A compilation of data on soft magnetic materials

Webb, E. L. R.

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RADIO AND ELECTRICAL ENGINEERING DIVISION

A COMPILATION OF DATA ON SOFT MAGNETIC MATERIALS

E. L. R. WEBB

OTTAWA

MARCH 1951

N.R.C. NO. 2360

NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

ERRATUM

Re: Report ERB-255 (NRC No. 2360), "A Compilation of Data on Soft Magnetic Materials," issued March, 1951.

FOR "43" appearing in column 7 of Table I as the Curie point of Mumetal (in degrees Centigrade)

READ "430"

Ottawa, Ont., Sept. 15/55.

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CONTENTS

INTRODUCTION

The information contained in the tables and graphs was obtained mainly from the sources listed in Table III, and represents an attempt to provide a wider coverage than has been attained in any one of the references. The tables are largely self-explanatory. Tables I and II list the better-known materials in groups characterized by some combination of properties from which the usefulness of the alloys of the group arises. Table IV gives typical uses for these groups.

In addition to indicating the manufacturer, the composition, and any special treatment, Tables I and II list values for the ferromagnetic Curie point, θ , the electrical conductivity, ρ , the initial and maximum permeabilities, μ_o and μ_m, the flux density at saturation, B_s, and the hysteresis loss, ω_h , corresponding to the flux density B_m at extremities of the loop. In Table I only, the coersive force, H_c, is listed for some alloys.

Table V is a more extensive alphabetical list of alloy trade names. It is intended to serve as an index for the benefit of the reader of technical literature, on the none too rare occasions when reference is made to an obscure (to the reader) alloy by name only.

To supplement the data in the tables, Figs. 1(a) and 1(b) give magnetization curves for a typical alloy in each group. Magnetization curves on log-log coordinates provide the best single feature for comparison over the wide range of permeability encountered. It will be noted that the H-scales for Figs. 1(a) and 1(b) have been shifted one decade, and that the dashed curve for silicon-iron appears on both curves for reference.

The hysteresis loss data given in Fig. 2 are useful in the design of equipment and may be readily converted into "equivalent watts per pound" by means of the formula given.

TABLE I

GROUP ① MODERATELY HIGH PERMEABILITY — HIGH RESISTANCE
GROUP ② 50-50-Ni-Fe HIGH PERMEABILITY — HIGH FIELD STRENGTH
GROUP ③ HIGH Ni-VERY HIGH PERMEABILITY — WEAK FIELD (REGION ZERO MAGNETOSTRICTION)
GROUP ④ RECTANGULAR HYSTERISIS LOOP (ORIENTED 50-50 ALLOYS-USUALLY VERY STRAIN SENSITIVE)

} SEE TABLE 4 FOR TYPICAL USES

MATERIAL	MFG.	Ni	Fe	OTHER	TREATMENT	θ	ρ	μ_0	μ_m	B_s	W_h 5000 GAUSS	H_c	COMMENTS	REFERENCES (SEE TABLE 3)
GROUP ①						°C	MICROHM-CM.			GAUSS	ERGS/CM³/CYCLE	OERSTEDS		
PERMALLOY D	W.E.	36	64	?			80	1,100	6,000	10,000	400		ALLOY PROPORTIONS NEAR ρ MAX.	4
RHOMETAL	T.C.&M.	40	52	Cr 5 Si 3	ANNEAL		95	1,500	8,000	11,000	450		EUROPE ONLY	2,4,5
TELCON 36													NORTH AMERICA	5a
GROUP ②														
45 PERMALLOY (B)	W.E.	45	55		ANNEAL 1050°C	440	50	2,500	25,000	16,000	200	·3		1,2,4
RADIOMETAL	T.C.&M.	47	49	Cu 3										1,2,4,5
ELECTRICMETAL-4750	A-L	48	52		H_2 ANNEAL 1,100°C		52	4,000	40,000	16,000	250	·07	SEE ALSO TABLE 4 FOR ADDITIONAL SIMILAR ALLOYS	3,7
49 ALLOY	CARPENTER													
MONIMAX	A-L	47	50	Mo 3	H_2 ANNEAL 1,100°C		80	3,000	38,000	15,000	150	·15	SINIMAX IS SIMILAR	3,7
HIPERNIK	WEST.	50	50		H_2 PURIFY 1,200°C	500	35	4,000	80,000	16,000		·05	MODERATELY RECT. HYST.	1,3,4
GROUP ③														
1040 ALLOY	SIEMANS HALSKE AG	72	11	Cu 14 Mo 3	H_2 PURIFY 1,100°C	290	56	40,000	100,000	6,000		·02	GERMAN	1,2,4
MUMETAL	A-L	77·2	16·8	Cu 4·5 Cr 1·5	H_2 PURIFY 1,100°C	430	60	20,000	100,000	7,200	45	·03		1,2,3,4,5,7
TELCON 79	T.C.&M.				N.B. — MUMETAL ORIGINALLY DEVELOPED BY T.C.&M. WHO SELL IT ONLY IN EUROPE									5a
78 PERMALLOY (A)	W.E.	78·5	21·5		ANNEAL 1050°C, BAKE 600°C	580	16	8,000	100,000	10,000	50	·05	THE ORIGINAL HI Ni ALLOY	1,2
4-79 PERMALLOY (C)	W.E.	78·5	17·7	Mo 3·8	ANNEAL 1,100°C	420	57	20,000	80,000	8,700	45	·05	+Cr 3·8 SIMILAR	1,2,3,4
HYMU "80"	CARPENTER													3a
SUPERMALLOY	W.E.	79	15	Mo 5 Mn ·5	H_2 PURIFY 1,300°C	400	60	100,000	10^6	8,000	6	·004		1,4
GROUP ④														
PERMENORM 5000 Z	HERAEUS VAC-SCHMELZE	48			C.R., H_2 PURIFY, MAG. ANNEAL					15,500		·07	GERMAN-FIRST OF TYPE	8
H.C.R. ALLOY	T.C.&M.	50	50		C.R., H_2 PURIFY, MAG. ANNEAL									5a
DELTAMAX	A-L	50	50		C.R., H_2 PURIFY, MAG. ANNEAL	500	40	500?	Hu 2×10^5	15,000		·06		7a
ORTHONAL	?	50	50		....."HIGHLY ORIENTED".....								U.S. NAVAL ORDNANCE LAB.	4a
HIPERNIK V, ORTHONIK	WEST	50	50		....."HIGHLY ORIENTED".....									9
PERMERON	?	50	50		V.C.R., HEAT TREAT, MAG. ANNEAL								SUPPLIED BY I.T.E. CIRCUIT BREAKER CO.	
65 PERMALLOY	W.E.	65			?	600		2,500	6×10^5	13,500	50	·012		4a

TABLE II

MISCELLANEOUS

MATERIAL	MFG.	Fe	OTHER	TREATMENT	ρ MICROHM-CM	μ_0	μ_m	B_s	W_h @ 5000 GAUSS ERGS/CM³/CYCLE	@ B_m	COMMENTS	REFERENCES (SEE TABLE 3)
IRON, CRYSTAL (PREFERRED-DIRECTION)		100	TRACE	H_2 PURIFY 28 HRS. @ 1500°C +24 HRS. @ 800°C			1.4×10^6	21,500			μ_m @ B=17,000	2
IRON "PURE"		99.9		ANNEAL 900°C	10	200	5,000	21,500	5,000	15,000	θ=770°C	1
4% Si-STEEL	MANY	96	Si 4	ANNEAL 800°C	59 55	400 450	7,000 8,000	19,000 19,500	400 4,000	5,000 15,000	TRANSFORMER-COMMERCIAL	1
C.R., Si-STEEL	MANY	96.7	Si 3.3	COLD ROLL, ANNEAL 800°C	50	600	10,000	20,000			θ=700°C	1
HIPERSIL SILECTRON	WEST. A-L.	96.7	Si 3.3	COLD ROLL, H_2 ANNEAL - 1,200°C	48	1,500	40,000	20,000	3,000	15,000?	GRAIN ORIENTED	1, 7, 9
GROUP ⑤												
PERMINVAR	W.E.	30	Ni 45 Co 25	ANNEAL 1,000°C, BAKE 400°C	19	365	1,800	15,500			SENSITIVE TO MAG. ANNEAL	1, 2, 4a, 8
CONPERNIK	WEST.		Ni 50	SPECIAL HEAT	45	1,500	4,500	16,000				4a
GROUP ⑥												
PERMENDUR	W.E.	50	Co 50 Mn .3	ANNEAL 800°C	7	800	5,000	24,500	12,000	B_s	BRITTLE θ=980°C	1, 10
V PERMENDUR	W.E.	49	Co 49 V2	ANNEAL 800°C	26	800	4,500	24,000	6,000	B_s	DUCTILE	1, 10
HYSTAT	T.C.&M.	SIMILAR IF NOT IDENTICAL TO V PERMENDUR			26						DUCTILE	5a
HIPERCO	WEST.	64	Co 35 Cr 1	ANNEAL 850°C	25	600	10,000	24,200	11,000	20,000	USEFUL FOR SMALL AIRCRAFT TRANFORMERS	3, 10
GROUP ⑦												
SENDUST	JAPANESE	85	Si 9 Al 5	CAST θ=500°C	80	30,000	120,000	10,000			ONE OF THE FEW CAST "SOFT" METALS	1
GROUP ⑧												
INVAR		64	Ni 36	ALLOY WITH ZERO THERMAL EXPANSION								4
GROUP ⑨												
		70	Ni 30	NON-MAGNETIC ALLOY, (PROPORTIONS VERY SENSITIVE TO SMALL C CONTENT – e.g. C .3 → Fe 75 Ni 25)								4
NOMAG		82	Ni 11 Mn 7	COMMERCIAL NON-MAGNETIC ALLOY								4
		18	Ni 82	ALLOY WITH ZERO MAGNETOSTRICTION (PROPERTIES SENSITIVE TO IMPURITIES)								
R2799	T.C.&M.	71	Ni 29	ALLOY WITH CURIE POINT (θ) NEAR ROOM TEMP. – USEFUL FOR TEMPERATURE COMPENSATION								5a
OTHER												
HEUSLER ALLOYS		$(Cu_2, Ag_5)\cdot Mn\cdot (Al, Sn, As, Sb, Bi, B)$									NO FERROMAGNETIC COMPONENTS	1, 2
MAGNETIC FERRITES	G.C.&S. AND OTHERS	$MO\cdot Fe_2O_3$, WHERE M IS A BIVALENT METAL – e.g. Fe (MAGNETITE Fe_3O_4) OTHERS Ni, Zn, Mg, Mn										11, ALSO ROGERS MAJESTIC
		PROPERTIES OF TYPICAL FERRITE $\rho=10^{10}$ μ_0=800 μ_m=4,000 B_s=3,400									USEFUL AT RADIO FREQUENCIES	

TABLE III

References

1. Bozorth R.M. Rev. Mod. Phys., Vol. 19, 1947.

2. Brailsford F. Magnetic Materials (book) Methuen.

3. Fed. Tel. and Radio Corp. Handbook, 3rd Ed., p. 193.

4. Magnetic Properties of Ni-Fe Alloys - Mond Nickel Co., Ltd.

4a. Fe-Ni Alloys for Magnetic Purposes - Inter. Nickel Co., Inc.

5. Telcon Metals - Booklet) Telegraph Construction and

5a. Data sheets) Maintenance Co. Ltd.

6. Pulse Generators - M.I.T. Rad. Lab. Series, Vol. 5.

7. Data sheets - Allegheny Ludlum Steel Corp.

7a. Technical Information - Arnold Engineering Co.

8. Standard Handbook for Elec. Eng., 6th Ed.

9. "Technical data" - Westinghouse Elec. Corp.

10. Rev. of Mag. Mat'ls - Bell Monograph B1605 (R.A. Chegwidden).

11. Magnetic Ferrites - Elec. Manufacturing Dec. 1949. E. Albers - Schoenberg et al.

Most of the above have their own list containing many references.

TABLE IV

Group	Typical Use
1.	Pulse transformer cores - (high permeability - high resistance) High frequency alternators Deflection yokes for C.R.T.
2.	Outer magnetic screening - (high permeability in strong fields) Wide dynamic range audio transformers Rapid relay armatures
3.	Inner magnetic screening - (very high permeability in weak fields) Continuous loading of telephone cables High fidelity audio transformers, (low level, wide range) Instrument transformers Moving iron instruments Sensitive relay armatures Magnetic recording and pick-up
4.	Magnetic amplifiers) Peaking transformers) (Rectangular hysteresis loop) Mechanical rectifiers)
5.	Constant permeability (at moderate fields)
6.	Extreme flux densities, e.g., small aircraft transformers
7.	One of few soft magnetic materials used in castings
8.	Zero coefficient of thermal expansion
9.	Non-magnetic components in machinery
10.	Magnetostriction oscillators Ultrasonic transducers

TABLE V

Alphabetical List of Soft Magnetic Alloy Trade Names

Alloy	Group	Manufacturer	Reference
"A" Nickel	10	- - -	4a
Anhyster	1, 2	Acierie d'Imphy	4
Audio Alloy	2	Crucible Steel	4
Armco 48	2	Armco	4a
Carpenter 49	2	Carpenter Steel	4a
Conpernik	5	Westinghouse	4a
Deltamax	4	Allegheny Ludlum	7
Electric Metal (4750)	2	Allegheny Ludlum	7a
Gamma	1	Acierie d'Imphy	4
H. C. R.	4	T. C. & M. (Telcon)	5a
Hiperco	6	Westinghouse	3, 10
Hymu 80	3	Carpenter Steel	3
Hyperm	2	Krupp	4
Hypernik (V)	2 (4)	Westinghouse	1, 2, 3, 9
Hysat	6	T. C. & M.	5a
Invar	8	- - -	4
Isoperm	5	A. E. G. (German)	2
Laminac	2	Mag. & Elect. Alloys	4
Megaperm	1, 2	German	4
Monimax	2	Allegheny Ludlum	3, 7
Mumetal	3	T. C. & M. and A-L	1, 2, 3, 4, 5, 7
Nicaloi	2	General Electric	4
Nomag	9	- - -	4
Orthonal	4	(U. S. Naval Ordnance Lab.)	4a
Orthonik	4	Westinghouse	9
Permafy	3	Acierie d'Imphy	4
Permalloy, various see Table I		Bell Labs - Western Elec.	1, 2, 3, 4
Permax	3	Commentry Fourchambault	4
Permenorm	4	Heraeus Vac-Schmelze	8
Permendur	6	Bell Labs - Western Elec.	1, 10
Permeron	4	I. T. E. Circuit Breaker	-
Perminvar	5	Bell Labs - Western Elec.	4a
Radiometal	2	T. C. & M.	1, 2, 4, 5
Rhometal	1	T. C. & M.	2, 4, 5
Sendust	7	Japanese	1
Sinimax	2	Allegheny Ludlum	3, 7
Supermalloy	3	Bell Labs - Western Elec.	1, 4a
Telcon 36	1	T. C. & M.	5a
Telcon 79	3	T. C. & M.	5a
1040	3	Siemans Halske	1, 2, 4
Corosil)	are silicon iron alloys given special properties by special		
Hipersil)	treatment.		
Silectron)			

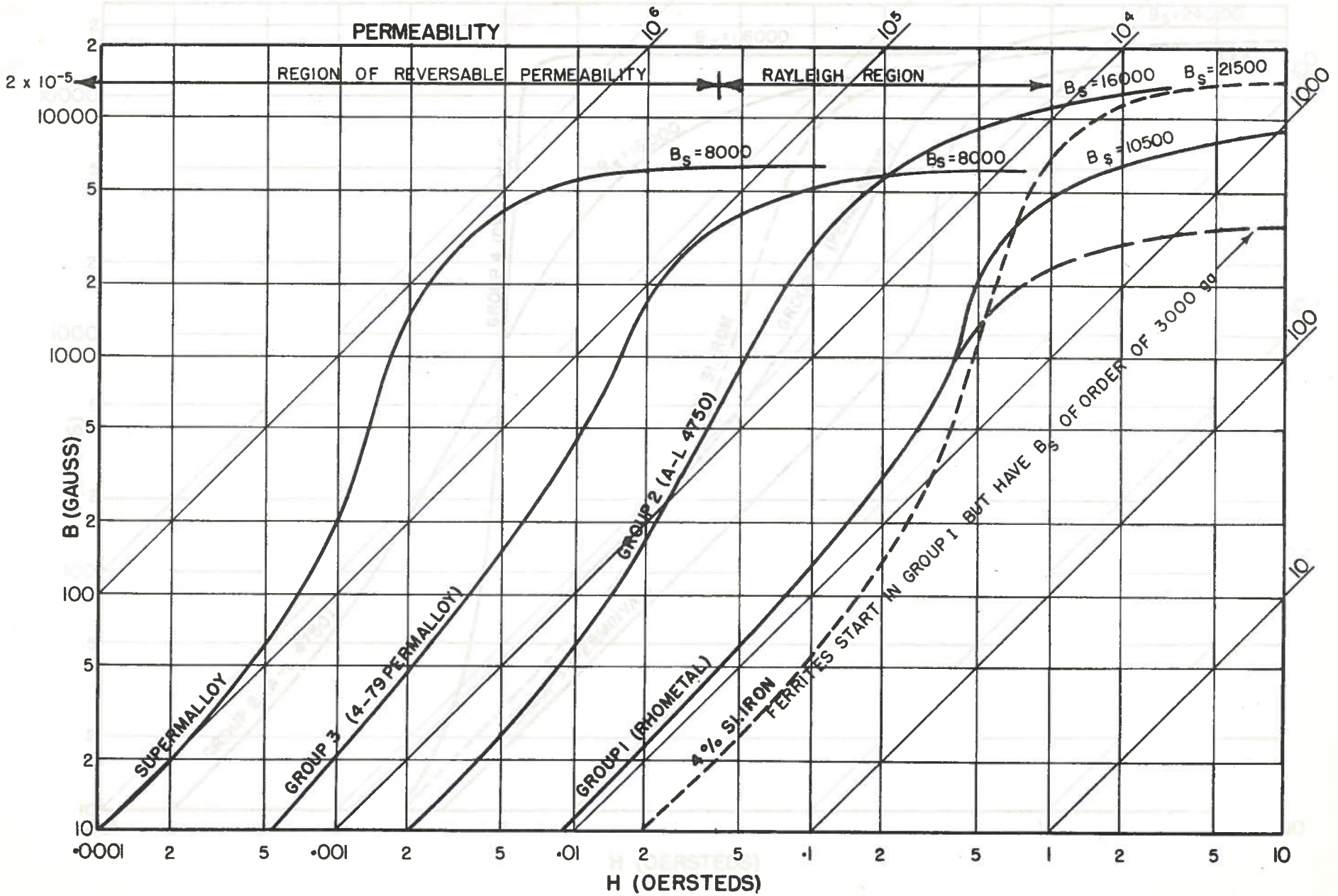
PERMEABILITY
REGION OF REVERSABLE PERMEABILITY
RAYLEIGH REGION
2 x 10⁻⁵
10⁶
10⁵
10⁴
1000
100
10
B (GAUSS)
H (OERSTEDS)
•0001
•001
•01
•1
1
10
Bs = 8000
Bs = 8000
Bs = 16000
Bs = 21500
Bs = 10500
SUPERMALLOY
GROUP 3 (4-79 PERMALLOY)
GROUP 2 (A-L 4750)
GROUP 1 (RHOMETAL)
4% Si IRON
FERRITES START IN GROUP 1 BUT HAVE Bs OF ORDER OF 3000 ga

Fig. 1(a)

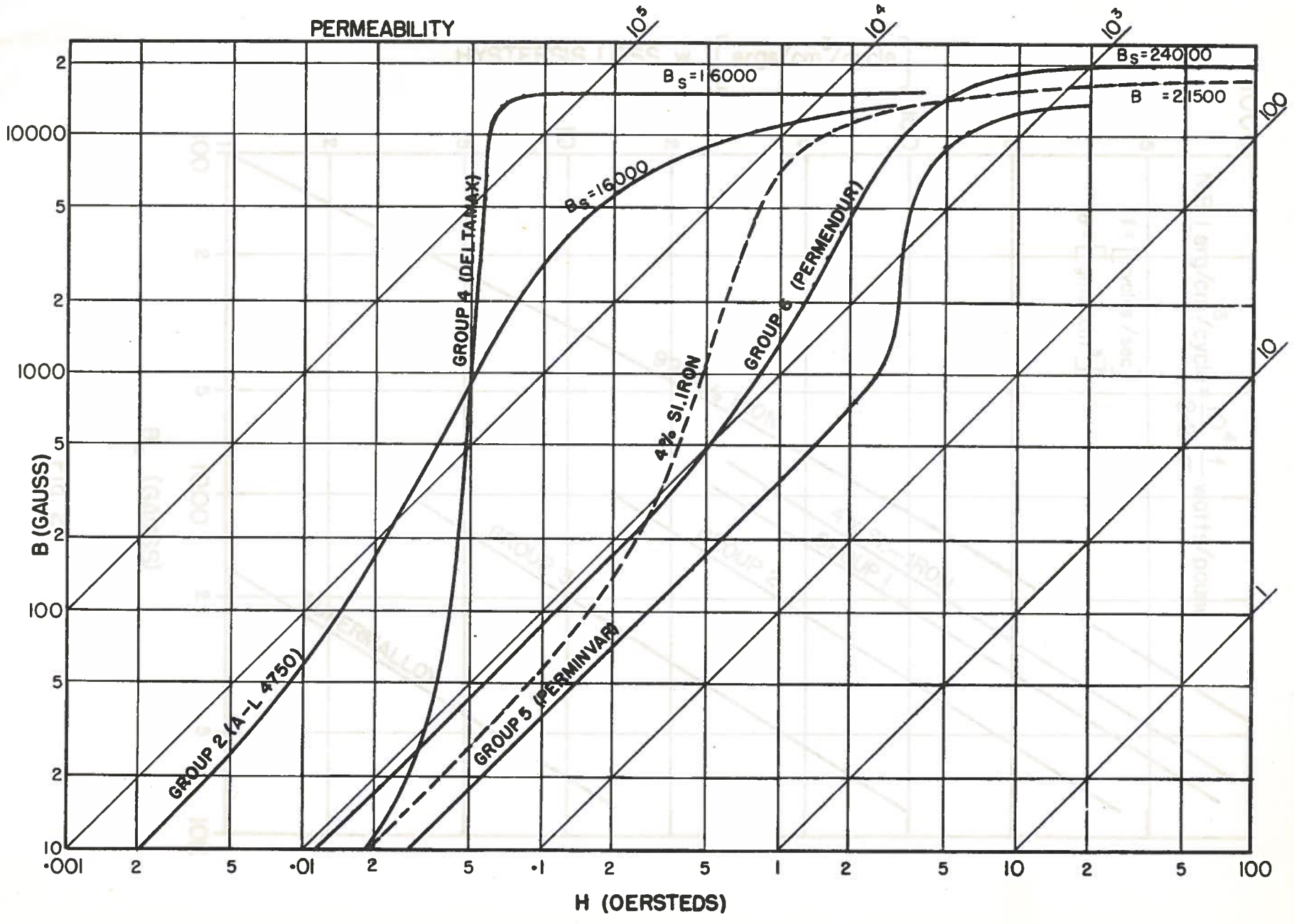
PERMEABILITY
10⁵
10⁴
10³
100
10
1
Bs=24000
Bs=16000
B =21500
Bs=16000
GROUP 4 (DELTAMAX)
GROUP 6 (PERMENDUR)
4% SI.IRON
GROUP 2 (A-L 4750)
GROUP 5 (PERMINVAR)
B (GAUSS)
10000
5
2
1000
100
10
·001
·01
·1
1
10
100
H (OERSTEDS)

Fig.1(b)

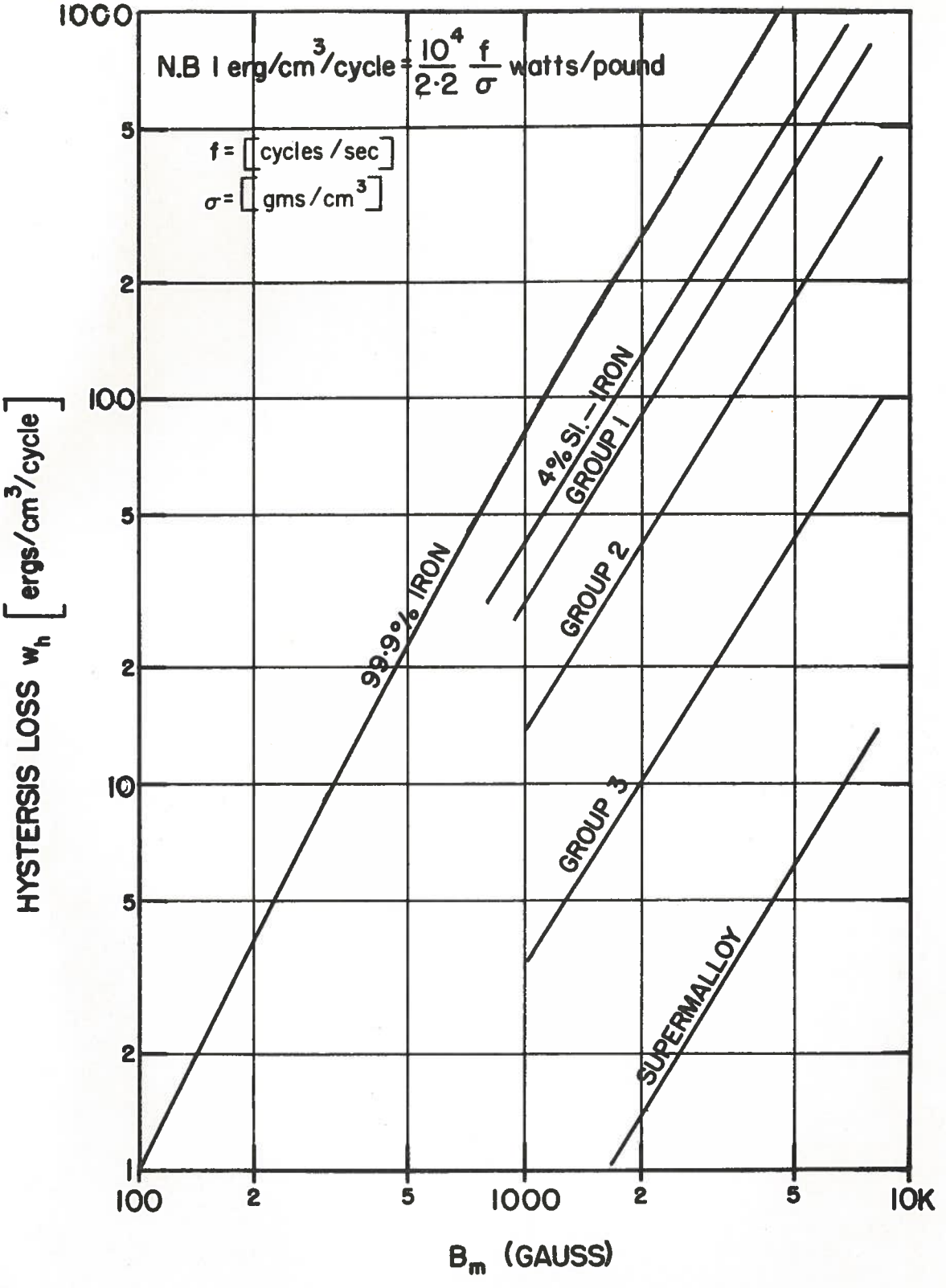
N.B 1 erg/cm³/cycle = 10⁴/2·2 f/σ watts/pound
f = [cycles/sec]
σ = [gms/cm³]
HYSTERSIS LOSS w_h [ergs/cm³/cycle]
1000
5
2
100
5
2
10
5
2
1
99.9% IRON
4% SI. — IRON
GROUP 1
GROUP 2
GROUP 3
SUPERMALLOY
100
2
5
1000
2
5
10K
B_m (GAUSS)

Fig. 2