High Magnetic Permeability Alloys "Hardperm" in the Ni-Fe-Nb-W and Ni-Fe-Ta-W Systems*

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Ni-Fe-Nb-W and Ni-Fe-Ta-W alloys were heated in pure hydrogen atmosphere at 1150°C for 3 hr and then cooled at various rates from a temperature above their order-disorder transformation points. In the Ni-Fe-Nb-W system, an alloy of 79.4% Ni, 11.54% Fe, 8.51% Nb and 0.50% W cooled at the rates of 240 and 300°C/hr showed the highest initial permeability of 109000 and the highest maximum permeability of 463000. In the Ni-Fe-Ta-W system, the highest initial permeability of 101000 is obtained with an alloy of 73.40% Ni, 10.96% Fe, 14.11% Ta and 1.53% W cooled at the rate of 200°C/hr, and the highest maximum permeability of 557000 with an alloy of 73.50% Ni, 10.96% Fe, 14.99% Ta and 0.55% W cooled at 300°C/hr. The hardness and electrical resistivity of these alloys are considerably higher than those of Permalloy-type alloys. The high permeability of these alloys is largely due to the major contribution of high-temperature heat treatment in hydrogen atmosphere to the homogenization, removal of impurities, and the very low saturation magnetostriction and crystal magnetic anisotropy in a proper state of ordering.

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I. Introduction

We found previously that the addition of the group Va elements Nb⁽¹⁾ and Ta⁽²⁾ to Ni-Fe alloys with the ordered Ni₃Fe structure substantially improves the magnetic properties and increases the electrical resistivity and hardness. We have given these alloys a generic name "Hardperm" (alloys with very high permeability and high hardness). Subsequently we carried out experiments of the addition of the group VIa elements Cr and Mo to Ni-Fe-Nb and Ni-Fe-Ta alloys in order to investigate the changes in the properties of the alloys with composition and heat treatment^{(3)~(6)}. This paper describes the experimental results on the addition of the group VIa element W to Ni-Fe-Nb and Ni-Fe-Ta alloys.

II. Experimental

For the preparation of the alloy specimens, high-purity Ni(99.9), Fe(99.9), Nb(99.9), Ta (99.9) and W(99.9) were weighed out to be 800 g for the Ni-Fe-Nb-W system and 500 g for the Ni-Fe-Ta-W system. These were vacuum-melted in a high frequency induction furnace and deoxidized with the addition of about 0.2%Mn. The molten alloys were cast into iron molds with cavities 25 and 20 mm in diameter and 150 mm long, respectively. The ingots were forged and then reduced to plates 0.3 mm in thickness by hot- and cold-rolling and to wires 2 mm in diameter by swaging and drawing. Ring specimen 33 mm in I.D. and 45 mm O.D. were punched from the thin plates, while rod specimens were cut from the wires to have the length of 100 mm. These specimens were heated at 1150°C for 3 hr under a Pd-purified hydrogen atmosphere with a dew point of -70°C and cooled to room temperature from a temperature above the order-disorder transformation points at various rates. In the case of the Ni-Fe-Nb-W system, the specimens used in the present investigation were fifty-eight alloys in the composition range of 76.84~80.02%Ni, 9.75~13.40%Fe, 5.06~

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9.04%Nb and 0.30~5.23%W. In the case of the Ni-Fe-Ta-W system, the specimens used were forty-one alloys of 72.45~75.61%Ni, 9.92~12.84%Fe, 10.13~15.98%Ta and 0.32~4.05%W. Using the ring specimens, the magnetic permeability was measured by the ballistic galvanometer method and hysteresis curve was obtained with the recording fluxmeter, respectively. The saturation magnetic induction, saturation magnetostriction and electrical resistivity were measured with the rod specimens by the ballistic galvanometer method, the optical roller method and the potentiometric method, respectively. The hardness measurements were made on the thin plates by the micro-Vickers hardness tester (load: 500 g).

III. Results and Discussion

1. Ni-Fe-Nb-W alloys

Figures 1 and 2 show the cooling rate dependence of initial permeability μ_0 and maximum permeability μ_m and that of coercive force H_c and residual magnetic induction B_r for a maximum magnetic induction of 5 kG, respectively, for Ni-Fe-Nb-W alloys No. 3, No. 17, No. 25, No. 34 and No. 47 (cf. Table 1). As shown in the figures, both μ_0 and μ_m exhibit a strong dependence on cooling rate and their maximum values almost correspond to the observed minima of H_c and B_r . It is highly probable that the appearance of the maxima and minima is due to the fact that the Ni-Fe-Nb-W alloys are brought into an initial state of ordering by proper choice of the cooling rate, as in the case of Ni-Fe alloys⁽⁷⁾. Figure 3 shows the W content dependence of the optimum cooling rate for μ_m for each of Ni-Fe-Nb-W alloys containing 78.25~79.93% Ni and 7.87~8.02%Nb. The effect of W on the reduction of the optimum cooling rate comes next to Cr⁽³⁾ and Mo⁽⁴⁾ and is similar to that of the addition of Cr, Mo, Ta or Nb to Ni-Fe alloys^{(1)(2)(8)~(10)}.

Figure 4 shows the dependence of μ_0 and μ_m on W content for Ni-Fe-Nb-W alloys containing 77.82~79.53%Ni and 6.95~7.09%Nb and Ni-Fe-Nb-W alloys containing 78.25~79.93%Ni and 7.87~8.02%Nb, marked (a)

Fig. 1 Variation of initial permeability μ_0 and maximum permeability μ_m with cooling rate for several high permeability Ni-Fe-Nb-W alloys. The alloy compositions are: Alloys No. 3(79.75% Ni, 11.75% Fe, 7.87% Nb, 0.63% W), No. 6 (79.45% Ni, 11.54% Fe, 8.51% Nb, 0.50% W), No. 17 (79.52% Ni, 11.56% Fe, 7.94% Nb, 0.98% W), No. 25(78.96% Ni, 11.57% Fe, 7.95% Nb, 1.52% W), No. 34(78.39% Ni, 11.60% Fe, 8.02% Nb, 1.99% W) and No. 47(78.24% Ni, 11.85% Fe, 7.01% Nb, 2.90% W).

Fig. 2 Variation of coercive force H_c and residual magnetic induction B_r with cooling rate for Ni-Fe-Nb-W alloys shown in Fig. 1.

and (b) respectively. In all cases, the maximum

Fig. 3 Optimum cooling rate for μ_m as a function of W content for Ni-Fe-Nb-W alloys containing 78.25–79.75% Ni and 7.87–8.02% Nb.

Fig. 4 Effect of W content on highest initial permeability μ_0 and maximum permeability μ_m for each of Ni-Fe-Nb-W alloys containing 77.82–79.5% Ni and 6.95–7.09% Nb (a) and containing 78.25–79.75% Ni and 7.87–8.02% Nb (b).

values of μ_0 and μ_m as a function of W content appear with the W content decreasing with increasing Nb content. This indicates that Nb and W generally have the effect of compositional substitution on μ_0 and μ_m . Figure 5 shows the dependence of H_c and B_r on W content for the alloys heat treated to maximize the value of μ_m . The values of H_c and B_r exhibit the minima which are in approximate

Fig. 5 Effect of W content on coercive force H_c and residual magnetic induction B_r of Ni-Fe-Nb-W alloys (a) and (b) shown in Fig. 4.

Fig. 6 Effect of W content on saturation magnetic induction $4\pi I_s$ and electrical resistivity ρ of Ni-Fe-Nb-W alloys (a) and (b) shown in Fig. 4.

agreement with the maxima of μ_0 and μ_m . Figure 6 shows the dependence of saturation magnetic induction $4\pi I_s$ and electrical resistivity ρ on W content for the alloys subjected to the same heat treatment as in Fig. 5. It is shown that $4\pi I_s$ decreases monotonically and ρ increases linearly with increase in W content.

Table 1 lists the magnetic properties and

Table 1 Magnetic properties, electrical resistivity and Vickers hardness of high permeability Ni-Fe-Nb-W alloys heated at 1150°C for 3 hr.

Alloy No.	Composition (Rest Ni, %)			Cooling rate (°C/hr)	μ_0	μ_1	μ_m	W_h (erg/cm ³ /cycle)	B_r (kG)	H_c (mOe)	$4\pi I_s$ (kG) ($\times 10^{-6}$)	λ_s	ρ ($\mu\Omega$ -cm, 20°C)	Hv (Vickers hardness)
	Fe	Nb	W		($\times 10^3$)			$B_m=5$ kG			$H=1$ kOe			
—	11.65	8.94	0	240	100	115	411	3.3	2.7	3.4	5.9	0.3	74.7	207
3	11.75	0.87	0.63	300	109	148	420	4.3	2.6	3.3	6.2	0.5	71.2	200
6	11.54	8.51	0.50	300	67	74	463	6.2	3.4	3.1	6.0	0.2	73.8	202
6	11.54	8.51	0.50	240	109	138	428	5.9	2.6	3.0	6.0	0.2	74.6	—
11	11.47	9.00	0.53	200	31	44	380	8.3	3.7	5.2	5.8	0.7	78.7	200
11	11.47	9.00	0.53	150	61	79	371	5.7	3.4	4.6	5.8	0.7	79.2	—
14	12.67	7.09	1.05	300	56	62	249	10.5	3.3	7.5	6.7	0.4	67.6	188
14	12.67	7.09	1.05	150	29	33	307	12.0	4.1	7.9	6.7	0.7	68.8	—
17	11.56	7.94	0.98	200	108	125	373	5.4	2.7	4.2	6.1	0.4	74.4	200
23	10.40	8.94	1.02	70	73	84	231	8.7	2.6	6.4	5.5	0.4	78.7	199
25	11.57	7.95	1.52	100	90	109	357	8.0	2.9	4.0	5.8	0.4	72.8	203
30	12.45	6.96	2.06	100	50	66	314	8.2	2.8	3.9	6.5	0.2	69.5	191
34	11.60	8.02	1.99	50	91	112	364	6.0	2.9	4.8	5.8	0.7	77.4	195
36	10.87	8.53	2.07	70	29	35	261	11.4	3.8	6.0	5.6	0.4	80.0	209
40	11.90	7.06	2.47	70	65	68	204	9.2	2.7	7.7	6.1	0.5	72.4	192
40	11.90	7.06	2.47	50	34	39	287	10.1	3.1	6.1	6.1	0.5	76.5	—
43	12.27	6.02	2.91	100	49	52	150	15.7	3.1	12.8	6.7	1.1	70.7	184
47	11.85	7.01	2.90	30	68	77	253	7.6	2.8	5.9	6.0	0.7	75.0	186
51	10.78	8.00	2.97	40	31	38	271	11.7	3.0	9.1	5.6	0.7	81.5	200
51	10.78	8.00	2.97	25	51	58	176	10.8	2.7	10.0	5.6	0.5	82.8	—
53	11.02	7.03	4.00	5	48	55	210	13.1	3.2	7.5	5.5	0.5	78.0	192
55	12.50	5.32	5.23	10	32	34	113	38.9	2.9	15.2	6.6	0.7	68.9	184
57	10.25	6.95	4.98	3	29	32	184	15.1	3.4	8.5	5.1	0.7	81.9	194

values of ρ and Vickers hardness Hv for typical high-permeability alloys in the Ni-Fe-Nb-W system. Here μ_1 is the permeability in a field of 1 mOe, W_h is the hysteresis loss for a maximum magnetic induction of 5 kG and λ_s is a magnetostriction constant. Alloy No. 6 (79.45%Ni, 11.54%Fe, 8.51%Nb, 0.50%W) exhibits the highest values of 109000 in μ_0 and 463000 in μ_m at the cooling rates of 240 and 300°C/hr, respectively, after heating at 1150°C for 3 hr. In addition, alloy No. 6 cooled at the rate of 240°C/hr has a fairly high ρ value of 74.6 $\mu\Omega$ -cm. Figure 7 shows the hysteresis curve of alloy No. 6 cooled at the rate of 240°C/hr.

The values of H_c and W_h of the alloy are as low as 3.0 mOe and 5.9 erg/cm³/cycle, respectively.

2. Ni-Fe-Ta-W alloys

Figures 8 and 9 show the cooling rate dependence of μ_0 and μ_m and of H_c and B_r

Fig. 7 Hysteresis curves of alloy No. 6 (79.45% Ni, 11.54% Fe, 8.51% Nb and 0.50% W) cooled at the rate of 240°C/hr.

for alloys No. 4, No. 8, No. 20, No. 28, No. 31 and No. 37 (cf. Table 2) in the Ni-Fe-Ta-W system. Both μ_0 and μ_m have a strong depend-

Fig. 8 Variation in initial permeability μ_0 and maximum permeability μ_m with cooling rate for several high permeability Ni-Fe-Ta-W alloys. The alloy compositions were: alloy No. 4 (74.02% Ni, 11.35% Fe, 14.08% Ta, 0.55%W), No. 8 (73.50% Ni, 10.96% Fe, 14.99% Ta, 0.55% W), No. 20 (73.40% Ni, 10.96% Fe, 14.11% Ta, 1.53% W), No. 28 (73.60% Ni, 11.30% Fe, 13.08% Ta, 2.02% W), No. 31 (73.00% Ni, 10.96% Fe, 14.00% Ta, 2.04%W) and No. 37 (73.05% Ni, 10.97% Fe, 12.98% Ta, 3.00% W).

ence on cooling rate, and their maximum values almost correspond to the minima of B_r and H_c . As in the case of Ni-Fe and Ni-Fe-Nb-W alloys, the appearance of these maxima and minima is most probably due to the initial state of ordering in the Ni-Fe-Ta-W alloys as a result of the choice of a proper cooling rate. Figure 10 shows the dependence of the optimum cooling rate for μ_m on the W content for Ni-Fe-Ta-W alloys containing 73.00~74.02%Ni and 14.00~14.11%Ta. The optimum cooling rate becomes smaller with increasing W content. As in the case of Ni-Fe-Nb-W alloys, the effect of W on the reduction of the optimum cooling rate comes next to Cr⁽⁵⁾ and Mo⁽⁶⁾.

The dependence of the maximum values of

Fig. 9 Variation in coercive force H_c and residual magnetic induction B_r with cooling rate for Ni-Fe-Ta-W alloys shown in Fig. 8.

Fig. 10 Optimum cooling rate for μ_m as a function of W content in Ni-Fe-Ta-W quaternary alloys containing 73.00–74.02% Ni and 14.00–14.11% Ta.

μ_0 and μ_m on W content is plotted in Fig. 11 for Ni-Fe-Ta-W alloys containing 73.05~74.51%Ni and 12.98~13.27%Ta(a) and Ni-Fe-Ta-W alloys containing 73.00~74.02%Ni and 14.00~14.11%Ta(b), respectively. In all cases μ_0 and μ_m exhibit their maxima. These maximum values shift to lower W content with increasing Ta content, which indicates that in general Ta and W have a compositional substitution effect on μ_0 and μ_m . Figure 12 illustrates the effect of W content on H_c and B_r for the alloys which were subjected to the heat

Fig. 11 Effect of W content on highest initial permeability μ_0 and maximum permeability μ_m for each of Ni-Fe-Ta-W alloys containing (a) 73.05–74.51% Ni and 12.98–13.27% Ta and (b) 73.00–74.02% Ni and 14.00–14.11% Ta.

Fig. 12 Effect of W content on coercive force H_c and residual magnetic induction B_r of Ni-Fe-Ta-W alloys (a) and (b) shown in Fig. 11.

treatment for the maximization of μ_m . Both H_c and B_r exhibit their minima, corresponding to the maximum values of μ_0 and μ_m . In Fig. 13 is shown the dependence of $4\pi I_s$ and ρ on W content for the same alloys subjected to the heat treatment for the maximization of μ_m . It is clear from this figure that $4\pi I_s$ decreases monotonically and ρ increases linearly with increasing W content.

Changes in magnetic properties, electrical resistivity and Vickers hardness with cooling rate and composition are illustrated in Table 2 for the very high-permeability alloys in the Ni-Fe-Ta-W system. Alloy No. 20(73.40%Ni,

Fig. 13 Effect of W content on saturation magnetic induction $4\pi I_s$ and electrical resistivity ρ of Ni-Fe-Ta-W alloys (a) and (b) shown in Fig. 11.

Fig. 14 Hysteresis curves of alloy No. 8 (73.50% Ni, 10.96% Fe, 14.99% Ta, 0.55% W) cooled at the rate of 300°C/hr and No. 20(73.40% Ni, 10.96% Fe, 14.11% Ta, 1.53% W) cooled at 200°C/hr.

10.96%Fe, 14.11%Ta, 1.53%W) exhibited the highest μ_0 value of 101000 when cooled at the rate of 200°C/hr after heating at 1150°C for 3 hr, while the highest μ_m value of 557000 was obtained with alloy No. 8(73.50%Ni, 10.96%Fe, 14.99%Ta, 0.55%W) when cooled at the rate of 300°C/hr after the same heat treatment. These μ_0 and μ_m values were very high, and the value of ρ for alloy No. 20 was as fairly high as 71.4 $\mu\Omega\text{-cm}$. Figure 14 shows hysteresis curves of alloys No. 8 and No. 20 cooled at 300 and 200°C/hr, respectively. These alloys have very small values of H_c

Table 2 Magnetic properties, electrical resistivity and Vickers hardness of high permeability Ni-Fe-Ta-W alloys heated at 1150°C for 3 hr.

Alloy No.	Composition (Rest Ni, %)			Cooling rate (°C/hr)	μ_0	μ_1	μ_m	W_h (erg/cm ³ /cycle)	B_r (kG)	H_c (mOe)	$4\pi I_s$ (kG)	λ_s ($\times 10^{-6}$)	ρ ($\mu\Omega$ -cm, 20°C)	Hv (Vickers hardness)
	Fe	Ta	W		$(\times 10^3)$			$B_m=5$ kG			$H=1$ kOe			
—	12.05	14.95	0	800	57	63	428	8.0	3.4	5.2	7.5	0.5	64.3	197
4	11.35	14.08	0.55	800	88	97	353	6.0	2.9	4.5	6.5	0.4	66.9	209
4	11.35	14.08	0.55	400	66	96	555	5.1	3.4	3.6	6.5	0.4	67.1	—
5	11.22	14.04	0.73	600	71	82	514	5.8	3.4	3.5	6.3	0.4	68.3	214
5	11.22	14.04	0.73	400	93	107	434	5.7	2.7	3.3	6.3	0.4	68.7	—
8	10.96	14.99	0.55	400	93	131	499	3.7	2.8	3.0	6.2	0.4	70.5	216
8	10.96	14.99	0.55	300	75	124	557	3.6	3.0	2.4	6.2	0.4	70.8	—
14	11.88	13.27	1.04	400	47	55	395	6.4	3.1	4.7	6.6	0.7	66.6	200
14	11.88	13.27	1.04	300	55	70	348	5.7	2.9	4.2	6.6	0.7	66.6	—
16	11.35	14.10	1.05	300	94	110	487	4.5	2.8	3.7	6.3	0.5	70.6	207
17	10.49	14.90	1.05	150	51	55	244	8.7	2.9	6.2	5.8	0	73.0	219
19	11.44	13.00	1.54	300	73	93	305	7.1	2.9	4.7	6.5	0.5	68.0	196
19	11.44	13.00	1.54	200	61	68	496	6.5	3.4	3.7	6.4	0.5	68.3	—
20	10.96	14.11	1.53	240	66	93	474	6.2	3.3	3.3	6.1	0.4	71.4	210
20	10.96	14.11	1.53	200	101	120	416	4.9	2.9	3.4	6.1	0.4	71.4	—
22	12.84	10.14	2.03	240	20	22	273	12.3	4.3	7.3	7.3	0.9	60.2	180
28	11.30	13.08	2.02	150	85	96	359	6.4	3.1	5.3	6.3	0.5	71.3	198
31	10.96	14.00	2.04	150	35	43	335	9.9	3.9	5.8	6.0	0.5	74.9	207
31	10.96	14.00	2.04	100	44	47	212	11.4	3.2	8.2	6.0	0.5	75.2	—
33	12.32	10.13	2.96	100	47	49	220	12.7	3.7	8.8	6.9	0.7	65.2	191
34	11.44	12.07	3.04	50	48	51	225	9.8	3.0	7.8	6.2	0.5	72.8	199
37	10.97	12.98	3.00	50	45	55	287	9.4	3.1	6.6	5.9	0.4	75.6	199
41	10.95	11.97	4.05	20	46	47	224	11.4	3.3	8.4	5.9	0.5	77.0	189

(2.4 and 3.4 mOe) and W_h (3.6 and 4.9 erg/cm³/cycle).

The Hv values (over 200) observed for the Ni-Fe-Nb-W and Ni-Fe-Ta-W alloys, are considerably higher than about 120 for Permalloy, Mo-Permalloy and Mumetal. We have given a generic name "Hardeperm" to these alloys because of their very high permeability and high hardness. The values of ρ for the Ni-Fe-Nb-W alloys No. 6, No. 11, No. 14, No. 40 and No. 51 in Table 1 and for the Ni-Fe-Ta-W alloys No. 4, No. 5, No. 8, No. 19 and No. 31 in Table 2 become a little larger with lower cooling rates. This is probably due to the formation of short-range order at a low cooling rate which has been observed for Ni-Fe-Mo alloys⁽¹¹⁾ and Ni-Fe-Nb alloys⁽¹²⁾.

As the causes for excellent magnetic properties of Ni-Fe-Nb-W and Ni-Fe-Ta-W alloys with very high permeability, the heat treatment at 1150°C for 3 hr under a purified hydrogen atmosphere brings about the homo-

genization, removal of impurities such as carbon, nitrogen and oxygen which induce internal strains, and coarsening of grains⁽¹³⁾⁽¹⁴⁾. The very low values of λ_s (cf. Table 1 and Table 2) and crystal magnetic anisotropy which are realized by the initial state of ordering as result of the application of the optimum cooling rate may be additional contributing factors as in the case of Ni-Fe-Mo and Ni-Fe-Nb ternary alloys⁽¹²⁾⁽¹⁵⁾⁽¹⁶⁾.

IV. Conclusions

From Ni-Fe-Nb-W alloys of 76.84~80.02% Ni, 9.75~13.40%Fe, 5.06~9.04%Nb and 0.30~5.23%W and Ni-Fe-Ta-W alloys 72.45~75.61%Ni, 9.92~12.84%Fe, 10.13~15.98%Ta and 0.32~4.05%W, ring and rod specimens were prepared by forging and rolling and by swaging and drawing, respectively, after vacuum melting. These specimens were heated at 1150°C for 3 hr and cooled to room

temperature from a temperature above their order-disorder transformation points at various cooling rates. The experimental results, obtained by measurements of the magnetic properties, electrical resistivity and hardness, are summarized as follows:

(1) The initial permeability μ_0 and maximum permeability μ_m of Ni-Fe-Nb-W alloys generally depend on the cooling rate, and their maxima are obtained for the optimum cooling rates applied. These optimum cooling rates decrease rapidly with increase in W content. Alloy No. 6 (79.45%Ni, 11.54%Fe, 8.51%Nb, 0.50%W) exhibits the highest values of 109000 and 463000 when cooled at the rates of 240 and 300°C/hr, respectively.

(2) As in the case of Ni-Fe-Nb-W alloys, both μ_0 and μ_m of Ni-Fe-Ta-W alloys depend significantly on the cooling rate and exhibit their maximum values for the optimum cooling rates, and the optimum cooling rates which correspond to these peak values are reduced with increase in W content. Alloy No. 20 (74.40%Ni, 10.96%Fe, 14.11%Ta, 1.53%W) shows the highest μ_0 value of 101000 when cooled at 200°C/hr, while the highest μ_m value of 557000 is obtained with alloy No. 8 (73.50%Ni, 10.96%Fe, 14.99%Ta, 0.55%W) cooled at 300°C/hr.

(3) The coercive force H_c and hysteresis loss W_h for a maximum magnetic induction of 5 kG depend on the cooling rate and exhibit their minima for the optimum cooling rates. In general these values are very low: e.g. 3.0 mOe and 5.9 erg/cm³/cycle for Ni-Fe-Nb-W alloy No. 6 cooled at 240°C/hr, and 2.4 and 3.4 mOe and 3.6 and 4.9 erg/cm³/cycle for Ni-Fe-Ta-W alloy No. 8 cooled at 300°C/hr and alloy No. 20 cooled at 200°C/hr, respectively.

(4) In all cases, the saturation magnetic induction $4\pi I_s$ decreases linearly and the electrical resistivity ρ increases with increase in W content. The values of $4\pi I_s$ and ρ for Ni-Fe-Nb-W alloy No. 6 are 6.0 kG and 74.6 $\mu\Omega$ -cm, and $4\pi I_s$ and ρ values for Ni-Fe-Ta-W

alloys No. 8 and No. 20 are 6.2 and 6.1 kG, 70.8 and 71.4 $\mu\Omega$ -cm, respectively. An increase in ρ presumably due to the presence of short-range order is observed in Ni-Fe-Nb-W and Ni-Fe-Ta-W alloys.

(5) Alloys with very high permeability in the Ni-Fe-Nb-W and Ni-Fe-Ta-W systems have a very low value of magnetostriction constant λ_s and show a fairly high value of Vickers hardness Hv as compared with conventional Permalloy, Mo-Permalloy and Mumetal. For example, the values of λ_s and Hv for Ni-Fe-Nb-W alloy No. 6 and Ni-Fe-Ta-W alloy No. 8 are 0.2×10^{-6} and 202, and 0.4×10^{-6} and 216, respectively.

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