annealed....	(not exposed)....	10
		H ₂ only.....	12
	vacuum annealed and air oxidized.	H ₂ only.....	10

¹ Note that first analysis of each alloy gives the base hydrogen level.
² Room temperature pressure of one atmosphere. Note that controls were not exposed. Additions were in percent by volume.

The data of Table II establishes that the hydrogen absorption for each of these alloys was substantially nil at temperatures up to 200° C., whether exposed to pure, dry hydrogen or to that containing additions of oxygen, nitrogen or water vapor.

This same high resistance to hydrogen absorption was also noted on specimens similarly processed and exposed at 200° C. for periods of 6 to 12 months, as shown in the following Table III which also includes the room temperature tensile properties of the specimens following exposure.

TABLE III
Mechanical Properties and Hydrogen Absorption
After 6 and 12 Months at 200° C.

Alloy	Ult. Tens. Str., KSI	0.2% Offset Yield Str., KSI	Percent Elong. in 1/2"	RA, percent	H Analyses, p.p.m. ¹		Time, mos.	Atmosphere ²
					Non-stressed	Stressed		
RC900-----	114.6	104.9	18.3	43.2	24	28	6	H ₂ only.
	112.4	105.2	15.0	39.2	17	17	6	H ₂ +1% H ₂ O.
	117.9	109.4	20.0	47.5	17	25	6	Argon only.
	119.5	112.4	18.3	41.0	24	64	12	H ₂ only.
	120.0	112.7	18.3	45.0	22	25	12	H ₂ +1% H ₂ O.
	120.0	112.5	18.3	46.2		27	12	Argon only.
8-1-1-----	144.8	122.5	15.0	38.3	27	46	6	H ₂ only.
	145.0	120.8	13.3	43.3	16	40	6	H ₂ +1% H ₂ O.
	138.4	115.6	16.7	39.2	21	21	6	Argon only.
	152.5	128.3	15.0	40.6	37	83	12	H ₂ only.
	152.2	127.4	13.3	34.4	32	58	12	H ₂ +1% H ₂ O.
	147.5	127.5	16.7	37.5	30	29	12	Argon only.
C120AV-----	135.8	122.2	13.3	36.1	30	50	6	H ₂ only.
	135.2	121.1	16.7	39.1	41	33	6	H ₂ +1% H ₂ O.
	135.6	120.9	15.0	41.2	14	23	6	Argon only.
	142.6	130.1	15.0	41.2	36	85	12	H ₂ only.
	136.6	124.0	13.3	42.9	20	30	12	H ₂ +1% H ₂ O.
	141.4	127.6	15.0	48.6	17	33	12	Argon only.
C135AMo-----	152.1	149.4	15.0	45.8	20	61	6	H ₂ only.
	140.6	137.7	16.7	51.3	18	39	6	H ₂ +1% H ₂ O.
	150.9	148.2	15.0	47.4	22	21	6	Argon only.
	153.6	152.2	16.7	42.9	29	68	12	H ₂ only.
	151.8	150.7	18.3	56.1	19	47	12	H ₂ +1% H ₂ O.
	153.9	152.0	8.3	54.4	30	29	12	Argon only.

¹ Specimens exposed to argon serve as controls.

² Room temperature pressures of one atmosphere. Water additions in percent by volume.

From Table III it will be seen, however, there is considerable hydrogen pickup in the stressed portions of the samples tested when exposed to pure, dry hydrogen, but that the absorption is greatly reduced or completely eliminated if the hydrogen atmosphere contains a small amount of moisture such as about 1% by volume of water vapor. It will be further noted from Table III that where hydrogen absorption does occur, the alloys are not embrittled thereby, the tensile elongations and area reductions being excellent following the tests.

The following Table IV shows the effect on mechanical properties and hydrogen absorption of exposing specimens for 30 days at 400° C. under the various testing conditions indicated, namely, exposure to dry hydrogen, also to hydrogen containing 1% by volume of oxygen, also to hydrogen containing 1% by volume of nitrogen, also to hydrogen containing 0.1% by volume of water, all for the surface condition of the alloy specimens as vacuum annealed, and in addition for the surface condition of a specimen of each alloy as vacuum annealed and air oxidized and then exposed to dry hydrogen only.

TABLE IV
Mechanical Properties and Hydrogen Absorption
in 30 Days at 400° C.

Alloy	Ult. Tens. Str., KSI	0.2% Offset Yield Str., KSI	Percent Elong. in 1/2"	RA, percent	H Analyses p.p.m. (1)	Atmosphere 2
A70-----	92.6 95.6 91.2 94.9 92.2 93.4	65.4 66.7 66.2 89.6 65.7 66.7	33.3 28.3 33.3 31.7 31.7 28.3	47.3 43.4 47.5 43.2 36.7 48.2	7 608 21 531 9 86	(not exposed). H ₂ only. H ₂ +1% O ₂ . H ₂ +1% N ₂ . H ₂ +1% H ₂ O. H ₂ only.
A110AT-----	128.2 130.1 158.6 133.6 128.7 130.7 132.6	113.9 116.3 151.6 129.3 118.0 122.5 122.5	20.0 31.7 13.3 20.0 23.3 23.3 23.3	46.7 38.4 29.6 40.5 44.3 34.7 42.9	4 4 1,020 61 (4) 46 69	(not exposed). Do. H ₂ only. H ₂ +1% O ₂ . H ₂ +1% N ₂ . H ₂ +1% H ₂ O. H ₂ only.
RC900-----	112.3 113.3 116.2 115.8 135.7 117.6 118.5	96.4 102.8 108.4 110.8 128.0 112.8 111.1	23.3 20.0 21.7 23.3 16.7 20.0 21.7	40.5 35.7 35.5 32.9 31.4 38.0 42.3	4 4 (4) 14 364 20 25	(not exposed). Do. H ₂ only. H ₂ +1% O ₂ . H ₂ +1% N ₂ . H ₂ +1% H ₂ O. H ₂ only.
C135AMo-----	151.3 152.2 167.7 162.3 168.6 143.5 156.4	143.9 146.8 152.7 152.1 115.4 129.3 142.9	15.0 16.7 16.7 15.0 15.0 18.3 16.7	33.4 41.7 33.7 31.4 35.7 43.2 40.2	8 6 905 110 283 10 107	(not exposed). Do. H ₂ only. H ₂ +1% O ₂ . H ₂ +1% N ₂ . H ₂ +1% H ₂ O. H ₂ only.
C120AV-----	127.6 125.0 150.5 143.0 138.5 140.3 136.0	105.8 94.4 140.1 130.3 113.3 124.2 105.6	20.0 16.7 18.3 18.3 16.7 18.3 18.3	38.7 37.0 34.4 40.9 39.7 38.1 46.6	4 4 645 94 (4) 46 40	(not exposed). Do. H ₂ only. H ₂ +1% O ₂ . H ₂ +1% N ₂ . H ₂ +1% H ₂ O. H ₂ only.
B120VCA-----	132.2 131.0 107.6	116.6 111.8	26.7 28.3	47.6 44.4	12 12 1,135	(not exposed). Do. H ₂ only.
12-4-----	141.5 145.5 179.1	129.2 136.4 165.9	13.3 11.7 3.3	29.1 42.5 19.3	10 10 675	(not exposed). Do. H ₂ only.

1 Note that first analysis of each alloy gives the base level.

2 Room temperature pressure of one atmosphere. Note that controls were not exposed.

3 Surface condition of specimens as vacuum annealed except those marked (4) which were vacuum annealed and air oxidized.

4 Vial ruptured during test.

Referring to the data in Table IV, it will be seen that the alpha alloys are inherently less susceptible to hydrogen absorption than are the alloys of the alpha-beta or all-beta types as seen by comparison of the results for the alpha materials A70, A110AT, RC900 and C120AV as compared to the results for the alpha-beta alloy C135AMo and the beta alloys B120VCA and 12-4. It will further be noted that the surface treatment consisting in vacuum annealing and thereupon air oxidizing the specimens tremendously reduced the absorption on exposure to dry hydrogen, particularly so with respect to the alpha alloys.

Thus for A70, the dry hydrogen pickup was reduced from 601 to 79 p.p.m.; for A110AT from 1016 to 65 p.p.m. and for C120AV from 641 to 36 p.p.m.; whereas the reduction in hydrogen pickup for the alpha-beta alloy C135AMo, i.e., from 905 to 107 p.p.m., was not so marked as for the alpha alloys. It will further be noted that the addition of a small amount of oxygen or water vapor to the hydrogen atmosphere also greatly reduced the hydrogen pickup as applied particularly to the alpha alloys, with respect to which the oxygen addition was in some instances more effective than that of the water vapor and vice versa. In the case of the alpha-beta alloy C135AMo, however, the oxygen addition was not nearly so effective as the water vapor addition to the hydrogen atmosphere, the same being true to a lesser degree for the C120AV alloy, which although of the alpha-beta type has predominantly the alpha structure at room temperature. Also, still referring to Table IV, it will be noted that where the hydrogen pickup was excessive, i.e., that resulting from exposure of the specimen to dry hydrogen only, there was no embrittlement of the alloy, the tensile elongations and area re-

ductions being excellent after the exposure. As further shown, some strengthening of the alloy resulted from the hydrogen pickup. And finally it is to be noted from the data of Table IV, that nitrogen additions to the hydrogen were quite ineffective in reducing hydrogen pickup.

The following Table V gives comparative test results on certain of the alloys of Table I, processed as aforesaid, as regards effect on mechanical properties and hydrogen absorption following exposures at 400° C. for 30 and 90 days, respectively, in both the stressed and unstressed conditions of the specimens.

TABLE V
Mechanical Properties and Hydrogen Absorption After
30 and 90 Days at 400° C.

Alloy	Ult. Tens. Str., KSI	0.2% Offset Yield Str., KSI	Percent Elong. in 1/2"	RA, Percent	H Analyses, p.p.m. ¹		Time, days	Atmosphere ²
					Non- stressed	Stressed		
RC900-----	134.4	128.7	16.7	43.0	147	280	30	H ₂ +1% H ₂ O.
	120.3	114.5	15.0	40.6	35	57	30	H ₂ +1% O ₂ .
	116.9	112.3	15.0	35.6	18	37	30	Argon only.
	136.9	130.4	15.0	31.0	248	945	90	H ₂ +1% H ₂ O.
	121.1	114.2	18.3	43.7	7	47	90	H ₂ +1% O ₂ .
	119.3	113.2	15.0	33.7	6	-----	90	Argon only.
8-1-1-----	146.2	122.9	15.0	43.0	143	310	30	H ₂ +1% H ₂ O.
	153.3	126.1	6.7	20.4	100	102	30	H ₂ +1% O ₂ .
	150.3	124.5	13.3	30.5	38	38	30	Argon only.
	127.8	110.8	10.0	40.9	356	81	90	H ₂ +1% H ₂ O.
	163.2	140.1	11.7	27.7	271	324	90	H ₂ +1% O ₂ .
	151.7	125.4	13.3	29.1	8	16	90	Argon only.
C120AV-----	139.5	127.6	13.3	42.5	84	160	30	H ₂ +1% H ₂ O.
	142.7	130.1	15.0	45.1	85	60	30	H ₂ +1% O ₂ .
	140.3	125.0	16.7	25.3	25	37	30	Argon only.
	144.3	134.6	16.7	42.8	238	456	90	H ₂ +1% H ₂ O.
	148.0	135.4	15.0	40.3	226	192	90	H ₂ +1% O ₂ .
	142.7	129.7	15.0	43.5	3	51	90	Argon only.
C135AM0-----	156.4	151.2	13.3	42.0	115	349	30	H ₂ +1% H ₂ O.
	158.0	151.9	15.0	40.2	214	258	30	H ₂ +1% O ₂ .
	152.4	146.3	13.3	38.7	22	29	30	Argon only.
	158.3	151.6	15.0	41.8	164	1,240	90	H ₂ +1% H ₂ O.
	161.6	-----	16.7	44.7	362	326	90	H ₂ +1% O ₂ .
	153.4	149.4	13.3	40.7	10	86	90	Argon only.

¹ Specimens exposed to argon serve as controls.
² Room temperature pressures of one atmosphere. Additions in percent by volume.

Referring to the data in Table V, it will be seen that the water vapor addition to the hydrogen atmosphere was in general not nearly so effective as the oxygen addition in suppressing hydrogen absorption in the specimens. Also that whereas the hydrogen absorption for the oxygen addition, was in general quite small for exposures up to 30 days, that in general there was a substantial increase in pickup when the exposure was continued to 90 days. But again the Table V tests demonstrate the superiority of the alpha alloys as regards resistance to hydrogen absorption as compared to the alpha-beta alloy C135AMo. It will further be noted that the pickup tends to be greater in the stressed areas of these specimens than in the non-stressed areas.

In order more clearly to compare the test results given in Tables IV and V for the alloys thereof, the results have been re-tabulated in the following Table VI for the various exposure times and for the non-stressed versus the stressed conditions to show the hydrogen pickup.

TABLE VI

30 DAYS AT 400° C.—NON-STRESSED CONDITION

Alloy	H ₂ +1% O ₂	H ₂ + 0.1% H ₂ O	H ₂ Only
RC900-----	10	16	-----
C120AV-----	90	40	641
8-1-1-----	-----	-----	-----
C135AMo-----	102	2	897

30 DAYS AT 400° C.—NON-STRESSED CONDITION

RC900-----	17	129	-----
C120AV-----	60	59	-----
8-1-1-----	62	105	-----
C135AMo-----	192	95	-----

90 DAYS AT 400° C.—NON-STRESSED CONDITION

RC900-----	1	242	-----
C120AV-----	223	235	-----
8-1-1-----	263	348	-----
C135AMo-----	352	154	-----

TABLE VI—Continued

30 DAYS AT 400° C.—STRESSED CONDITION

Alloy	H ₂ +1% O ₂	H ₂ + 0.1% H ₂ O	H ₂ Only
RC900-----	20	243	-----
C120AV-----	23	123	-----
8-1-1-----	64	272	-----
C135AMo-----	229	320	-----

90 DAYS AT 400° C.—STRESSED CONDITION

RC900-----	47	-----	-----
C120AV-----	141	405	-----
8-1-1-----	308	65	-----
C135AMo-----	240	1154	-----

Referring to the foregoing data, it will be seen that for exposure times up to 90 days at 400° C., under the non-stressed condition, the RC900 alpha alloy is far superior to any of the others as regards hydrogen pickup, being substantially nil, although the alpha alloys C120AV and 8-1-1 show good performance up to 30 days' exposure, especially in the oxygen-containing atmosphere. These three alloys also show excellent performance for exposures up to 30 days at 400° C. under stressed conditions in the oxygen-containing atmosphere. For an exposure time up to 90 days at 400° C. under the stressed conditions, the alloy RC900 shows the best performance in the oxygen-containing atmosphere while the 8-1-1 alloy shows the best performance in the water vapor-containing atmosphere.

The 90-day test at 400° C. is of course excessive and would never be encountered in operation, for example, of an electrical generator of the hydrogen-cooled type, nor in fact would 30 days of continuous operation at such temperature be encountered.

The invention is exemplified in one of its applications by the annexed drawing comprising a longitudinal sectional elevation of an alternating current generator mounted in a gas-tight housing filled with a hydrogen-containing atmosphere according to the invention, and wherein the armature retaining rings are made of an alpha titanium base alloy according to the invention.

Referring to the drawing, the stator is shown at 10

and the rotor or armature at 11. Mounted on the armature are armature retaining rings 12—13, made of an all-alpha or substantially all-alpha titanium base alloy according to the invention, these rings being preferably vacuum annealed and surface oxidized prior to installation for minimizing hydrogen pickup as explained above. The retaining rings are backed by support rings 14, 15, which may also be made of a titanium base alloy of the type aforesaid. The armature is mounted on a shaft 17, journaled at its opposite ends in bearing members 18, 19, carried by supports 20, 21. The armature shaft carries the usual slip rings 22, for tapping off the alternating current power supply. The armature and stator assembly is mounted within a housing 23, filled with an atmosphere 24 consisting of hydrogen and 0.1 to 1% of oxygen and/or water vapor in accordance with the invention. This atmosphere is circulated by means of fan blades 25, 26, mounted on the rotor shaft, which circulate the hydrogen-containing atmosphere to and from a water cooling unit 27 in the manner shown by the arrows, thus to cool the rotor and stator elements and appurtenant components.

As shown by the above test results, preferred alpha alloys for purposes of the invention are those containing zirconium, preferably together with aluminum and/or tin. Excellent alloys for such applications are the following: Ti-(3-6)% Al-(4-15)% Zr, Ti-(3-10)% Al-(4-15)% Zr and Ti-(3-6)% Al-(4-10)% Sn-(5-10)% Zr. These alloys have excellent elevated temperature strength and creep resistance and also excellent room temperature strength and ductility. They are inherently relatively resistant to hydrogen pickup at elevated temperatures up to 400° C., particularly when vacuum annealed and thereafter air oxidized. Also they are not embrittled by hydrogen pickup.

What is claimed is:

1. An article made of a titanium base alloy containing about 5 to 30% of at least one alpha promoter selected from the group consisting of aluminum, tin and zirconium, up to about 5% of beta isomorphous promoters of the group vanadium, molybdenum, columbium and tantalum, balance substantially titanium, said article having an oxidized surface and being characterized by retention of high strength and ductility on prolonged exposure to hydrogen and hydrogen-containing atmospheres at temperatures up to about 400° C. and being resistant to hydrogen absorption at such temperatures.

2. An article made of a titanium base alloy containing about 3 to 6% aluminum, 4 to 15% zirconium, up to 5% of beta isomorphous promoters of the group vanadium, molybdenum, columbium and tantalum, balance substantially titanium, said article having an oxidized surface and being characterized by retention of high strength and ductility on prolonged exposure to hydrogen and hydrogen-containing atmospheres at temperatures up to about 400° C., and being resistant to hydrogen absorption at such temperatures.

3. An article made of a titanium base alloy containing about 3 to 6% aluminum, 4 to 10% tin, 5 to 10% zirconium, up to 5% of beta isomorphous promoters of the group vanadium, molybdenum, columbium and tantalum,

balance substantially titanium, said article having an oxidized surface and being characterized by retention of high strength and ductility on prolonged exposure to hydrogen and hydrogen-containing atmospheres at temperatures up to about 400° C., and being resistant to hydrogen absorption at such temperatures.

4. An article made of a titanium base alloy containing about 3 to 10% of metal of the group aluminum and tin, but not to exceed about 6% aluminum, about 4 to 15% zirconium and the balance substantially titanium, said article having an oxidized surface and being characterized by retention of high strength and ductility on prolonged exposure to hydrogen and hydrogen-containing atmospheres at temperatures up to about 400° C., and being resistant to hydrogen absorption at such temperatures.

5. An article made of a titanium base alloy containing about 3 to 6% aluminum, about 4 to 15% zirconium, and the balance substantially titanium, said article having an oxidized surface and being characterized by retention of high strength and ductility on prolonged exposure to hydrogen and hydrogen-containing atmospheres at temperatures up to about 400° C., and being resistant to hydrogen absorption at such temperatures.

6. The method of minimizing hydrogen absorption in articles made of titanium and titanium base alloys exposed in service to hydrogen atmospheres at temperatures up to about 400° C., which consists in maintaining in said hydrogen atmosphere about 0.1 to 1% by volume of at least one gas selected from the group consisting of oxygen and water vapor.

7. In combination: an electrical current generator, a substantially gas-tight housing encasing the same, a low-density, heat-transferring atmosphere within said housing, consisting of hydrogen containing about 0.1 to 1% of at least one member of the group consisting of oxygen and water vapor, and at least one component of said generator exposed to said atmosphere within said housing being composed of a metal of the group consisting of titanium and titanium base alloys.

8. In combination: an electrical current generator, a substantially gas-tight housing encasing the same, a low-density, heat-transferring atmosphere within said housing, consisting of hydrogen containing about 0.1 to 1% of at least one member of the group consisting of oxygen and water vapor, and at least one component of said generator exposed to said atmosphere within said housing being made of a titanium base alloy containing about 5 to 30% of at least one alpha promoter selected from the group consisting of aluminum, tin and zirconium, up to about 5% of isomorphous beta promoters of the group vanadium, molybdenum, columbium and tantalum, balance substantially titanium.

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