CARPENTER ELECTRIFICATION®

DATASHEET

HIGH PERMEABILITY 49®

UNS Number:
K94840

Type analysis

Single figures are nominal except where noted.

Iron	Balance	**Nickel**	48.00 %	**Manganese**	0.50 %
Silicon	0.35 %	**Carbon**	0.02 %		

Forms manufactured

Bar-Rounds	**Billet**	**Sheet**	**Strip**	**Wire**	**Wire-Shapes**

Description

High Permeability 49 is a 48% nickel-iron alloy that possesses the highest saturation flux density of any nickel-iron alloy. The saturation flux density of about 16000 gauss (1.6 Tesla) combined with high magnetic permeability and low core loss makes this a versatile alloy with many potential applications.

High Permeability 49 has been used in laminated cores for instrument transformers, magnetic shields and cores for certain electronic and communications devices in which extremely high permeability at low magnetizing forces greatly increases the efficiency and effectiveness of the equipment.

Because of its high permeability, it has also been used in solenoid cores and sensitive relays that must respond to low magnetizing forces.

Key Properties:

- High saturation flux density
- High magnetic permeability
- Low core loss

Markets:

- Aerospace
- Automotive
- Consumer
- Industrial

Applications:

- Instrument transformers
- Magnetic shields and cores
- Sensitive relay and solenoid components

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Available grades

High Permeability 49	Available in bar, wire, rod, and strip form in thicknesses of 0.020 in. (0.51 mm) and over by various widths, this grade has been used for magnetic shielding and sensitive relay and solenoid components.
High Permeability 49, rotor grade	This grade is specially processed to yield uniform, isotropic properties and is supplied as cold rolled strip in thicknesses from 0.004 to 0.020 in. (0.1 to 0.51 mm). It has been used for laminations for rotating components such as resolvers and servo-synchros where the magnetic properties must be highly isotropic (i.e., not directionally dependent).
High Permeability 49, transformer grade	This semi-isotropic grade is specially processed to produce higher magnetic permeabilities parallel to the rolling direction of the strip and is suitable for use in transformer laminations and tape wound cores where the directionality of magnetic properties can be an advantage. It is available as cold rolled strip in thicknesses ranging from 0.001 to 0.020 in. (0.03 to 0.51 mm).

Corrosion resistance

High Permeability 49 resists weather and moisture corrosion to a moderate extent.

IMPORTANT NOTE:
The following 4-level rating scale is intended for comparative purposes only. Corrosion testing is recommended; factors that affect corrosion resistance include temperature, concentration, pH, impurities, aeration, velocity, crevices, deposits, metallurgical condition, stress, surface finish, and dissimilar metal contact.

Humidity	Good

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Physical properties

PROPERTY	At or From	English Units	Metric Units
SPECIFIC GRAVITY	—	8.18	8.18
DENSITY	—	0.2950 lb/in^3	8165.57 kg/m^3
MEAN SPECIFIC HEAT	—	0.1200 Btu/lb/°F	502.41J/kg·K
MEAN COEFFICIENT OF THERMAL EXPANSION	77 to 399°F	4.61 x 10^{-6} length/length/°F	8.3 length/length/°C
THERMAL CONDUCTIVITY	—	90.20 Btu-in/hr/ft^2/°F	13 W/m·K
ELASTIC MODULUS			
AFTER PROCESS ANNEAL, IN TENSION, BAR	871°C	22.0 x 10^3 ksi	—
AFTER PROCESS ANNEAL, IN TORSION, BAR	871°C	7.60 x 10^3 ksi	—
COLD DRAWN, IN TORSION, BAR	—	7.80 x 10^3 ksi	—
COLD DRAWN, IN TENSION, BAR	—	24.0 x 10^3 ksi	—
COLD DRAWN, IN TENSION, STRIP	—	24.0 x 10^3 ksi	—
FORMING AND DEEP DRAW QUALITY, IN TENSION, STRIP	—	24.0 x 10^3 ksi	—
HYDROGEN ANNEALED, IN TENSION, BAR	1177°C	22.5 x 10^3 ksi	—
HYDROGEN ANNEALED, IN TORSION, BAR	1177°C	7.50 x 10^3 ksi	—
ELECTRICAL RESISTIVITY	70°F (21°C)	290.0 ohm-cir-mil/ft	48 microohm·cm
TEMPERATURE COEFF. OF ELECTRICAL RESIST.	0 to 930°F	20.0 x 10^{-4} ohm/ohm/°F	—
CURIE TEMPERATURE	—	860 to 930°F	460 to 499°C
MELTING RANGE	—	2600°F	1427°C

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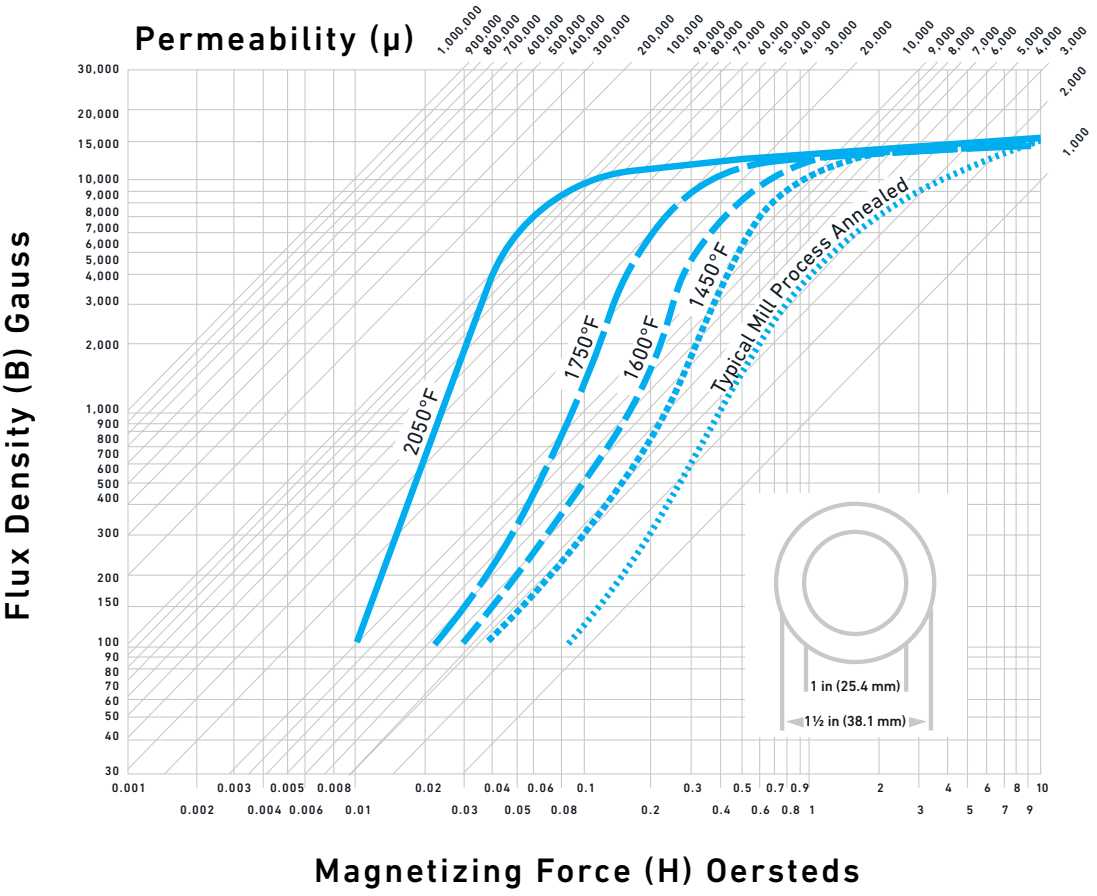
Magnetic properties

DC NORMAL INDUCTION FROM RING SPECIMEN

0.060 in (1.52 mm) thick in the typical mill process annealed condition and dry hydrogen annealed at 1450°F (788°C), 1600°F (871°C), and 1750°F (954°C) for 2 hours and at 2050°F (1121°C) for 4 hours.



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DIRECT CURRENT (DC) MAGNETIC PROPERTIES

ASTM A-596			
PROPERTIES	**BAR**	**STRIP**	
		0.014 IN (.036 MM)	**0.025 - 0.125 IN (0.64 - 3.18 MM)**
Initial permeability B_{100}	6,500	12,000	8,000
Maximum permeability	75,000	150,000	90,000
Remanent flux (Br), Gauss	9,000	9,000	9,000
Coercive force (Hc)[1], Oersted	0.04/0.07	0.05/0.06	0.04/0.07
Saturation inductance (G)[2]	15,000	15,000	15,000

[1] From 10,000 gausses
[2] From H-100 oersteds

MINIMUM ALTERNATING CURRENT (AC) PERMEABILITY REQUIREMENTS, ROTOR AND TRANSFORMER GRADE

These minimum permeability requirements are based on evaluating the properties via a ring specimen 1.5 in (38.1 mm) OD x 1 in (25.4 mm) ID hydrogen annealed at 2150°F (1177°C) 4 hours, furnace cooled at a rate of 150/220°F (83/122°C) per hour through the Curie point.

0.014 IN (0.36 MM) AND 0.006 IN (0.15 MM)								
GRADE	**THICKNESS**		**MINIMUM 60 Hz AC PERMEABILITY**					
	IN	**MM**	**B40**	**B200**	**B2000**	**B4000**	**B8000**
Rotor	0.014	0.36	8,000	14,000	30,000	43,000	46,000
Transformer	0.014	0.36	12,000	19,000	36,000	45,000	50,000
Rotor	0.006	0.15	10,000	17,000	40,000	55,000	70,000
Transformer	0.006	0.15	13,000	24,000	50,000	60,000	65,000

REMANENT FLUX AND COERCIVE FORCE

0.060 IN (1.52 MM) THICK RINGS FROM A FLUX DENSITY OF 13,000 GAUSSES		
TREATMENT	**REMANENT FLUX (Br), GAUSS**	**COERCIVE FORCE (Hc), OERSTED**
Typical mill process annealed	6300	0.85
1450°F (788°C), 2 hr, dry H_2	9900	0.48
1600°F (871°C), 2 hr, dry H_2	10200	0.32
1750°F (954°C), 2 hr, dry H_2	10300	0.18
2050°F (1121°C), 2 hr, dry H_2	10900	0.05

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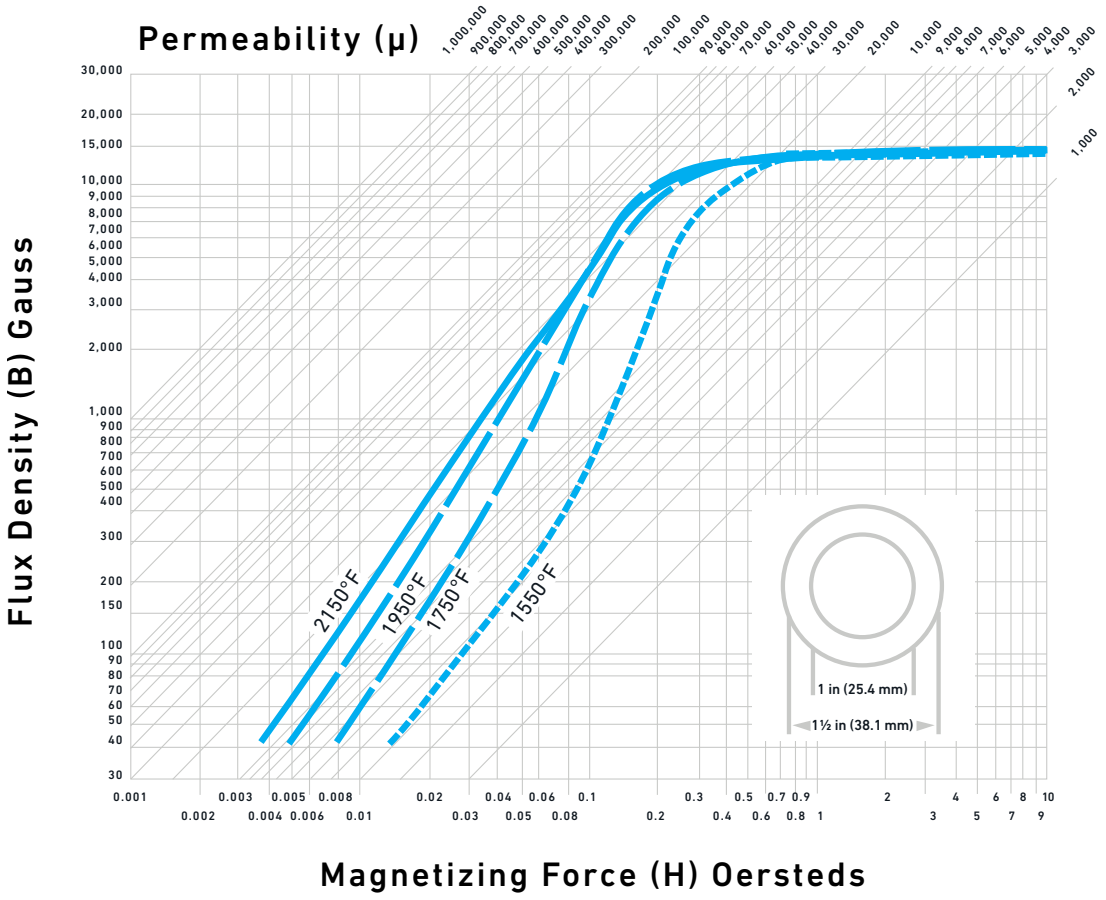
ROTOR GRADE AT 60 Hz

From stamped ring specimen 0.014 in (0.36 mm) thick, dry hydrogen annealed at 1550°F (843°C), 1750°F (954°C), 1950°F (1066°C), and 2150°F (1177°C), 4 hours.



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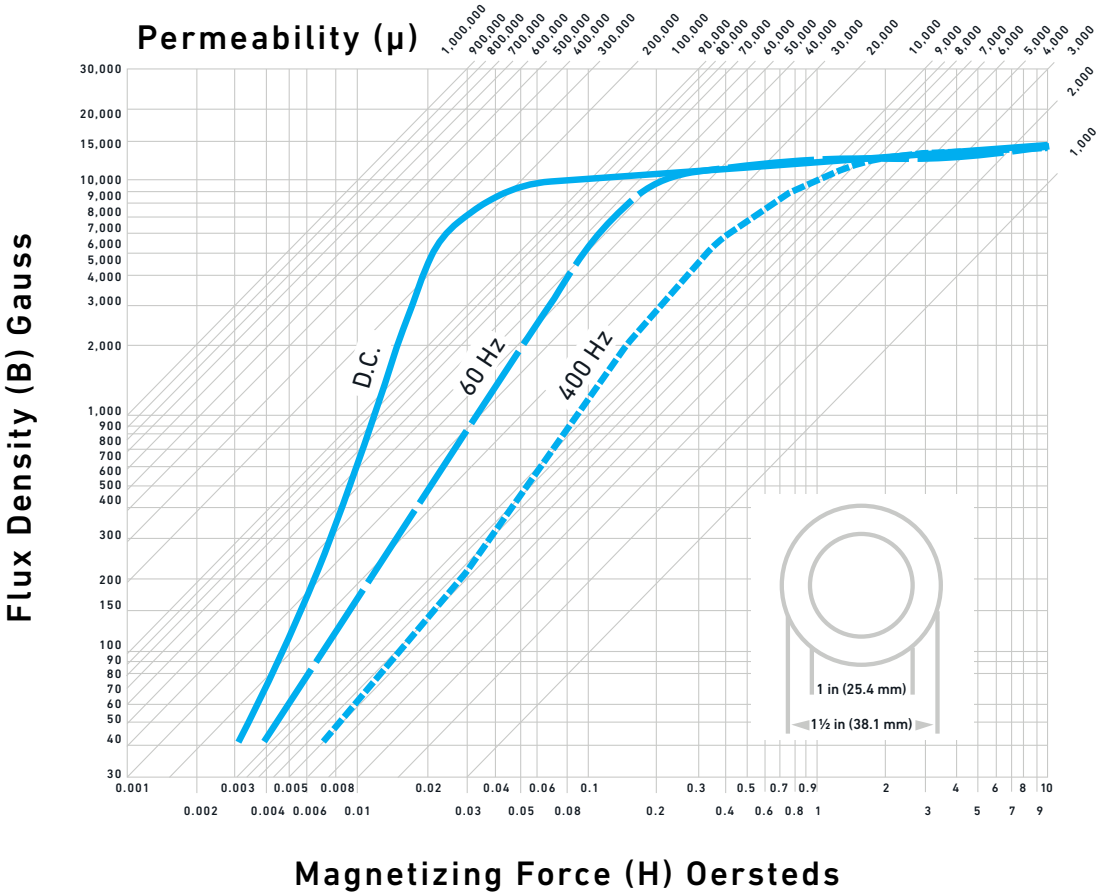
ROTOR GRADE AT 0.014 IN (0.36 MM) THICK



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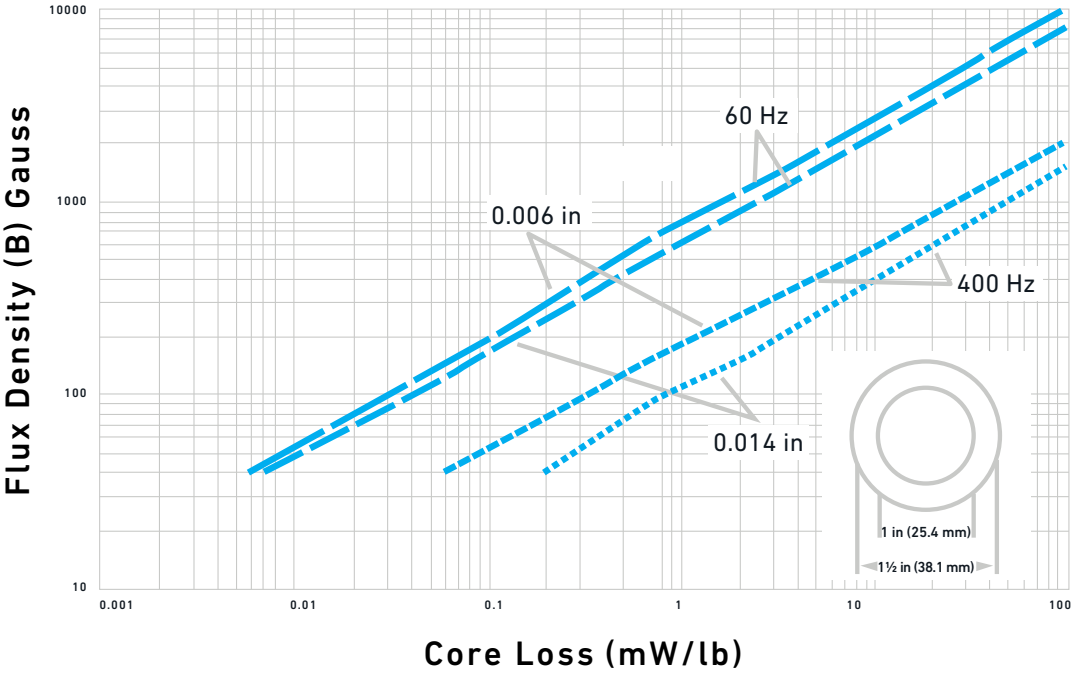
ROTOR GRADE



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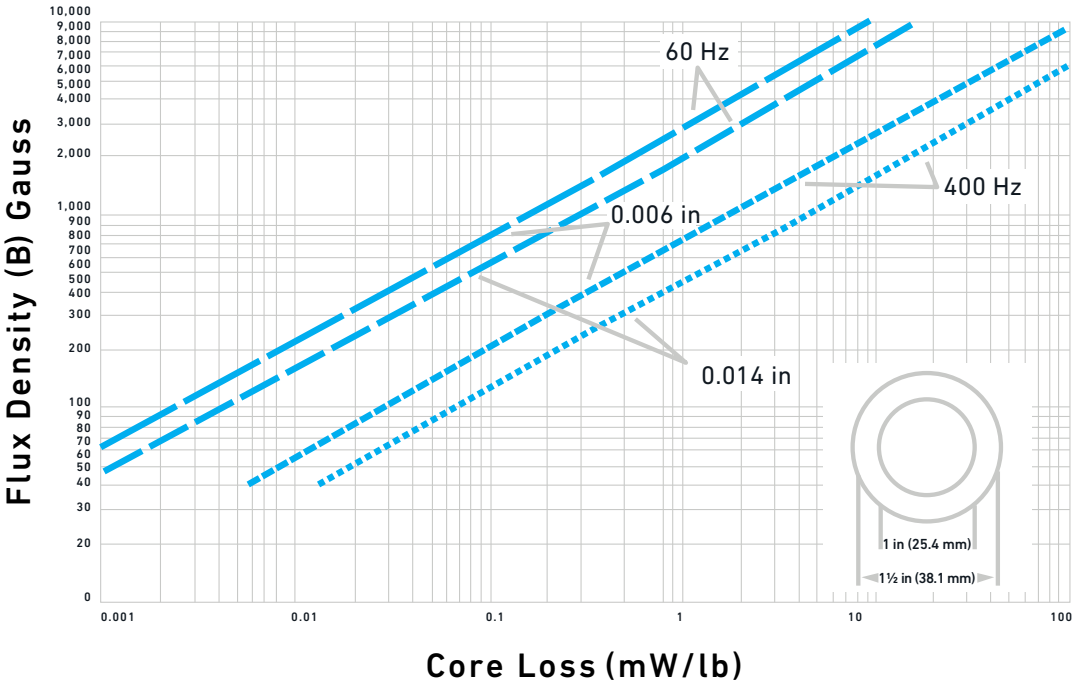
SPECIFIC CORE LOSS CURVES

At 60 Hz and 400 Hz from stamped ring specimen 1 in (25.4 mm) ID x 1.5 in (38.1 mm) OD, dry hydrogen annealed at 2150°F (1177°C), 4 hours.

TRANSFORMER GRADE



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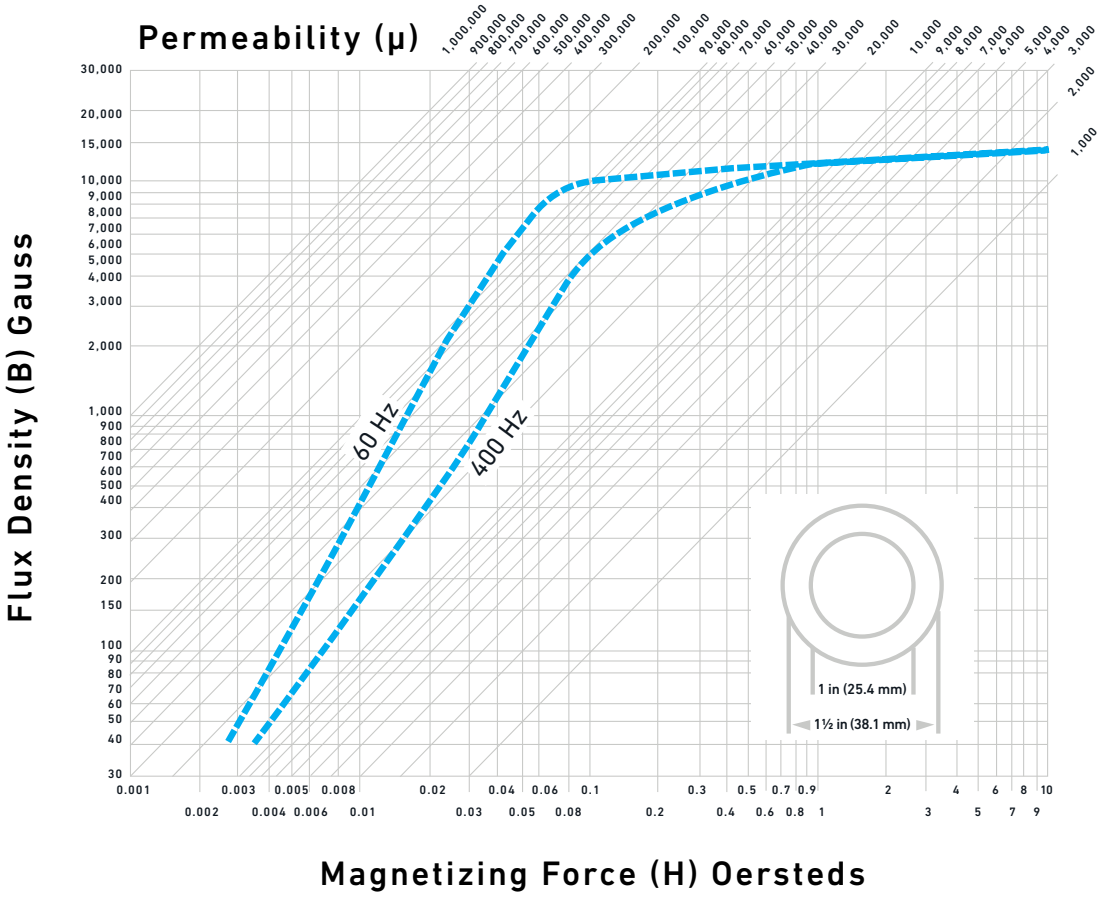
TRANSFORMER GRADE AT 0.014 IN (0.36 MM) THICK



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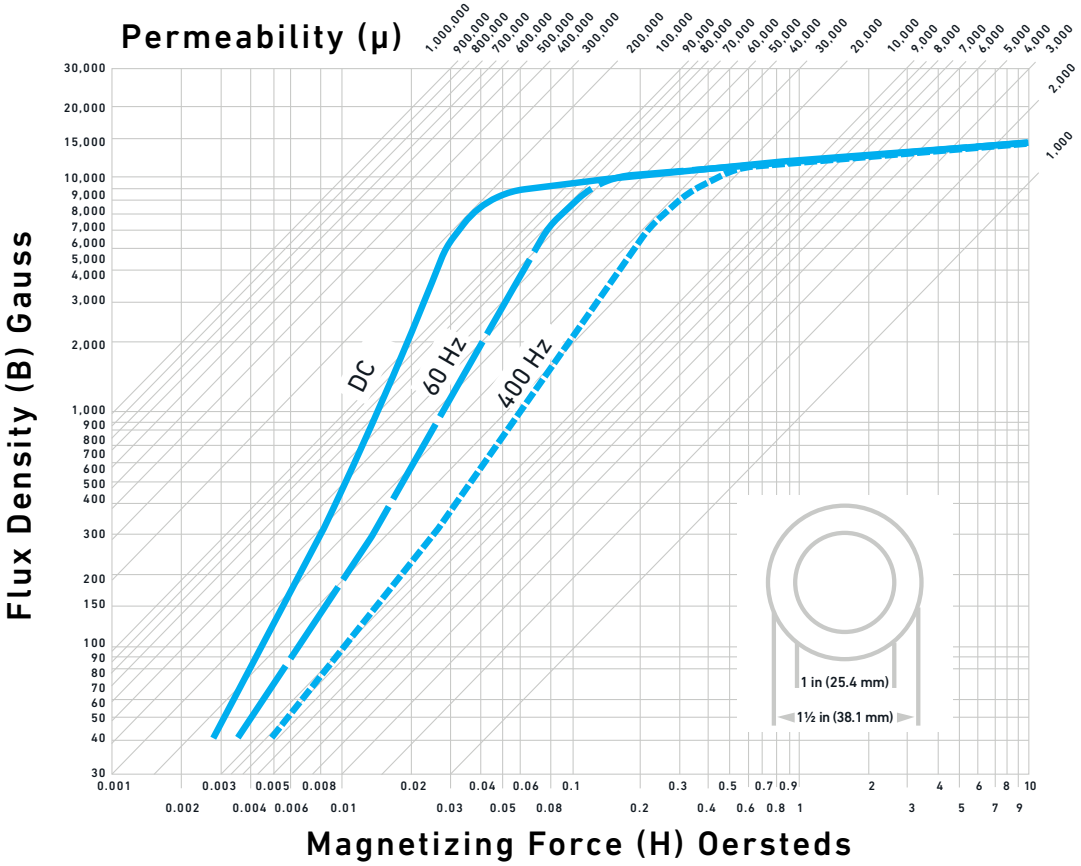
TYPICAL MAGNETIZATION CURVES
ROTOR GRADE AT 0.007 IN (0.18 MM) THICK

DC, 60 Hz and 400 Hz from stamped ring specimen at indicated thickness, dry hydrogen annealed at 2150°F (1177°C), 4 hours.



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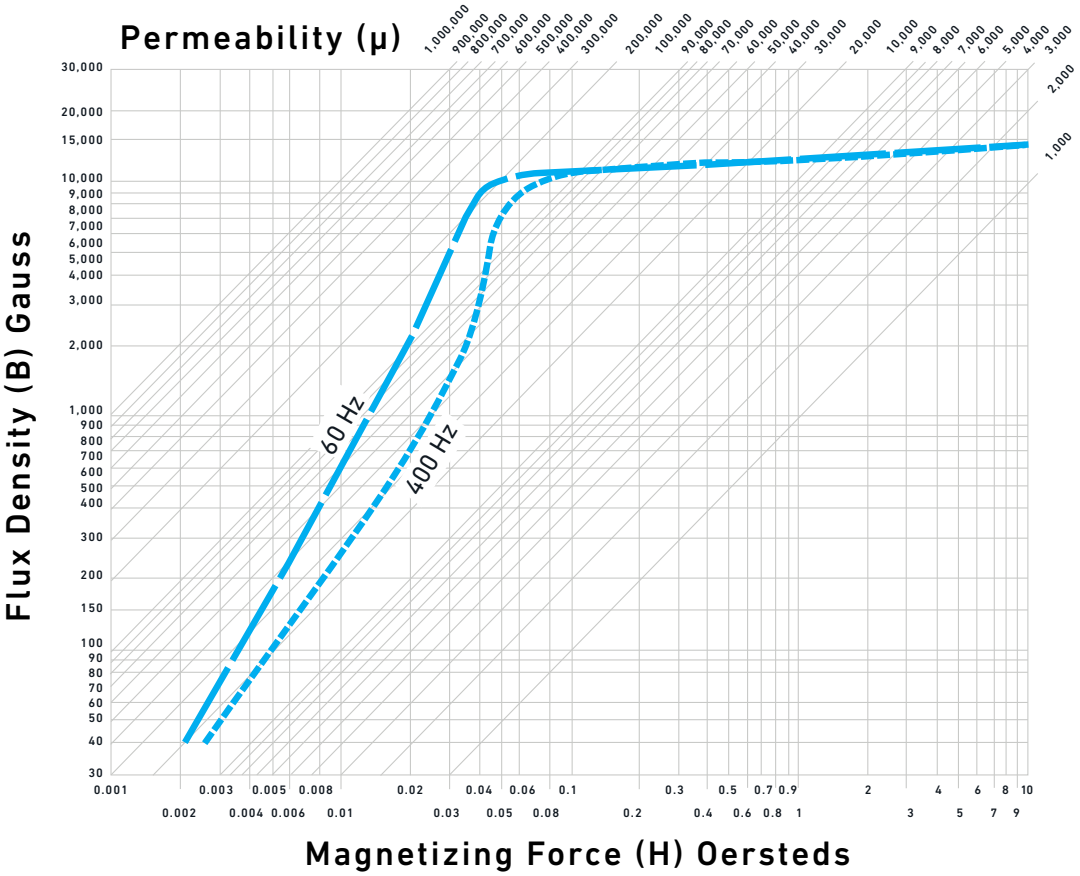
TYPICAL MAGNETIZATION CURVES
TRANSFORMER GRADE AT 0.006 IN (0.15 MM) THICK

60 Hz and 400 Hz sine flux excitation 1-DU laminations at indicated thickness, dry hydrogen annealed at 2150°F (1177°C), 4 hours.



SATURATION FLUX DENSITY (Bs)	15000 G
COERCIVITY (Hc)	0.0400 Oe
MAXIMUM PERMEABILITY	75000

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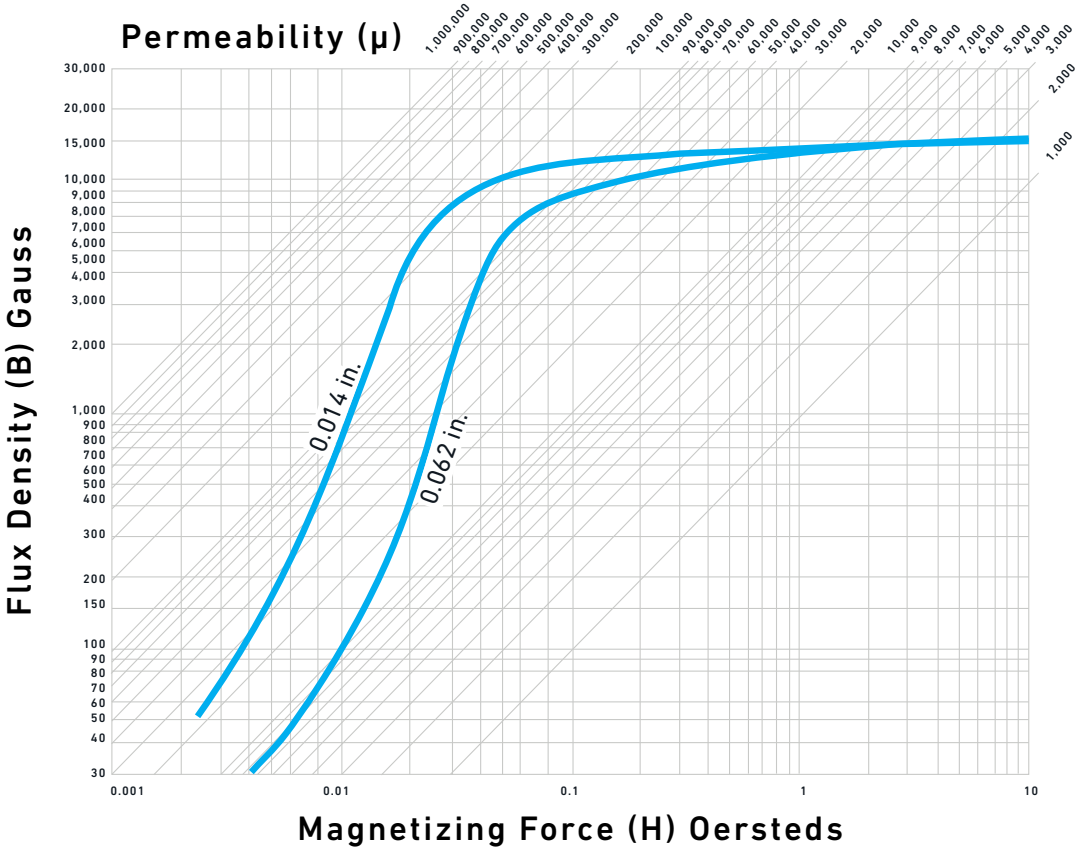
TEMPERATURE VARIATION OF PERMEABILITY

Expressed in % of value of 77°F (25°C).

AC AND DC MAGNETIC PROPERTIES OF LAMINATION STRIP 0.006 IN (0.15 MM) AND 0.014 IN (0.36 MM) THICK		
TEMPERATURE	**PERMEABILITY AT 1000 GAUSSES**	**MAXIMUM PERMEABILITY**
-94°F (-70°C)	75/90	90/95
212°F (100°C)	120/130	100/105

TYPICAL DC PERMEABILITY RANGE

0.014 in (0.36 mm) to 0.062 in (1.57 mm) thick, hydrogen annealed at 2150°F (1177°C).



RESIDUAL INDUCTION	9000 G

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Typical mechanical properties

BAR

HEAT TREATMENT	YIELD STRENGTH		ULTIMATE TENSILE STRENGTH		PROPORTIONAL LIMIT		ELONGATION	REDUCTION OF AREA
	ksi	MPa	ksi	MPa	ksi	MPa	%	%
Cold drawn	80	552	95	655	35	241	25	62
Hydrogen annealed 2150°F (1177°C)	22	152	70	483	12	83	45	68
After process anneal 1600°F (871°C)	23	154	75	517	13	90	43	65

BAR ELASTICITY AND IMPACT

HEAT TREATMENT	ELASTIC MODULUS				IZOD IMPACT		HARDNESS
	IN TENSION		IN TORSION				
	psi x 10^4	MPa x 10^3	psi x 10^4	MPa x 10^3	FT-LBS	J	HRB
Cold drawn	24.0	166	7.8	54	93/99	126/134	98
Hydrogen annealed 2150°F (1177°C)	22.5	155	7.5	52	93/98	126/133	62
After process annealed 1600°F (871°C)	22.0	152	7.6	52	95	129	75

EFFECT OF HEAT TREATING TEMPERATURE ON TYPICAL MECHANICAL PROPERTIES[1]

TEMPERATURE	YIELD STRENGTH 2% OFFSET		TENSILE STRENGTH		ELONGATION IN 2 IN (50.8 MM)
	ksi	MPa	ksi	MPa	%
1450°F (788°C)	37	255	79	545	30
1600°F (871°C)	34	234	75	517	31
750°F (954°C)	27	186	71	490	32

[3] Strip 0.060 in (1.52 mm) thick heat treated for 2 hours at indicated temperature.

STRIP

HEAT TREATMENT	TENSILE STRENGTH		ELASTIC MODULUS (IN TENSION)		ELONGATION	HARDNESS
	ksi	MPa	psi x 10^4	MPa x 10^3	%	ROCKWELL HRB
Cold rolled	130	896	24.0	166	5	100
Forming and deep draw quality	80	552	24.0	166	32	68

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Heat treatment

Annealing	**Standard hydrogen anneal** For maximum softness and optimum magnetic and electrical properties, High Permeability 49 should be annealed in an oxygen-free, dry hydrogen atmosphere with a dew point below -40°F (-40°C) for 2 to 4 hours at 2150°F (1177°C), followed by a furnace cool at a rate of 100/200°F (55/110°C) per hour down to 800°F (427°C) and at any rate thereafter. Oil, grease, lacquer, and any other contaminants must be removed before annealing. During hydrogen annealing, the individual parts should be separated by a surface insulation media or an inert insulating powder, such as magnesium or aluminum oxide.
Stress relieving	To relieve all strains and restore the alloy to a soft condition suitable for drawing, spinning, forming, bending, and similar operations, anneal for not more than 1 hour at 1450/1600°F (788/871°C). Since high-nickel, high permeability alloys readily absorb carbon, sulfur, oxygen, and other contaminants from combustion furnace gasses, in-process annealing should be done in a hydrogen or inert gas atmosphere.

Workability

Forging	The recommended forging temperature is 2150°F (1177°C).
Cold working	For best blanking characteristics, strip should be ordered in the cold rolled condition at Rockwell B 90 minimum. For best forming characteristics, strip should be ordered as cooled rolled and annealed for forming. Best drawing characteristics are obtained when ordered as annealed, deep drawing quality.

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Machinability

Machining	If components are to be machined in volume from bar stock, High Permeability 49-FM, a free-machining grade, is recommended.
Work hardening	The standard grade, High Permeability 49 alloy, machines somewhat like the austenitic stainless alloys. It develops gummy chips but does not work harden as rapidly as the stainless alloys.
Final magnetic properties	Sulfur-bearing cutting compounds are highly detrimental to the final magnetic properties. Animal lard oil should be used in drilling and machining operations, which must be performed at slow speeds.
Best machining characteristics	Work hardened bars offer the best machining characteristics. Parts should be degreased and cleaned as soon as possible.

Typical feeds and speeds

TURNING — SINGLE-POINT AND BOX TOOLS

DEPTH OF CUT, IN	HIGH-SPEED TOOLS			CARBIDE TOOLS (INSERTS)			
	SPEED, FPM	FEED, IPR	TOOL MATERIAL	SPEED, FPM		FEED, IPR	TOOL MATERIAL
				UNCOATED	COATED		
.150	30	.010	M-41, M-42, M-47	120	—	.010	C-2
.025	40	.005		130	—	.005	C-3

TURNING — CUT-OFF AND FORM TOOLS

SPEED, FPM	FEED, IPR							TOOL MATERIAL	
	CUT-OFF TOOL WIDTH, IN			FORM TOOL WIDTH, IN				HIGH-SPEED TOOLS	CARBIDE TOOLS
	1/16	*1/8*	*1/4*	*1/2*	*1*	*1-1/2*	*2*		
25	.001	.001	.0015	.0015	.001	.0007	.0007	M-42	—
80	.003	.003	.0045	.003	.002	.002	.002	—	C-2

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ROUGH REAMING

HIGH-SPEED TOOLS		CARBIDE TOOLS		FEED, IPR, REAMER DIAMETER, IN					
SPEED, FPM	TOOL MATERIAL	SPEED, FPM	TOOL MATERIAL	1/8	1/4	1/2	1	1-1/2	2
30–60	M-42	70	C-2	.002	.006	.008	.010	.012	.014

DRILLING

SPEED, FPM	FEED, IPR								TOOL MATERIAL
	NOMINAL HOLE DIAMETER, IN								
	1/16	1/8	1/4	1/2	3/4	1	1-1/2	2	
40	.001	.002	.004	.007	.008	.010	.012	.015	M-42

TAPPING — HIGH-SPEED TOOLS

SPEED, FPM	TOOL MATERIAL
6–15	M-1, M-7, M-10

BROACHING — HIGH-SPEED TOOLS

SPEED, FPM	CHIP LOAD, IN PER TOOTH	TOOL MATERIAL
8–12	.002	M-42

DIE THREADING — HIGH-SPEED TOOLS

SPEED, FPM				TOOL MATERIAL
7 OR LESS, TPI	8 TO 15, TPI	16 TO 24, TPI	25 AND UP, TPI	
8–20	10–25	15–30	20–35	M-1, M-2, M-7, M-10

MILLING — END PERIPHERAL

DEPTH OF CUT, IN	HIGH-SPEED TOOLS					CARBIDE TOOLS				
	SPEED, FPM	FEED, IN PER TOOTH / CUTTER DIAMETER, IN				TOOL MATERIAL	SPEED, FPM	FEED,IN PER TOOTH / CUTTER DIAMETER, IN				TOOL MATERIAL
		1/4	1/2	3/4	1-2			1/4	1/2	3/4	1-2	
.050	35	.0005	.001	.002	.003	M-42	200	.001	.002	.003	.004	C-6

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Other information

Additional machinability notes	When using carbide tools, surface speed feet/minute (sfm) can be increased between 2 to 3 times over the high-speed tool suggestions. Feeds can be increased between 50 and 100%. Figures used for all metal removal operations reported are average. On certain work, the nature of the part may require adjustment of the speeds and feeds. Each job has to be developed for best production results with optimum tool life. Speeds or feeds should be increased or decreased in small steps.
Weldability	High Permeability 49 is readily brazed, welded, and soft or hard soldered by employing the usual practices used on ferrous alloys.
Applicable specifications	ASTM A753 Alloy 2 IEC 404-8-6 (Alloy class E3) MIL-N-14411B (MR) (Composition 3 and 4)

For additional information, please contact your nearest sales office:
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