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REPORT

Magnetic Characteristics of "Non-Magnetic" Metallic Materials Comparison of Properties in Strong and Weak Fields

- NS-011-083 - NS-013-118 -

ANNAPOLIS, MARYLAND

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U. S. NAVAL ENGINEERING EXPERIMENT STATION

Annapolis, Maryland

Magnetic Characteristics of "Non-Magnetic" Metallic Materials Comparison of Properties in Strong and Weak Fields

By

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Submitted by

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ABSTRACT

This is the second report relating to the magnetic properties of "non-magnetic" or feebly magnetic metallic materials. The report contains both weak and strong field magnetic data on a wide variety of materials such as brasses, bronzes, cupronickel alloys, nickel-base alloys, wrought and cast austenitic stainless steels, austenitic stainless steel weld metal, precipitation hardening stainless steels, and austenitic manganese steels. Tabulations include strong field normal permeability and coercive force measurements, weak field normal and "ideal" permeability measurements, and normal permeability at various temperatures. In addition to conclusions relative to the correlation of test results, the report contains generalizations in the form of recommendations as to the expected magnetic behavior of the various types of materials.

TABLE OF CONTENTS

INTRODUCTION

1. This is the second report on the magnetic properties of "non-magnetic" metallic materials. In writing this report, it is assumed that the reader is familiar with the first report, reference (a), which describes in considerable detail the magnetic properties of many types of materials in strong magnetic fields (100 to 200 oersteds). It is the purpose of this report to present the data obtained in weak fields (0-1 oersted) by the U. S. Naval Ordnance Laboratory, White Oak, Maryland, and to compare these data with strong field determinations. This test was authorized in reference (b).

DESCRIPTION OF MATERIAL

2. Both ferrous and non-ferrous metals, constituting a wide variety of constructional alloys, have been tested. As the composition and mechanical properties of nearly all of these materials have been presented previously in reference (a), these data will not be repeated. Instead, the materials are identified by commercial designations together with brief descriptions of the condition of the material at the time of test.

METHOD OF TEST

3. The Fahy Low-mu permeameter and the procedure used in determining the normal permeability and coercive force of the various materials at the Station have been fully described in reference (a). The Naval Ordnance Laboratory, at the request of the Bureau of Ships, Bureau of Ordnance, and the Station, determined the following additional magnetic characteristics:

(a) Normal permeability (μ) at -40°C, +24°C, +49°C in a magnetic field of 0.5 oersted.

(b) Normal permeability (μ) at +24°C in a magnetic field of either 20 oersteds (1/2" diam samples) or 7 oersteds (1" diam samples).

(c) Ideal permeability at 24°C in a magnetic field of 0.5 oersted.

(d) Intrinsic coercive force (iH_c) and residual induction (B_r) at +24°C after subjecting the sample to a magnetizing force greater than 2000 oersteds.

4. If we assume the sample to be in a symmetrically cyclically magnetized condition, i.e., the induction will trace a hysteresis loop with reversals in magnetic field, then the above properties are defined in the following way: Normal permeability is the ratio of the normal induction (B) to the magnetizing force (H) where B is the sum of the two factors: the magnetizing force acting (H) and the intrinsic induction (B_i). The coercive force (H_c) is the magnetizing force required to reduce the normal induction (B) to zero. The intrinsic coercive force (iH_c) is the magnetizing force required to reduce the intrinsic induction (B_i) to zero. The residual induction (Br) is the induction remaining in the material after the magnetizing force has been reduced to zero. The "ideal permeability" differs from the normal permeability both in magnetic environment and technique. The conditions surrounding the "ideal" tests were proposed to simulate the effects caused by mechanical shaking under service conditions. As such, the samples are "idealized" by applying a 0.5 oersted d-c magnetic field and then super-imposing an a-c magnetic field of 50 oersteds or greater. The a-c field is then diminished to zero. The sample is pushed out of its search coil without changing the d-c field and the fluxmeter is read. The fluxmeter reading thus obtained is proportional to the magnetization of the sample, B-H. The ideal permeability is then computed as (μ ideal = $1 + \frac{B-H}{H}$).

5. In many instances, samples too large for testing at EES were furnished NOL by the Station and other agencies. On several occasions, samples tested at the EES were unsuitable for testing at NOL. In any event, the available data on all of the materials submitted to NOL to date are included in this report.

RESULTS OF TESTS ON NON-FERROUS MATERIALS

Copper-Base Alloys

6. Test results for the copper-base alloys tested at EES and NOL are tabulated in Table I. Except for the 80:20 cupronickel alloy, the correlation between the laboratories appears to be good. More will be said, however, on this correlation later in the report.

TABLE I

Magnetic Properties of Copper-Base Alloys

Material	Grade	NOL Specimen Shape	NOL Specimen Diam	Described Condition	Source	Remarks	NOL Data: Normal μ at H=0.5, -40°C	NOL Data: Normal μ at H=0.5, +24°C	NOL Data: Normal μ at H=0.5, +49°C	NOL Data: Normal μ H=20 at +24°C	NOL Data: Ideal μ H=0.5 at +24°C	NOL Data: iHc	NOL Data: Br	EES Data at +24°C: Normal μ 100H	EES Data at +24°C: Normal μ 200H	EES Data at +24°C: Hc
Brass	SAE-72	Rod	1"	Wrought bar Original size 1-3/16" rod machined to 1" rod	General Motors Co.	NM-21	1.04	1.04	1.06	Δ 1.05	1.75	25.15	2.58			
Naval Brass	SAE-73	Rod	1"	Wrought bar Original size 1-1/8" machined to 1" rod	General Motors Co.	NM-22	<1.004	<1.004	<1.004	Δ <1.004	<1.004	-	<0.02			
Red Brass	SAE-40	Rod	1/2"	Rod brass - as cast Original size .505"-machined to 1/2" rod	General Motors Co.	NM-26	<1.02	<1.02	<1.02	<1.02	<1.02	21.08	0.07			
Al-Bronze	46B18 Cl 1 (Ampco 12)	Rod	1/2"	Sand cast Ampco heat #P7923	Ampco Metal Inc.		1.23	1.19	1.20	1.20	1.54	29.72	7.69	1.17	1.18	1
Al-Bronze	Ampco 18	Rod	1"	Wrought bar Original size 1-1/8" machined to 1" rod	General Motors Co.	NM-16	1.16	1.15	1.20	Δ 1.19	1.25	17.36	5.68			
Al-Mn Bronze	46B29a (Ampco 64)	Rod	1/2"	Sand cast Ampco heat #07770	Ampco Metal Inc.		1.22	1.22	1.20	1.23	1.33	12.10	3.68	1.27	1.24	1
Al-Ni Bronze	46B17 (Ampco 45)	Rod	1/2"	Ampco heat #LN3143	Ampco Metal Inc.		<1.02	1.04	<1.02	<1.02	1.04	83.16	1.80	1.02	1.02	0
Al-Ni Bronze		Rod	1"	Cast	Bison Bronze Foundry Co.		1.24	1.22	1.19	Δ 1.23	1.23	1.26	3.00	1.06	1.06	0
Mn-Bronze(Wrought)	46B15e	Rod	1/2"	As received	J.H. Jolley & Co.	VV 27595	1.08	1.09	1.11	1.10	1.11	39.21	5.14	1.09	1.09	1
Mn-Bronze(Cast)	46B3f	Rod	1"	As received (cast)	Cramp Brass Iron Foundry	CHC 430	1.09	1.09	1.09	Δ 1.11	1.25	10.55	[illegible]	1.09	1.10	0
Mn-Bronze	46B3f (Ampco 62)	Rod	1/2"	Centrifugally cast Ampco heat #P7962	Ampco Metal Inc.		1.10	1.14	1.09	1.10	1.15	25.21	3.13	1.10	[illegible]	[illegible]
Mn-Bronze	SAE-43	Rod	1"	Manganese bronze-as cast - Original size-test bar billet-machined to 1" rod	General Motors Co.	NM-24	1.10	1.10	1.12	Δ 1.12	1.17	18.35	4.76			
Leaded Tin Bronze	46B8i (Ampco 71)	Rod	1/2"	Sand cast Ampco heat #LN3136	Ampco Metal Inc.		<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02	1.00	1.00	0
Leaded Tin Bronze	46B8i	Rod	1/2"	As cast	EES		<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02	1.00	1.00	0
Tin Nickel Bronze	46B32 Type I	Rect.	-	As cast	NRL	Wrong Shape								1.00	1.00	0
Tin Nickel Bronze	46B32 Type II	Rect.	-	As cast	NRL	Wrong Shape								1.00	1.00	0
Bronze	SAE-430	Rod	1/2"	High tensile manganese bronze-as cast Original size-.505" test bar-machined to 1/2" rod	General Motors Co.	NM-25	1.27	1.27	1.31	1.31	1.42	7.67	3.05			
Bronze	SAE-620	Rod	1"	Gun metal as cast Original size 1-5/8" rod machined to 1" rod	General Motors Co.	NM-13	<1.004	<1.004	<1.004	Δ <1.004	<1.004	-	<0.02			
Bronze	SAE-622	Rod	1/2"	Valve bronze-as cast - Original size -.505" test bar-machined to 1/2" rod	General Motors Co,	NM-14	<1.02	<1.02	1.02	<1.02	<1.02	-	<0.02			
70:30 Cu-Ni Alloy		Rect.	-	As received (wrought)	(Stock)	CEY 4900 Wrong Shape								1.00	1.00	0
80:20 Cu-Ni Alloy		Rod	1/2"	As-cast centrifugally	Sand. Fdy. & Mach. Co.		2.84	1.97	1.65	1.86	1.96	-	-	1.50	1.29	0
80:20 Cu-Ni Alloy		Rod	1/2"	Cast centrifugally	Sand. Fdy. & Mach. Co.			1.84			1.94			1.48	1.48	0
Cu-Si Alloy	46B27a	Rod	1/2"	As received	Bridgeport Brass Co.	AHP-20	<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02	1.00	1.00	0
Cu-Si Alloy	46B28a Class 1	Rect.	-	As cast	NRL	Wrong Shape								1.10	1.10	0
Cu-Si-Mn Alloy		Rod	1/2"	From wire .185 x .775	American Brass Co.	Too short								1.00	1.00	0

Δ H ≅ 7.0

7. Table II is a tabulation of results obtained at the Station on several aluminum bronzes. Examination of this data reveals that quenching from 1200°F is not effective in reducing the as-cast permeability of the Ampco 18 alloy. Quenching from 1650°F gave inconsistent results in that it reduced the permeability of the Ampco 18 but increased that of the Ampco 45. In general, the double treatment (Treatment D) substantially lowered the permeability of all of the alloys tested except Ampco 45. This alloy was initially low, however, in the as-cast condition.

8. Analysis by the Statistician's Office of the composition and permeability data of Table II resulted in the following:

(a) The concentration of iron is an important factor in determining the permeability of these alloys.

(b) The concentration of nickel has no effect on the permeability of these alloys.

(c) Manganese content does affect permeability. The nature of its effect, however, is not clear-cut. Alloys having .03% Mn or more give a different relationship with Fe than those having less than this amount, the higher Mn alloys tending toward lower permeabilities.

TABLE II

Effect of Heat Treatment on the Room Temperature Magnetic Properties of Several Aluminum Bronze Samples Furnished by Ampco Metals, Inc.

	Chemical Composition-%					Total No. of	Avg. Normal Permeability (μ) & Avg. Coercive Force H_c											
							Treatment A			Treatment B			Treatment C			Treatment D		
Specification	Cu	Al	Fe	Ni	Mn	Samples	100H	200H	H_c	100H	200H	H_c	100H	200H	H_c	100H	200H	H_c
Ampco 18-S. C.	86.10	10.63	3.11	.13	.01	8	1.25	1.26	2	1.24	1.25	2	1.17	1.17	0	1.16	1.16	0
Ampco 18-S. C.	84.34	10.70	4.71	.22	.01	8	1.47	1.52	4	1.48	1.52	4	1.30	1.32	2	1.32	1.34	2
Ampco 46-S. C.	81.59	10.32	4.38	3.59	.10	4	1.25	1.26	2							1.10	1.10	2
Ampco 46-S. C.	79.58	10.38	5.33	4.66	.03	4	1.38	1.38	1							1.18	1.18	1
Ampco 46-S. C	78.08	10.23	5.79	5.86	.02	4	1.69	1.74	6							1.32	1.35	2
Ampco 46-S. C.	79.78	10.09	4.30	5.76	.02	4	1.35	1.39	5							1.18	1.20	4
Ampco 46-S. C.	79.95	10.04	6.01	3.95	.01	4	1.43	1.45	2							1.28	1.29	0
Ampco 45-Ext.	81.25	9.90	2.98	5.12	.79	3	1.05	1.05	1				1.11	1.11	0	1.05	1.05	0
Ampco 45-Ext.	81.91	9.95	2.54	4.80	.80	3	1.03	1.03	0				1.11	1.11	0	1.04	1.04	0

Treatment A - As Cast
Treatment B - Heated to 1200°F - Quenched
Treatment C - Heated to 1650°F - Quenched
Treatment D - Heated to 1650°F - Quenched then heated to 1200°F - Air cooled

Nickel-Base Alloys

9. Results for the nickel-base alloys are tabulated in Table III. It will be noted that only two samples have been tested jointly by EES and NOL. As was expected, the permeability of "R" monel is in excess of that desired and this material is not considered to be acceptable. Monel 326 is a new low permeability monel developed by the International Nickel Company. This alloy is similar to the standard monel except that the nickel content has been reduced to approximately 60%. The sample tested at EES had the following composition:

Ni - 59.3%	Cu - 38.2%
C - 0.14	Mn - 1.21
Si - .13	Fe - 1.07

In general, the Curie point of this alloy appears to be near -40°C. Accordingly, the normal permeability measurements made at -40°C and shown in Table III exhibit a wide range of values. The results obtained for monel 326 - Heat No. M 9119-BL should be noted. Originally, specimens of this heat were furnished in the form of 1" diameter bars taken from hot worked billets or sheet bar. Measurements indicated a high permeability at 0°C. However, after further hot reduction to 1/4" thickness, the normal permeability dropped to a low value.

Aluminum-Base Alloys

10. Because of their high electrical conductivity, aluminum-base alloys have not been investigated in this program. However, two alloys have been tested by NOL and the results are included in Table III.

RESULTS OF TESTS ON FERROUS MATERIALS

Austenitic Stainless Steels - Wrought

11. This category comprises the largest group of materials tested jointly by EES and NOL. Table IV presents the results obtained to date. The metallurgical features of these alloys have been discussed in reference (a). In so far as normal permeabilities go, agreement between EES and NOL appears to be good. There is a difference, however, with respect to ideal permeability vs EES normal permeability, the ideal permeability showing a large increase with but a slight increase in normal permeability.

TABLE III

Magnetic Properties of Nickel-Base and Aluminum-Base Alloys

Material	NOL Specimen Shape	NOL Specimen Diam	Described Condition	Source	Remarks	NOL Data: Normal μ at H = 0.5, -40°C	NOL Data: Normal μ at H = 0.5, +24°C	NOL Data: Normal μ at H = 0.5, +49°C	NOL Data: Normal μ H = 20 at +24°C	NOL Data: Ideal μ H = 0.5 at +24°C	NOL Data: iHc	NOL Data: Br	EES Data at +24°C: Normal μ 100H	EES Data at +24°C: Normal μ 200H	EES Data at +24°C: Hc
Nickel Base Alloys															
"K" Monel	Rod	1/2"	As received - age hardened	N. Y. Naval Shipyard		<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02	1.01	1.01	0
" "	Rod	1"	Age hardened	General Motors Co.	NM-11	<1.004	<1.004	<1.004	<1.004▲	1.01	25.80	0.15			
"R" Monel	Rod	1"	Cold drawn, original size 1-1/8" rod	" " "	NM-12	9.4●	16.8●	19.0●	-	123	0.96	25.18			
" "	Rod	1"	Annealed - 1600°F, half hour soak, water quench, original size 1-1/8" machined to 1" rod	" " "	NM-12	30.0●	46.5●	46.2●	-	127	0.31	8.66			
"S" Monel	Rod	1/2"	Cast, age hardened - 1090°F - 5 hrs	Norfolk Naval Shpyd		<1.02	<1.02	<1.02	1.01	<1.02	73.72	0.88	1.01	1.01	0
Monel 326	Rod	1"	As received	Int. Nickel Co.	Melt No. 8787-BL								1.02	1.02	0
" "	Rod	1"		" " "	M-9119-BL	31.0	1.01	9.20*		1.02					
" "	Rod	1"		" " "	#1 9119 B-L	61.0	1.03	5.21*		1.02					
" "	Bar	-	3 bars 1/4" x 1/2" x 6"	" " "	M-9119-BL #4			1.02*							
" "	Bar	-	3 bars 1/4" x 1/2" x 6"	" " "	M-9119-BL #2			1.02*							
" "	Bar	-	3 bars 1/4" x 1/2" x 6"	" " "	M-9119-BL #1			1.04*							
" "	Bar	-	3 bars 1/4" x 1/2" x 6"	" " "	M-9119-BL #3			1.01*							
" "	Rod	1"		" " "	M-9120-BL	6.60	1.02	1.27*		1.02					
" "	Rod	1"		" " "	M-9121-BL	2.46	1.02	1.04*		1.02					
" "	Rod	1"		" " "	M-9123-BL	1.05	1.01	1.03*		1.01					
" "	Rod	1"		" " "	M-9124-BL	4.89	1.02	1.26*		1.02					
" "	Rod	1"		" " "	M-9125-BL	1.67	1.01	1.03*		1.01					
" "	Rod	1"		" " "	M-9130-BL	1.51	1.01	1.03*		1.02					
" "	Rod	1"		" " "	M-9131-BL	2.36	1.02	1.04*		1.02					
" "	Rod	1"		" " "	M-9132-BL	4.11	1.02	1.11*		1.02					
" "	Rod	1"		" " "	M-9140-BL	2.68	1.01	1.03*		1.01					
" "	Rod	1"		" " "	M-9141-BL	1.34	1.02	1.03*		1.02					
" "	Rod	1"		" " "	M-9142-BL	1.24	1.02	1.03*		1.02					
" "	Rod	1"		" " "	M-9143-BL	2.89	1.01	1.05*		1.01					
" "	Rod	1"		" " "	M-9144-BL	1.87	1.01	1.03*		1.01					
" "	Rod	1"		" " "	M-9145-BL	2.48	1.02	1.03*		1.02					
" "	Rod	1"		" " "	#2 9120-BL	6.27	1.02	1.12*		1.02					
" "	Rod	1"		" " "	#3 9124-BL	7.09	1.02	1.09*		1.02					
" "	Rod	1"		" " "	#4 9142-BL	1.48	1.02	1.01*		1.02					
Aluminum Base Alloys															
Aluminum (355-T7)	Rod	1/2"	Cast aluminum-precipitation hardened Original size-.505" machined to 1/2" rod	General Motors Co.	NM-27	<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02			
Aluminum (SAE 33)	Rod	1/2"	As Cast Original size-.505" machined to 1/2" rod	General Motors Co.	NM-28	<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02			

● H = 0.2
▲ H ≅ 7.0
* 0°C

TABLE IV

Magnetic Properties of Wrought Austenitic Stainless Steels

Material	NOL Specimen		Described Condition	Source	Remarks	NOL Data							EES Data at +24°C		
						Normal μ at H=0.5			Normal μ H=20 at +24°C	Ideal μ H=0.5 at +24°C	iH_c	Br	Normal μ		Hc
	Shape	Diam				-40°C	+24°C	+49°C					100H	200H	
Stainless Steel-AISI 302	Rod	1/2"	From wire .188 x .755	Carpenter		1.35	1.36	1.36	1.41	2.40	126.6	141.0	1.38	1.66	30
" " " "	Rod	1/2"	From wire .188 x .755	Carpenter		1.56	1.55	1.55	1.64	5.01	108.5	192.0	1.56	2.00	37
" " " "	Rod	1/2"	Cut from bar stock	D. K. Manfg. Co.		1.08	1.07	1.06	1.07	1.22	156.7	36.69	1.08	1.13	0
" " " "	Rod	1/2"	Machined from 1" bar	" " " "		1.34	1.35	1.43	1.59	2.33	13.09	12.83	1.28	1.33	5
" " " "	Rod	1/2"	3/4" bar pulled in tension reduced 28.3%	" " " "		1.30	1.34	1.37	1.46	2.57	42.59	37.03	1.34	1.43	10
" " " "	Rod	1/2"	3/4" ø tension spec. reduced 30.0%	" " " "		1.94	1.91	1.97	2.04	8.60	73.72	193.8	-	>3.0	-
" " " "	Rod	1/2"	Machined from 1-5/8 ø as rec'd bar	" " " "		1.62	1.66	1.55	1.91	3.10	5.60	8.96	1.33	1.36	2
" " " "	Rod	1"	Annealed. Machine straightened & centerless ground	Armco Steel Corp	Heat No. 69217	<1.004	<1.004	<1.004	<1.004Δ	1.01	306.0	1.92	1.01	1.05	0
" " " "	Rod	1"	Annealed, cold drawn approximately 18%, machine straightened & stress relieved	" " "	Heat No. 18791	1.04	1.04	1.04	1.04Δ	1.39	350.0	39.56	1.09	1.18	16
" " " "	Rod	1/2"	Annealed, cold drawn approximately 25%, machine straightened & stress relieved	" " "	Heat No. 18693 turned down from 5/8" by NOL	1.13	1.15	1.14	1.19	1.15	151.5	12.21	1.18	1.44	34
" " " "	Rod	1"	Hot cold forged - 25% cold reduction	General Motors Corp	NM-3	<1.004	<1.004	<1.004	1.004Δ	1.01	75.53	0.70			
Stainless Steel-AISI 303	Rod	1"	Annealed 2 hours at 2000°F, water quenched	" " "	NM-5	1.01	1.01	1.01	1.01 Δ	1.23	34.00	0.13			
" " " "	Rod	1"	Annealed, machine straightened & centerless ground	Armco Steel Corp	Heat No. 60520	1.09	1.10	1.10	1.12 Δ	1.10	204.0	79.10	1.03	1.04	2
" " " "	Rod	1"	Cold drawn	General Motors Corp	NM-5	<1.004	<1.004	<1.004	<1.004Δ	1.03	490.0	5.91			
Stainless Steel-AISI 304	Rod	1/2"	Cut from bar	D. K. Manfg. Co.		<1.02	<1.02	<1.02	<1.02	<1.02	113.7	0.45	1.00	1.00	0
" " " "	Rod	1/2"	As rec'd Machined from 1" diam bar, shot peened	EES Stock		<1.02	<1.02	<1.02	<1.02	1.04	170.7	1.43	1.01	1.01	0
" " " "	Rod	1/2"	As rec'd. Machined down to 1/2" diam	D. K. Manfg. Co.		1.30	1.27	1.32	1.55	2.03	10.71	9.17	1.23	1.26	6
" " " "	Rod	1/2"	Machined from 3/4" diam. after 27.9% red. by pulling	" " " "		1.02	<1.02	<1.02	1.08	<1.02	233.0	2.40	1.01	1.01	0
" " " "	Rod	1/2"	Tension spec. reduced 29.3%	" " " "		1.87	2.43	2.45	2.72	24.5	58.66	432.0	-	>3.0	-
" " " "	Rod	1/2"	Spec. machined from 1" bar and twisted to rupture in stake torsion machine as 1/2" diam	EES Stock	Cut down to 3"	1.07	1.02	1.07	1.06	1.22	317.4	59.30	1.08	1.12	9
" " " "	Rod	1/2"	Machined from 1-5/8" ø as rec'd	D. K. Manfg. Co.		<1.02	<1.02	<1.02	<1.02	<1.02	46.20	0.15	1.00	1.00	0
" " " "	Rod	1/2"	1.008" pulled reduced diam 23.3%, elongation 27.6%	EES Stock	Turned down to 1/2" rod by NOL	<1.02	<1.02	<1.02	1.02	<1.02	154.3	8.23	1.02	1.04	3
" " " "	Rod	1/2"	Spec. machined from 1.008" bar pulled in tension, Machine reduced 37.5%, elongation 55.7%	EES Stock		1.04	1.04	1.05	1.05	1.37	166.3	40.62	1.06	1.15	16
" " " "	Rod	1"	Heated 1900°F 20 min. quench in water	Rustless Iron Steel Corp.	4F518e Cl 7	<1.004	<1.004	<1.004	1.01Δ	1.02	17.61	0.27	1.02	1.02	0
" " " "	Rod	1"	"Hot" cold worked, forged from 2" ø to 1-1/2" ø, finished. Forged to 1-1/4" while cooling from 1400°F to block. 1" øx6" specimen machined & stress relieved 2 hrs at 1075°F	Western Gear Works	"Specimen C"	<1.004	<1.004	<1.004	<1.004Δ	[illegible]	73.0	3.30			
" " " "	Rod	1"	"Hot" cold rolled as "Specimen C" plus shot peening to Almen .012/.016 A_2 & then pickled	" " "	"Specimen D"	<1.004	<1.004	<1.004	1.01Δ	1.01	225.0	2.21			
" " " "	Rod	1"	"Hot" cold rolled as "Specimen C" plus nitriding by "Chapmanizing" process	" " "	"Specimen B"	1.11	1.13	1.12	1.14Δ	1.34	200.0	86.10			
" " " "	Rod	1"	As received	D. K. Manfg. Co.	Heat No. 24246	1.20	1.19	1.21	1.29Δ	1.60	19.69	10.48			

Δ H ≅ 7.0

TABLE IV

(contd)

Magnetic Properties of Wrought Austenitic Stainless Steels

Material	NOL Specimen		Described Condition	Source	Remarks	NOL Data							EES Data at +24°C		
						Normal µ at H=0.5			Normal µ H=20 at +24°C	Ideal µ H=0.5 at +24°C	iH_c	Br	Normal µ		
	Shape	Diam				-40°C	+24°C	+49°C					100H	200H	Hc
Stainless Steel-AISI 304	Rod	1"	Anneal - atmosphere controlled furnace at 1900°F for 1 hr - cooled in atmosphere air	D. K. Mandy Co.	Heat No. 24246	1.04	1.05	1.05	1.05 Δ	1.10	15.87	11.99			
" " " "	Rod	1"	Annealed, open fire at 1900°F for 1 hr, water quenched & sodium hydride descale at 750°F for 15 min	"	Heat No 24246	1.08	1.08	1.09	1.10 Δ	1.17	12.33	16.17			
" " " "	Rod	1"	Mill annealed	Lukens Steel Co.	Heat No 40113	1.02	1.02	1.02	1.02 Δ	1.02	15.27	2.98			
" " " "	Rod	1"	Mill annealed, stress relieved at 1500°F, 5 hrs-F.C.		Heat No. 40113	1.02	1.02	1.01	1.02 Δ	1.02	55.44	1.65			
" " " "	Rod	1"	Mill annealed		Heat No 40696	<1.004	<1.004	<1.004	<1.004 Δ	<1.004	21.29	0.92			
" " " "	Rod	1"	Mill annealed, stress relieved at 1500°F, 5 hrs-F.C.		Heat No 40696	1.03	1.03	1.04	1.04 Δ	1.13	56.37	5.64			
" " " "	Rod	1"	Mill annealed		Heat No. 60534	1.51	1.72	1.77	-	2.87	12.05	13.01			
" " " "	Rod	1"	Mill annealed, stress relieved at 1500°F, 5 hrs-F.C.		Heat No 60534	1.33	1.39	1.41	1.44 Δ	2.28	37.20	33.41			
" " " "	Rod	1/2"	Forged and annealed		Melt No. 41043	<1.02	<1.02	<1.02	<1.02 Δ	1.05	57.65	1.58	1.01	1.01	0
" " " "	Rod	1/2"	Forged, annealed, strain relieved at 1500°F, 5 hrs-F.C.		Melt No. 41043	1.04	1.06	1.05	1.04 Δ	1.14	48.77	4.28	1.01	1.01	0
" " " "	Rod	1/2"	Forged, annealed		Melt No. 41044	<1.02	<1.02	<1.02	<1.02 Δ	1.04	57.25	0.64	1.01	1.01	0
" " " "	Rod	1/2"	Forged, annealed, strain relieved at 1500°F, 5 hrs-F.C.		Melt No 41044	<1.02	<1.02	<1.02	<1.02 Δ	1.47	52.27	1.48	1.01	1.01	0
Stainless Steel-AISI 305	Rod	1/2"	Annealed, bumper straightened	Armco Steel Corp	Heat No 10846 turned down from 21/32" by NOL	<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02	1.00	1.00	0
Stainless Steel-AISI 309	Rod	1"	Annealed, machine straightened & centerless ground		Heat No 19098	2.73	3.70	3.72	-	10.8	5.93	0.31	2.47	2.56	5
Stainless Steel-AISI 310	Rod	1"	Annealed, machine straightened & centerless ground	"	Heat No 40596	<1.004	<1.004	<1.004	<1.004 Δ	<1.004	-	<0.02	1.00	1.00	0
Stainless Steel-AISI 316	Rod	1"	Heated 1900°F, 20 min quench in water	Rustless Iron Steel Corp.	46S18e Cl 9	<1.004	<1.004	1.004	<1.004 Δ	<1.004	sample destroyed		1.00	1.00	0
" " " "	Rod	1/2"	As received	Boston Naval Shipyard	NOL turned down to 1" rod	<1.02	<1.02			<1.02			1.00	1.00	0
" " " "	Rod	1/2"	As received, specimen turned to 0.622" and pulled in tension, cold reduced 26%		NOL turned down to 1" rod, max stress 86,000	<1.02	<1.02			<1.02			1.00	1.00	0
" " " "	Rod	1"	Nitrided	Packard Motor Car Co.	#1	1.16	1.15	1.15	1.19 Δ	1.28	135.3	57.03			
Stainless Steel-AISI 321	Rod	1"	Nitrided		#3	1.34	1.37	1.38	1.44 Δ	2.05	71.70	63.15			
" " " "	Rod	1/2"	Heat 60966, annealed and pickled	Allegheny Ludlum Steel		1.20	1.22	1.24	1.29	1.55	12.40	5.71	1.18	1.20	2
Stainless Steel-AISI 347	Rod	1/2"	Wrought pipe stabilized at 1600°F	M. W. Kellogg Co.		<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02	1.00	1.00	0
" " " "	Rod	1/2"	Bar nitrided	Packard Motor Car Co.	[illegible] turned down to 1/2" rod	<1.02	<1.02	<1.02	<1.02	<1.02	16.86	0.15			
" " " "	Rod	1"	Nitrided - CB & Ta stabilized		#4	1.19	1.19	1.19	1.21 Δ	1.24	143.7	72.56			
Cyclops 19-9 DL	Rod	1"	Hot cold forged - 25% cold reduction	General Motors Corp	NM-10	1.02	1.04	1.03	1.03 Δ	1.05	29.73	1.29			
Timken 16-25-6	Rod	1"	Hot cold forged - 25% cold reduction		NM-31	1.01	<1.004	<1.004	1.004 Δ	1.01	-	<0.02			
Discaloy	Rod	1/2"	Machined from 3/4" bar, heat treated completely, bar marked D30 14D	Westinghouse Elec Co		<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02	1.00	1.01	0
"	Rod	1/2"	Spec. machined from tension specimen 5/8" diam after being reduced 12.3%			<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02		1.01	0
Thermalloy 30	Rod	1"	As Received	Amer. Brake Shoe Co.	Code No. 51-209	<1.004	<1.004	<1.004	≤1.004 Δ	1.01	54.83	0.20	1.00	1.00	0
Thompson Alloy	Rod	1"	Nitrided	Packard Motor Car Co.	#2	1.11	1.11	1.10	1.13 Δ	1.40	94.80	29.64			

Δ H ≅ 7.0

Precipitation Hardening Stainless Steels

12. Permeability data on the precipitation hardening stainless steels are tabulated in Table V. The mechanism of precipitation hardening in these steels is not too well understood, but information contained in reference (c) indicates that chemical composition is an important variable. In general, hardening occurs in one of two ways. First, an alloying element is added to the steel which has a higher solubility in austenite, the non-magnetic phase, than it does in ferrite, the magnetic phase. By proper manipulation of heat treatment, it is possible to make the steel entirely austenitic and then to partially transform this constitutent to ferrite with subsequent precipitation of the hardening phase. In the second method, the annealed structure consists of a mixture of austenite and ferrite. By suitable heat treatment, the ferrite and a part of the austenite is transformed to a hard non-magnetic phase called sigma.

13. The first described hardening mechanism involves the formation of magnetic ferrite and unless closely controlled, the permeability of the hardened alloy will exceed the prescribed limits. The 17-4 PH, 17-7 PH, and AISI 322 steels are of this type. It is unfortunate also that the ferrite is not always completely transformed to non-magnetic sigma phase during the second mentioned hardening procedure. Such is the case for the AISI 329 steel.

14. In general, the precipitation hardening stainless steels constitute a group of materials whose use must be advised with extreme caution, as delicate control of analysis and heat treatment are required to remain within the permeability limits.

Austenitic Stainless Steels - Cast

15. As in reference (a), weld metals and non-magnetic cast irons have been included under this group. The results for these alloys are shown in Table VI.

Austenitic Manganese Steels

16. The metallurgical features of these alloys have also been described in reference (a). Table VII presents the data on these steels. Attention is called to the two alloys which have been noted in the table. Both alloys were supplied in the form of 1" diameter cast bars. It is not unusual for cast and heat treated austenitic manganese steels to have a "skin" of decarburized material on the surface. This skin is high in ferrite. The apparent discrepancies in results are due to the fact that NOL tested the materials with the skin intact, whereas the Station machined 1/2" diameter specimens from the core of the samples.

TABLE VI

Magnetic Properties of Cast Austenitic Stainless Steels

Material	NOL Specimen		Described Condition	Source	Remarks	NOL Data							EES Data at +24°C		
						Normal μ at H=0.5			Normal μ H=20	Ideal μ H=0.5			Normal μ		
	Shape	Diam				-40°C	+24°C	+49°C	at +24°C	at +24°C	iHc	Br	100H	200H	Hc
Cast-Type 304	Rod	1/2"	2050°F water quench - L - 22 heat C7514	Lebanon Steel Fdy.		1.06	1.07	1.07	1.08	1.10	9.53	0.88	1.08	1.08	0
Cast-Type 347	Rod	1/2"	2050°F air quench - L - 21 heat B5978	Lebanon Steel Fdy.	Turned down to 1/2" rod	<1.02	1.03	1.02	1.03	1.06	12.56	0.50	1.03	1.02	0
Cast-Type 316	Rod	1/2"	2050°F water quench - L - 22XM heat D8905	Lebanon Steel Fdy.		1.40	1.43	1.45	1.49	1.70	10.33	6.44	1.44	1.45	2
Cast-18-8 Cb	Rod	1/2"	Casting	Crane Co.	CND 7030	1.91	2.14	2.10	2.12	4.13	12.31	23.28	2.48	2.66	not detd
Cast-25-20	Rod	1/2"	As cast - AMS-5366 heat Y-435	Mich Stl. Cast Co.	CPT1-15	<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02	1.01	1.02	0
CAST IRONS															
Ductile Ni-Resist	Rod	1/2"	As received	Straight Line Fdy. & Mach. Co. Int. Nickel Co.		1.03	<1.02	1.02	<1.02	1.19	51.42	2.11	1.02	1.03	1
Ductile Ni-Resist	Rod	1/2"	Annealed at 1700°F-1 hr air cooled	"		1.05	1.03	1.03	1.05	1.38	29.12	2.32	1.03	1.04	3
Ductile Ni-Resist	Rod	1/2"	Annealed at 1150°F-1 hr furnace cooled	"		1.03	<1.02	1.02	1.03	1.10	64.28	2.48	1.02	1.03	1
Cast Iron-Ni Resist	Rod	1/2"	As cast - Original size 1/2" rod-machined to 1/2" rod	General Motors Co.	NM-29	<1.02	1.03	1.02	1.03	1.28	32.04	2.19			
Ductile Ni-Resist Type 2	Rod	1"	Original size 1/2" rod-machined to 1" rod - As cast condition	General Motors Corp.	NM-30	1.06	1.03	1.02	1.03▲	1.06	39.37	1.26			
WELD METALS															
19-9 Weld (Chromend K)			Electrodes 5/32" - As deposited	Arcos Corp.	Weld made at EES		1.15						1.15	1.17	4
18-8 Cb Weld (Stainweld A5 Cb)			Electrodes 5/32" - As deposited	Lincoln Elect.	Weld made at EES		2.06			3.35			2.06	2.29	17
19-9 Cb Weld (Long. weld)	Rod	1/2"	Electrodes 5/32" stabilized at 1550°F	M.W. Kellogg Co.		1.72	1.77	1.79	1.91	3.32	27.41	45.80	1.73	1.92	20
19-9 Cb Weld (Trans. weld)	Rod	1/2"	Electrodes 5/32" stabilized at 1550°F	M.W. Kellogg Co.	Too short								1.04	1.04	1
19-9 Ti Weld	Rod	1/2"	Electrodes 3/32" as deposited	M.W. Kellogg Co.	Weld made at EES	1.29	1.30	1.31	1.34	1.57	32.04	19.14	1.33	1.38	2
18-13-2 Weld (Chromend KMo)			Electrodes 1/8" as deposited	Arcos Corp.	Weld made at EES		1.05			1.22			1.02	1.02	0
25-12 Weld (Chromend HC)			Electrodes 5/32" as deposited	Arcos Corp.	Weld made at EES		1.57		-	2.01			1.54	1.60	8
25-12 Ti Weld	Rod	1/2"	Electrodes 1/16" as deposited		Weld made at EES	1.05	1.07	1.07	1.07	1.09	30.36	4.01	1.08	1.09	2
25-20 Weld (Chromend HCN)			Electrodes 1/8" as deposited	Arcos Corp.	Weld made at EES		<1.004			<1.004			1.00	1.00	0
25-20 Weld	Rod	1/2"	Electrodes 5/32" stabilized at 1550°F	M.W. Kellogg Co.		<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02	1.00	1.00	0
Stainless 304 & Weld Metal 19:9 + 308	Rod	1/2"	Annealed parent metal and 15% weld metal	Lukens Steel Co.	#3 Diesel crankcase	1.08	1.07	1.09	1.11	1.38	55.84	16.88			
Stainless 304 & Weld Metal 19:9 + 308	Rod	1/2"	Annealed and sodium hydride descaling process	Lukens Steel Co.	#1 Diesel crankcase	1.08	1.10	1.09	1.11	1.23	57.25	15.45			
Stainless 304 & Weld Metal 19:9 + 308	Rod	1/2"	Annealed plus sodium hydride descaling process plus stress relieving 1500° - 5 hrs - FC	Lukens Steel Co.	#2 Diesel crankcase	1.08	1.07	1.11	1.11	1.27	16.95	2.72			
Frogalloy Type M Weld			Electrodes 1/4" as deposited	Norfolk Naval Shipyard	Weld made at EES								1.00	1.00	0

▲ H ≅ 7.0

TABLE VII

Magnetic Properties of Austenitic Manganese Steels

Material	NOL Specimen Shape	NOL Specimen Diam	Described Condition	Source	Remarks	NOL Data: Normal μ H=0.5 -40°C	Normal μ H=0.5 +24°C	Normal μ H=0.5 +49°C	Normal μ H=20 at +24°C	Ideal μ H=0.5 at +24°C	iHc	Br	EES Data at +24°C: Normal μ 100H	Normal μ 200H	Hc
Hadfield Man. Steel (1% C, 13% Mn)	Rod	1/2"	Annealed at 1950°F - 1.2 hr - water quenched	Taylor-Wharton		<1.02	<1.02	<1.02	<1.02	<1.02	4.06	0.10	1.00	1.00	0
Hadfield Man. Steel (1% C, 13% Mn)	Rod	1/2"	As received	Boston Naval Shipyard	NOL turned down to 1" rod	<1.02	<1.02			<1.02			1.00	1.00	0
Hadfield Man. Steel (1% C, 13% Mn)	Rod	1/2"	As received - specimen turned to 0.622" & pulled in tension - cold reduced 26%	Boston Naval Shipyard	NOL turned down to 1" rod max stress 115,200	1.02	<1.02			<1.02			1.01	1.01	0
*Hadfield Man. Steel (1% C, 13% Mn)	Rod	1"	As received	Amer. Brake Shoe Co.	Code No. 51-238	1.36	1.35	1.36	Δ 1.39	2.71	51.22	52.00	1.00	1.00	0
Jessop #9 (.4% C, 13% Mn, 3.5% Ni, 4% Cr)	Rect.	-	As received	Phila. Navy Yard	Wrong shape								1.00	1.00	0
Jessop #9 (.4% C, 13% Mn, 3.5% Ni, 4% Cr)	Rect.	-	Cold reduced in tension 15%	Phila. Navy Yard									1.04	1.07	5
Jessop #9 (.4% C, 13% Mn, 3.5% Ni, 4% Cr)	Rod	1/2"	Machined from 1" diam bar	Jessops Steel Co.		<1.02	<1.02	<1.02	1.05	<1.02	70.31	0.14	1.00	1.00	0
Jessop #9 (.4% C, 13% Mn, 3.5% Ni, 4% Cr)	Rod	1/2"	Spec. machined from 3/4" diam after tension reduction of 31.1%	Jessops Steel Co.		1.08	1.08	1.09	1.10	1.14	204.9	108.3	1.13	1.32	28
Mn-Ni Steel (.7% C, 14% Mn, 3% Ni)	Rod	1"	As received with scale	Taylor-Wharton		1.01	1.01	1.01	Δ 1.01	1.01	105.0	3.04	1.00	1.00	0
Mn-Ni Steel (.8% C, 14% Mn, 4% Ni)	Rod	1"	As received with scale	Amer. Brake Shoe Co.		<1.004	<1.004	<1.004	Δ 1.01	<1.004	124.4	1.15	1.00	1.00	0
Jessop #200 (.3% C, 11% Mn, 7% Ni)	Rod	1/2"	Pulled in tension 11% reduction in area	Jessops Steel Co.		<1.02	<1.02	<1.02	<1.02	<1.02	26.98	0.15	1.00	1.00	0
Jessop #200 (.3% C, 11% Mn, 7% Ni)	Rod	1/2"	Machined from 5/8" bar	Jessops Steel Co.		<1.02	<1.02	<1.02	<1.02	<1.02	-	<0.02	1.00	1.00	0
Mn-Ni Steel (.3% C, 11% Mn, 8% Ni)	Rod	1"	Natural finish (hot rolled)	Crucible Steel Co.	ASTM A-289-46-T	<1.004	<1.004	<1.004	Δ <1.004	<1.004	2.73	<0.02	1.00	1.00	0
*Cromanal (1.1% C, 12% Mn, 2% Cr)	Rod	1"	As received	Amer. Brake Shoe Co.	Code No. 51-239	1.32	1.31	1.31	Δ 1.34	2.29	53.03	30.50	1.00	1.00	0
Midvale Non-mag. (.7% C, 8% Mn, 9% Ni, 4% Cr)	Rod	1"	As received - cold worked	Midvale Co.	Heat No. S/9435	<1.004	<1.004	<1.004		<1.004			1.00	1.00	0

Δ H ≅ 7.0

* See paragraph 16

Correlation of Permeability Data

17. It is desirable from both a practical and academic standpoint to determine the relationship that exists between EES and NOL permeability measurements. Examination of the data contained herein, indicated that the materials could be separated into two groups. The first or non-ferrous group is composed of the copper-base, nickel-base, and aluminum-base alloys. The ferrous group contains the wrought and cast austenitic stainless steels, the precipitation hardening stainless steels, and the austenitic manganese steels.

18. The room temperature relationship for $\mu_{0.5}$ (NOL) vs μ_{100}(EES) and μ_{ideal} (NOL) vs μ_{100} (EES) are shown for the non-ferrous materials in Figures 1 and 2 of Plate 1. The normal permeability at 100 oersteds was selected for comparison purposes because these results generally exhibited a closer correlation with the NOL data. The upper 95% confidence limits are also presented in the figures of Plate 1. These limits are useful in determining the maximum acceptable μ_{100} (EES) which will insure a $\mu_{0.5}$ (NOL) or a μ_{ideal} (NOL) of not greater than 2.0. For example, the limit in Figure 1 indicates that if μ_{100} (EES) is approximately 1.5, then there is only one chance in twenty that $\mu_{0.5}$ (NOL) will be greater than 2.0. Consequently, the value $\mu_{100} \leqq 1.5$ becomes an acceptance limit. Likewise for the case μ_{ideal} (Figure 2) except that in this instance the limit is $\mu_{100} \leqq 1.4$.

19. Figures 3 and 4 of Plate 1 show similar relationships for the ferrous alloys. As mentioned previously and as shown in Figure 4, the ideal permeabilities for the ferrous materials are quite variable. The acceptance limits for $\mu_{0.5}$ and μ_{ideal} of the ferrous alloys are $\mu_{100} \leqq 1.6$ and $\mu_{100} \leqq 1.08$, respectively

20. Except for the monel 326 material, temperature appears to have little effect on the normal permeability of the various materials. The variability of monel 326 has been mentioned previously in the text.

Supplementary Information

21. In addition to the permeability measurements shown in Tables I to VII inclusive, NOL has conducted two supplementary investigations. One investigation was to determine the effect of varying the amplitude of the diminishing a-c field on the ideal permeability, and the other was to determine the effect of mechanical vibration on permeability. The results of these tests are presented herein as a matter of record.

22. The results of varying the amplitude of the diminishing a-c field on five samples are shown in Plate 2. The data indicate that the ideal permeability increases with increasing amplitude, and that some of the alloys are completely idealized by as little as 15 oersteds, while others are still incompletely idealized at 50 oersteds.

23. In order to compare the effects of idealization and mechanical shaking on permeability at 0.5 oersted, eight samples, which exhibited ideal permeabilities greater than two, were vibrated mechanically along their axes at stresses of the order of 10,000 psi at a rate of 23 cycles per second while in a 0.5 oersted field. The stresses were applied by means of an electric hammer (Master Hammer, Model 1R, Style V-199, Dayton, Ohio). Table VIII shows the results of this test. The data indicate that permeability is increased by mechanical vibration, but the effects are small as compared with the effects of idealization.

TABLE VIII

Comparison of Effects of Idealization and Mechanical Vibrations in a Magnetic Field on Permeability at H=0.5 Oersted

Material	Permeability at H=0.5 oersted at 24°C		
	Normal	Mechanical* Vibration	Ideal**
AISI 320-Wrought	1.77	2.03	3.10
AISI 302-Cold Red. 30%	2.02	2.05	7.76
AISI 302-Cold Reduced	1.38	1.47	2.40
AISI 302-Cold Reduced	1.43	1.66	3.51
AISI 302-Wrought	1.39	1.51	2.33
AISI 320-Cold Red. 28%	1.36	1.42	2.57
AISI 304-Wrought	1.36	1.51	2.03
19-9 CB - Weld Metal	1.86	1.92	3.32

* At approximately 10,000-15,000 psi and 23 cps
** From 50 oersteds a-c peak

24. It was recognized early in the program that unusual magnetic requirements would pose a problem in the procurement and inspection of shipboard components. Faced with this problem, the Bureau of Ships expressed a desire to obtain a simple field inspection device for inspecting low permeability materials and structures. Such a device, called a permeability indicator, has been developed by the Station and is shown in Plates 3 and 4. The Bureau has been furnished with thirty-six indicators for distribution in the field.

25. The permeability indicator indicates the normal magnetic permeability of low permeability materials. The indicator is of limited accuracy and is not entirely foolproof. Consequently, it should not be used as the sole basis for the rejection of materials. The advantage of the indicator lies in its ability to cast suspicion on certain materials and thus enable inspectors and others to intelligently examine materials and structures so as to determine whether or not more elaborate laboratory tests are required.

26. The operation of the permeability indicator is based on the mutual attraction of a permanent bar magnet for a known standard and an unknown material. The indicator is furnished with three known permeability inserts or standards, namely 1.2, 1.6, and 2.0. In use, an insert is placed in the seat of the indicator; the magnet being attracted to the insert by a force dependent upon the inserts permeability. While holding the indicator in the hand, the projecting end of the magnet is placed in contact with the material being tested. It is essential that the contact surface be clean and free of oxide scale. The indicator is then moved away in a direction normal to the surface. If the test material has a permeability higher than that of the insert, the magnet will break contact with the insert as the indicator is moved away. On the other hand, if the permeability of the test material is lower, then the magnet will break contact with the test material as it is moved away. Thus, by interchanging inserts, it is possible to bracket the permeability of various materials and structures.

27. Two features of the indicator deserve special mention. First, the balanced beam to which the magnet is attached permits the use of the indicator in all positions without corrections due to gravity. Second, the hemispherical ends on the magnet provide point contact with both the insert and test material. This eliminates to a great extent the affect of the shape of the materials being tested.

CONCLUSIONS

28. The conclusions are based on the data and information contained herein, and apply only to feebly magnetic materials.

29. It is concluded that strong field, room temperature, normal permeability measurements can predict the weak field normal permeability of both ferrous and non-ferrous materials. As one would expect, statistical variations exist in the results which require the establishment of certain acceptance limits. These limits insure acceptable weak field permeabilities based on strong field measurements.

30. The correlation between ideal permeability and normal permeability appears to be good for the non-ferrous materials. On the other hand, considerable variation exists for the ferrous materials. It is concluded that the ideal permeability of non-ferrous materials can be predicted from strong field normal permeability measurements, but that similar predictions for the ferrous materials are limited to the lower permeability values.

31. Available data indicate that the precipitation hardening stainless steels constitute a group of materials whose magnetic properties are extremely sensitive to composition and heat treatment. It is concluded, therefore, that use of these materials must be advised with caution in order to remain within the prescribed permeability limits.

32. In general, the conclusions reached in reference (a) remain valid. Any corrections or additions have been incorporated in the recommendations.

DISCUSSION

33. The metallurgical features affecting the magnetic properties of the various materials have been discussed in reference (a). A discussion of the results presented herein have been incorporated in appropriate sections of the text. It appears that most of the future work, both at this Station and NOL, will be directed toward the investigation of newly developed materials and the testing of questionable materials submitted by inspectors in the field.

RECOMMENDATIONS

34. The following recommendations concerning materials to be used in the construction program are based on the information presented in reference (a), this report, and in the literature. For simplification the materials have been divided into six categories:

Class I - Those materials which undoubtedly will have satisfactory normal permeability, ideal permeability, and coercive force, especially at room temperature and higher.

(a) All as-cast, annealed, or cold worked brasses, bronzes, cupronickel and other copper-base alloys containing less than 0.20% iron.

(b) All fully annealed brasses, bronzes, cupronickel, and other copper-base alloys containing iron in excess of 0.20% but less than 6%.

(c) Nickel-base alloys of the following types: "K" monel, "S" monel, and inconel.

(d) Unannealed 25 Cr - 20 Ni austenitic stainless steel in the form of castings, weld metal or wrought material.

(e) Fully annealed wrought austenitic stainless steels of the following types: 301, 302, 303, 304, 305, 308, 309, 310, 316, 321, 347.

(f) Fully annealed austenitic manganese-nickel steels similar to Jessop No. 9, Jessop No. 200, Taylor Wharton Mn-Ni, American Brake Shoe Mn-Ni, Crucible Mn-Ni and Midvale Non-Magnetic.

Class II - Those materials whose normal and ideal permeabilities are less than 2 but which may exhibit coercive forces of varying magnitude.

(a) All brasses and bronzes containing 6% or less of iron whether as-cast, hot rolled, cold rolled, or annealed.

(b) All cupronickel alloys containing 0.60% or less iron in the as-cast, hot rolled, cold rolled, or hardened condition.

(c) Austenitic cast irons such as Ni - resist Type 2.

(d) Commercial annealed, pickled, and straightened; or cold formed or unannealed but scale free hot worked wrought austenitic stainless steels Types 305 and 310.

(f) Fully annealed, "skin free" plain Hadfield and manganese-chromium austenitic steels.

Class III - Those materials whose normal permeability is less than 2 but whose ideal permeability may be greater or less than 2 and may also exhibit coercive forces of varying magnitude.

(a) Commercial annealed, pickled, and straightened; or unannealed but scale free hot worked wrought austenitic stainless steels of the following types: 302, 303, 304, 316, 321, and 347.

Class IV - Those materials whose normal and/or ideal permeability because of composition range or treatment, may be greater or less than 2 and may also exhibit coercive forces of varying magnitude.

(a) Unannealed cupronickel alloys containing more than 0.60% iron.

(b) Austenitic stainless steel castings conforming to Classes I, II, and III of Specification MIL-S-867 (Ships).

(c) Austenitic stainless steel weld metal of the 19-9 and 25-12 types.

(d) Cold worked wrought austenitic stainless steels of the following types: 301, 302, 303, 304, 308, 309, 316, 321 and 347.

(e) As-cast or cold worked plain Hadfield manganese steels.

(f) As-cast and/or heat treated with "skin" intact austenitic manganese steels.

Class V - Those recently developed materials which appear to have satisfactory normal permeability, ideal permeability, and coercive force; but because of composition, treatment, or insufficient number of commercial heats require additional study or tests.

(a) Nickel-base alloy monel 326.

(b) Precipitation hardening stainless steels similar to Rezistal 3311, Armco 21-4 Mn-S, Armco 21-4 Mn-S-N, and Armco Special Cr-Ni-P.

Class VI - Those materials which show unacceptable magnetic properties in the condition in which they must be used.

(a) Monel and "R" monel.

(b) Precipitation hardening stainless steels similar to and including 17-4 PH, 17-7 PH, AISI 322, and AISI 329.

REFERENCES

(a) EES Report 4E(1)66904, 4P(1)66918 dtd 6 April 1951
(b) BuShips ltr JJ46-1(19)(343) Serial 343-505 dtd 10 Oct 1950
(c) "A Precipitation Hardening Stainle[illegible] Steel of the 18% Chromium, 8% Nickel Typ[illegible]," by R. Smith, E. H. [illegible]yche, and W. W. Gorr, Trans Am. Inst. Min. and Met. Engrs., Iron and Steel Division, Vol 167, 1946, pp 313-345.

RELATIONSHIP BETWEEN EES & NOL ROOM TEMPERATURE PERMEABILITY DATA

NON-FERROUS ALLOYS

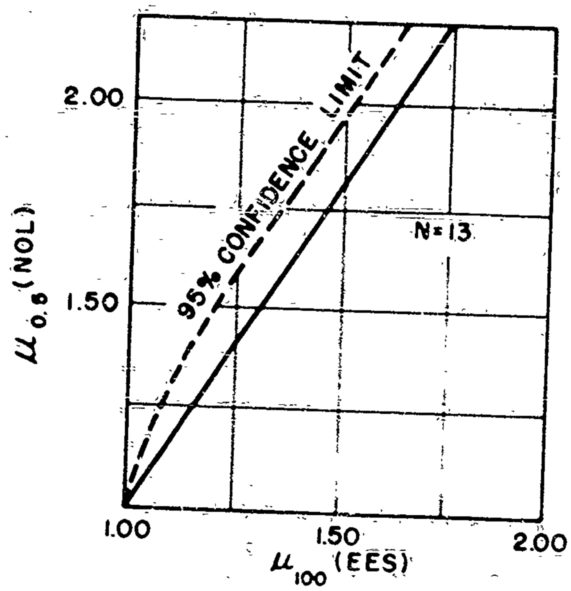


FIG. 1

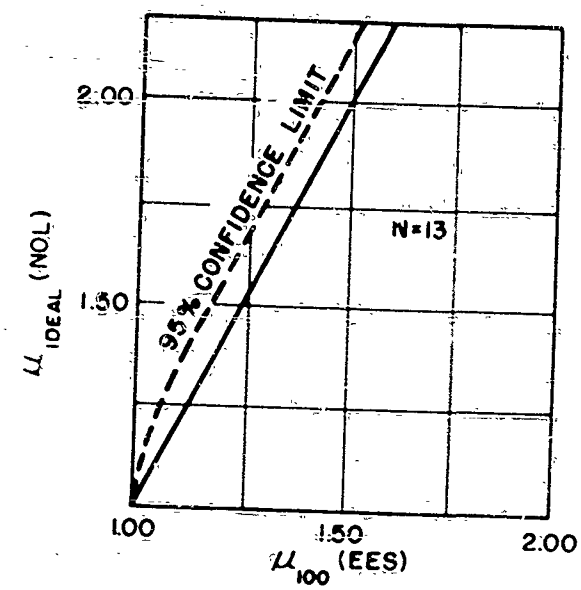


FIG. 2

FERROUS ALLOYS

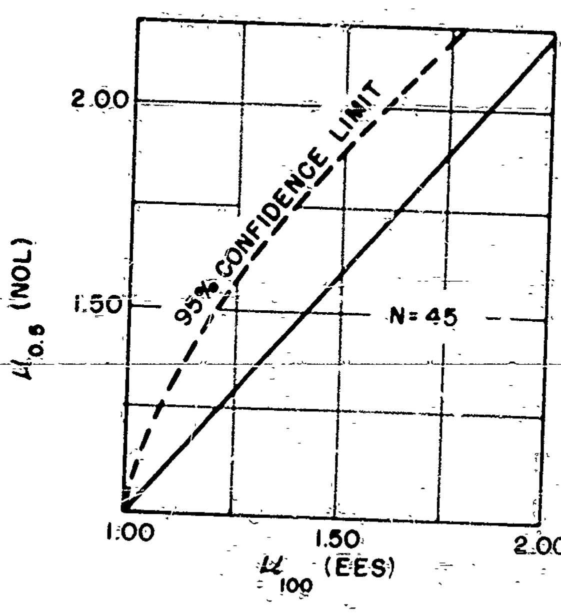


FIG. 3

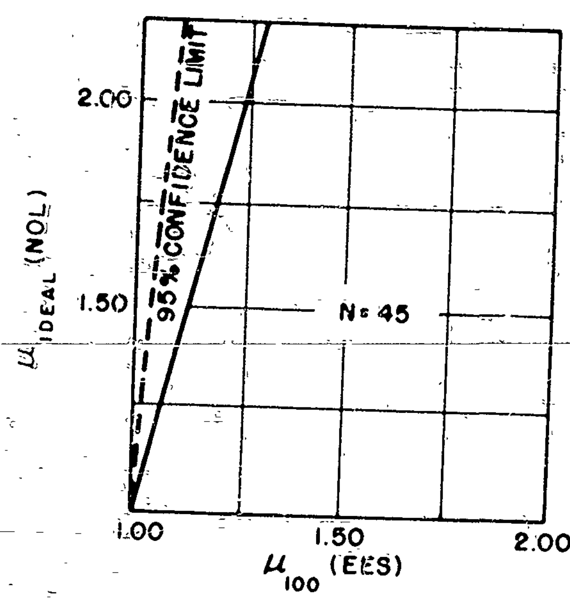
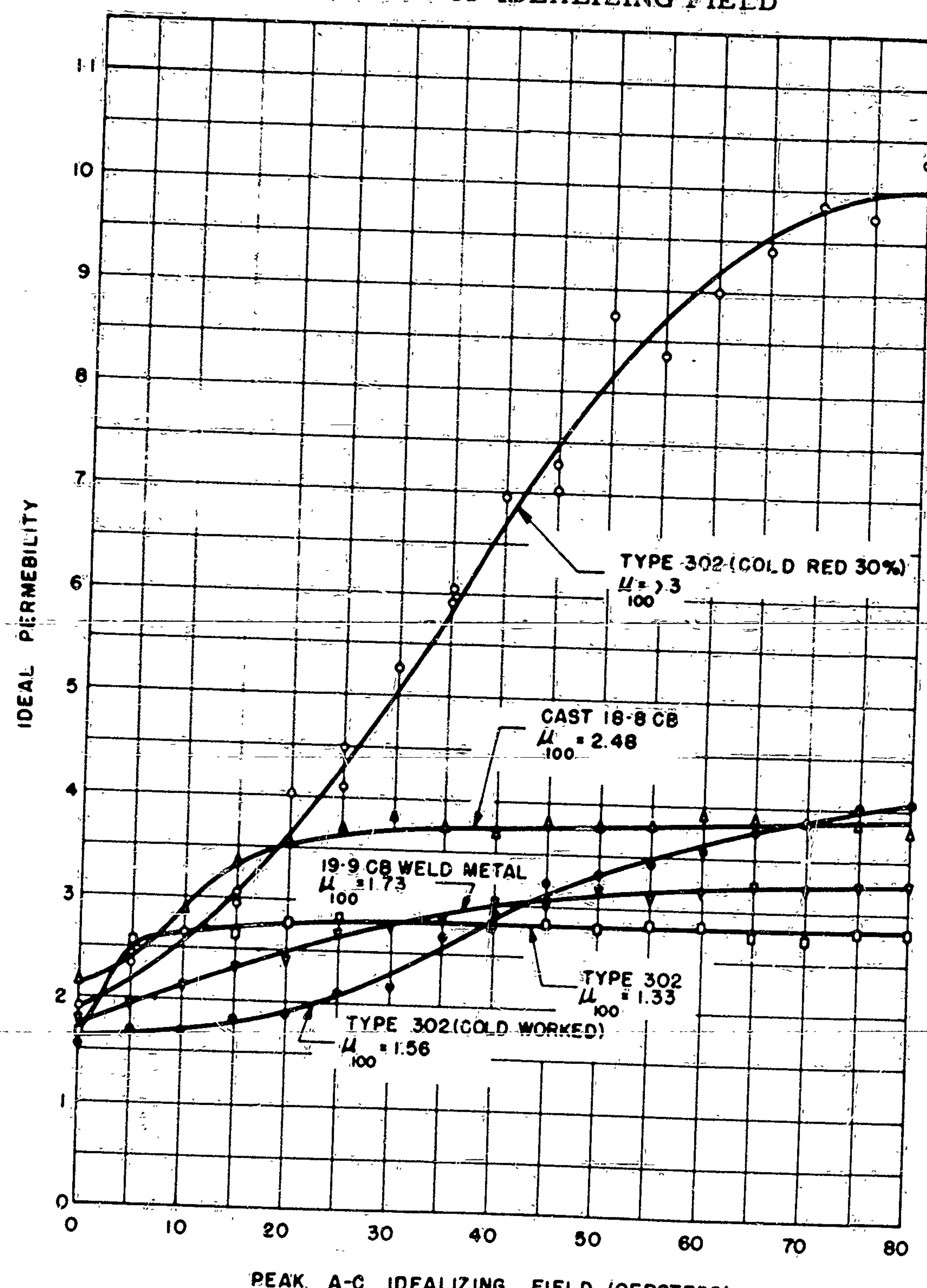


FIG. 4

PLATE 1

IDEAL PERMEABILITY AT H=0.5 OE. AS A FUNCTION OF AMPLITUDE OF IDEALIZING FIELD



PERMEABILITY INDICATOR

PLATE 3

PERMEABILITY INDICATOR

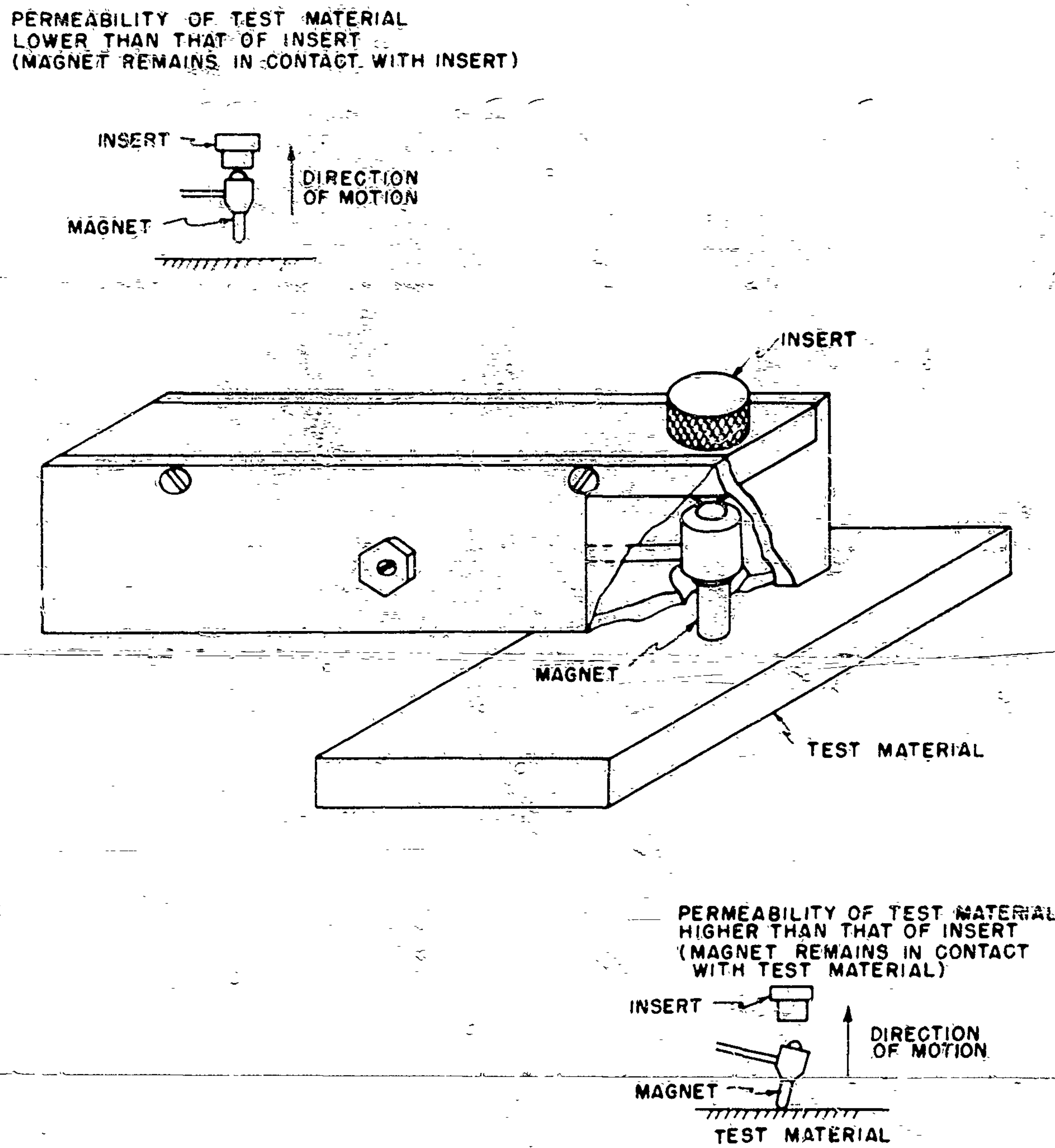


PLATE 4

III

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P11/6, S20/3 Metals

NEES

SUBJECT HEADINGS

Metals - Magnetic properties

DIV: Metallurgy (17)

SECT: Bronze, Brass, & Bearing Alloys (3)

Iron & Alloys (5)

Light Metals & Alloys (6)

Miscellaneous Non-Ferrous Metals & Alloys (7)

Magnetic Properties

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