



Magnetic Powder Cores

ARNOLD[®]
THE MAGNETIC PRODUCTS GROUP OF **SPS**
TECHNOLOGIES

ARNOLD MAGNETICS LTD
Powder Core Division

Introduction

Arnold manufactures the world's largest selection of magnetic materials. We are magnetic specialists of both hard and soft magnetic materials. This product information guide is focused on our soft magnetic powder core products; Molybdenum Permalloy Powder, SUPER-MSS™, and HI-FLUX™.

Today, electrical design engineers need to identify and compare product capabilities, performance and effectiveness for high frequency power conversion inductors, noise filters and various tuned circuit applications to meet their design objectives. To assist in this selection process, we have included the following information:

- How to order parts
- Design information
- Formulas and definitions for design calculations
- Comparative magnetic curves for performance evaluation
- Electrical and physical specifications with part numbers
- "Q" curves for Molybdenum Permalloy Powder cores

In 1995 Arnold initiated a complete upgrade of our powder core manufacturing facility providing the most advanced equipment to process, control and monitor our products. The upgrade for Molybdenum Permalloy Powder (MPP) and HI-FLUX was completed in 1996. In early 1997 the Sendust (SUPER-MSS) upgrade was completed.

To further our commitment to Magnet Materials advancement, Arnold opened the Magnetics Technology Center (MTC) in 1996. This "state-of-the-art" magnetics development laboratory is used for new product and improved process development by Arnold and their customers.

Arnold's commitment to continuous improvement and customer satisfaction is best reflected in our commitment to excellence:

Our Commitment to Excellence

Arnold is committed to providing quality products and services that conform to our customers' requirements.

We will have an environment which encourages teamwork and in which each employee learns, understands, and practices quality conformance as an integral part of his or her job function. All departments will establish goals consistent with our commitment to continuous improvement.

We will judge our performance on how well we satisfy our customers' needs and be guided by the belief that our customers will ultimately determine how successful we will be.

We appreciate your selection of our products.

ARNOLD® is a registered trademark of The Arnold Engineering Co., a subsidiary of SPS Technologies, Inc.

Arnold HI-FLUX™ and SUPER-MSS™ are trademarks of The Arnold Engineering Co., a subsidiary of SPS Technologies, Inc.

Table of Contents

	Page
Part Number Ordering Information	3
Design Information.....	4-6
Winding Notes.....	7, 8
Notes on Molybdenum Permalloy Q Curves	9, 10
MPP Core Loss (Ohms per Millihenry)	11, 12
Typical Core Loss Curves	13-16
Typical Permeability vs. Temperature	17
Typical Incremental Permeability vs. D.C. Bias	18
Normal Magnetization Curves	19
Normal Permeability vs. AC Flux Density	20
Typical Permeability vs. Frequency	21

Specifications and "Q" Curves

0.140" o.d.	22-23
0.155" o.d.	24-25
0.183" o.d.	26-27
0.250" o.d.	28-29
0.260" o.d. (i.d. 0.105/ht.0.100)	30-31
0.260" o.d. (i.d. 0.105/ht.0.188)	32-33
0.277" o.d.	34-35
0.310" o.d.	36-37
0.380" o.d. (i.d. 0.188/ht.0.125)	38-39
0.380" o.d. (i.d. 0.188/ht.0.156)	40-41
0.400" o.d.	42-43
0.440" o.d.	44-45
0.500" o.d.	46-47
0.655" o.d.	48-49
0.680" o.d.	50-51
0.800" o.d.	52-53
0.900" o.d.	54-55
0.928" o.d.	56-57
1.060" o.d. (i.d. 0.580/ht.0.340)	58-59
1.060" o.d. (i.d. 0.580/ht.0.440)	60-61
1.300" o.d. (i.d. 0.785/ht.0.345)	62-63
1.300" o.d. (i.d. 0.785/ht.0.420)	64-65
1.300" o.d. (i.d. 0.785/ht.0.440)	66-67
1.350" o.d.	68-69
1.410" o.d.	70-71
1.570" o.d.	72-73
1.840" o.d. (i.d. 0.950/ht.0.710)	74-75
1.840" o.d. (i.d. 1.130/ht.0.600)	76-77
2.000" o.d.	78-79
2.250" o.d. (i.d. 1.039/ht.0.600)	80-81
2.250" o.d. (i.d. 1.400/ht.0.550)	82-83
3.063" o.d. (i.d. 1.938/ht.0.500)	84-85
3.063" o.d. (i.d. 1.938/ht.0.625)	86-87
4.000" o.d. (i.d. 2.250/ht.0.535)	88-89
4.000" o.d. (i.d. 2.250/ht.0.650)	90-91
5.218" o.d. (i.d. 3.094/ht.0.800)	92-93
5.218" o.d. (i.d. 3.094/ht.1.000)	94-95
Index	96-98

© 1998 The Arnold Engineering Company

Notes on Molybdenum Permalloy Q Curves

Note: The following information applies to frequency tuned circuit applications.

The Q formula calculates the ratio of reactance to effective resistance for an inductor and thus indicates its quality. For electrical wave filters, an increase in Q provides sharper cut-off, higher attenuation ratios, and better defined resonance. Q is affected by the distributed capacitance of an inductor's winding.

Neglecting the effects of self-resonance caused by the distributed capacitance (see paragraph 4c, below) Q can be calculated, when designing inductors, by this formula:**

$$Q = \frac{\omega L}{R_{dc} + R_{ac} + R_{cd}}$$

- Q = quality factor
- L = inductance (henries)
- $\omega = 2\pi \times$ frequency (frequency in hertz)
- R_{dc} = dc winding resistance (ohms)
- R_{ac} = resistance due to core losses (ohms)
- R_{cd} = resistance due to dielectric losses in winding (ohms)

The Q curves published in this manual are not to be construed as guaranteed minimum values. Instead they represent what might be attainable under ideal conditions. They were developed theoretically and have been checked with various core sizes and inductances to assure reasonable correspondence to the real world of wire, insulation and winding. The user's ability to get equivalent results depends in part upon his ability to duplicate the assumed conditions.

These are:

1. A "full-wound core" is defined to be one in which the minimum winding ID or residual hole left after winding is one-half of the inside diameter of the core.
2. This leaves a useful winding area which is three-quarters of the available window area. It was assumed that 70% of this space would be filled with copper wire including heavy synthetic film insulation.
3. The dc resistance of a full-wound core varies as the square of the number of turns in the same manner that the resultant inductance varies as the square of the turns. Therefore, each core size has a table of calculated ohms per millihenry based on the "full-wound core" definition above. This resistance determines the positive slope of the low frequency portion of the Q curve and is assumed to be independent of inductance.
4. Three factors affect the high frequency performance of an inductor.
 - a. The most fundamental is the loss of the core material which is mostly responsible for the negative slope of the low inductance curves at frequencies above the frequency of maximum Q. This is calculated from Legg's equation (see next section).

**This analysis follows Herman Blinichkoff, "Toroidal Inductor Design," *Electro-Technology*, November, 1964.

- b. The second factor is caused by dielectric loss. Dielectric loss resistance is significant at higher frequencies and can be calculated from the equation found in Terman's Handbook.***

$$R_{cd} = d\omega^3 L^2 C_d$$

d = power factor of distributed capacitance

Values of d	
125 μ & over	.0118
60 μ	.0417
26 μ	.0750
14 μ	.0900

$\omega = 2\pi \times$ frequency in hertz

L = Inductance in henries

C_d = distributed capacitance in farads

- c. The most dramatic factor is the effect of self resonance of the distributed capacitance and the inductance. For small inductances, such as the 0.001 henry or the 0.01 henry curve for each core, the self-resonant frequency f_o is well above the normal useful frequency range of the component. Therefore, these curves tend to indicate the component performance with a negligible effect of self resonance. The distributed capacitance and the self inductance determine a self-resonant frequency according to:

$$f_o = \frac{1}{2\pi\sqrt{LC_d}} \text{ hertz.}$$

At some lower frequency, f, the value Q_f can be calculated from:

$$Q_f = Q \left[1 - \left(\frac{f}{f_o} \right)^2 \right]$$

where Q is calculated from determined values of loss resistances as indicated above, and Q_f is the apparent Q, taking into account the effect of the distributed capacitance. It should be noted that when f is 20% of f_o , Q_f is 96% of its original value. However, when f is 70% of f_o , Q_f drops to 51% of its original value. The apparent value of the inductance, L_a , is also affected as follows:

$$L_a = \frac{L}{1 - \left(\frac{f}{f_o} \right)^2}$$

5. Because the distributed capacitance is determined by the winding method, the user can obtain different results from those plotted, depending on this value of the capacitance. Each Q curve is marked with the capacitance value used.

****Radio Engineer's Handbook*, F.E. Terman, McGraw-Hill, Inc., New York (1943), p. 84.

Notes on Molybdenum Permalloy Q Curves (Cont.)

Molybdenum Permalloy Core Loss at Low Magnetic Flux Densities

LEGG'S EQUATION!...total core loss at low flux densities is the sum of three component losses - hysteresis, residual and eddy current. Values of typical loss coefficients are found in the following table for each permeability. The core loss in terms of ohms per henry per unit of permeability is calculated from Legg's Equation:

$$\frac{R_{ac}}{\mu L} = aB_{max}f + cf + ef^2$$

Watts of loss from Legg's Equation may be determined by:

$$\text{Watts of Loss} = 3.98 B_{max}^2 A l \left[\frac{R_{ac}}{\mu L} \right] 10^{-9}$$

or

$$\text{Watts of Loss} = \frac{3.98 B_{max}^2 A l}{\mu 10^6} \left[\text{ohms/mhy}^{**} \right]$$

** from core loss curves

- R_{ac} = effective resistance due to core losses (ohms)
- μ = permeability of core
- L = inductance (henries)
- a = hysteresis loss coefficient
- B_{max} = maximum flux density (gausses)
- c = residual loss coefficient
- f = frequency (hertz)
- e = eddy loss coefficient
- A = core area (cm²)
- l = mean magnetic path (cm)

Molybdenum Permalloy Electrical Specifications and Typical Loss Coefficients

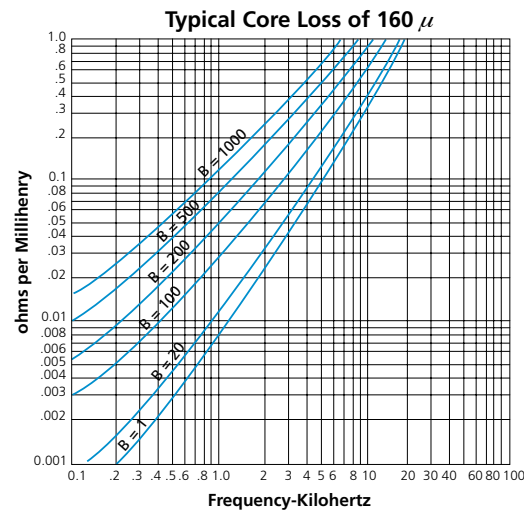
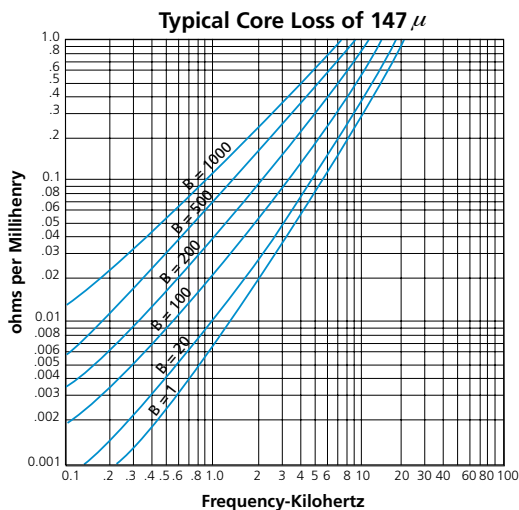
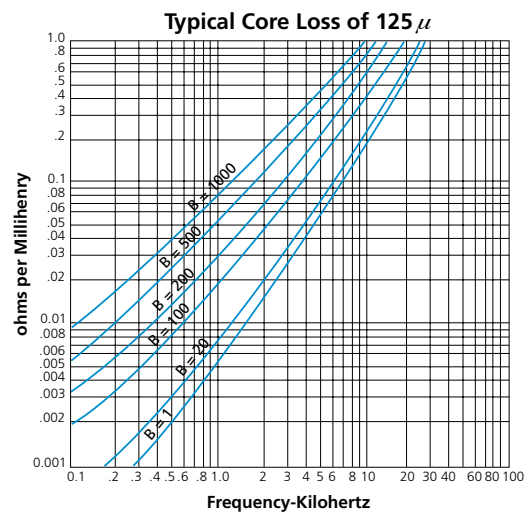
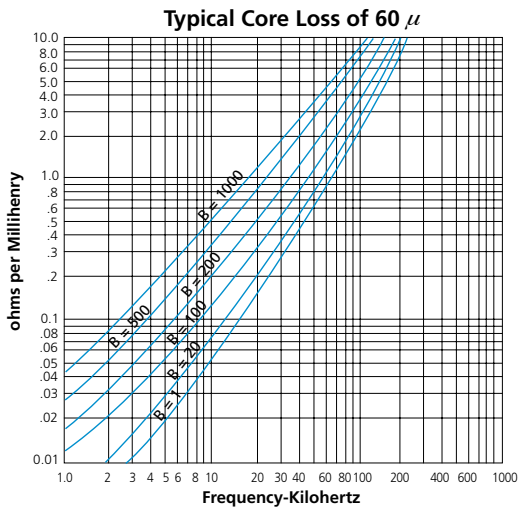
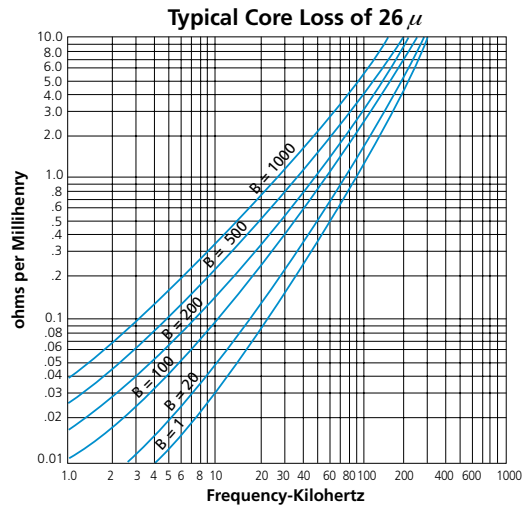
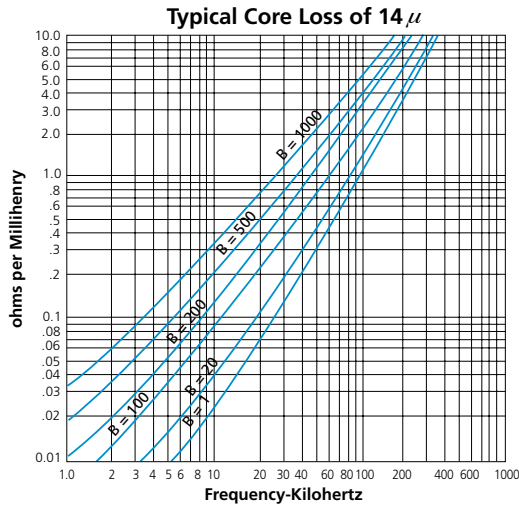
SPECIFICATIONS					TYPICAL VALUES		
Perm. μ $\pm 8\%$	Maximum Core Loss		Test		Hysteresis Loss Coefficient a	Residual Loss Coefficient c	Eddy Current Loss Coefficient e
	$\frac{R_{ac}}{\mu L}$ ohms Henry x μ	Flux Density (Gausses)	Frequency Hertz	Maximum Permeability Change after Magnetization [†]			
300	0.25	20	1800	$\pm 0.5\%$	1.1×10^{-6}	30.0×10^{-6}	43.0×10^{-9}
250	0.25	20	1800	$\pm 0.5\%$	1.2×10^{-6}	26.0×10^{-6}	37.0×10^{-9}
205	0.25	20	1800	$\pm 0.5\%$	1.3×10^{-6}	25.0×10^{-6}	30.0×10^{-9}
173	0.20	20	1800	$\pm 0.5\%$	1.4×10^{-6}	25.0×10^{-6}	25.0×10^{-9}
160	0.20	20	1800	$\pm 0.5\%$	1.5×10^{-6}	25.0×10^{-6}	22.0×10^{-9}
147	0.20	20	1800	$\pm 0.5\%$	1.6×10^{-6}	25.0×10^{-6}	20.0×10^{-9}
125	0.20	20	1800	$\pm 0.5\%$	1.6×10^{-6}	25.0×10^{-6}	13.0×10^{-9}
60	1.50	10	8000	$\pm 0.3\%$	3.2×10^{-6}	50.0×10^{-6}	10.0×10^{-9}
26	70	4	75000	$\pm 0.2\%$	6.9×10^{-6}	96.0×10^{-6}	7.7×10^{-9}
14	65	4	75000	$\pm 0.1\%$	11.4×10^{-6}	143.0×10^{-6}	7.1×10^{-9}

[†] Measured three minutes after the application of a dc magnetizing force of 30 oersteds for 60 and higher permeabilities or 60 oersteds for 26 and 14 permeabilities.

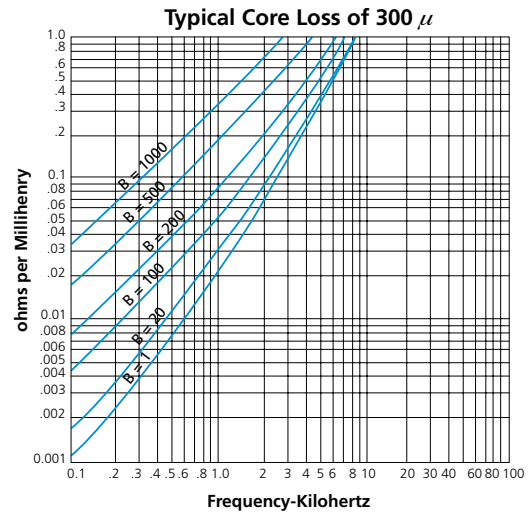
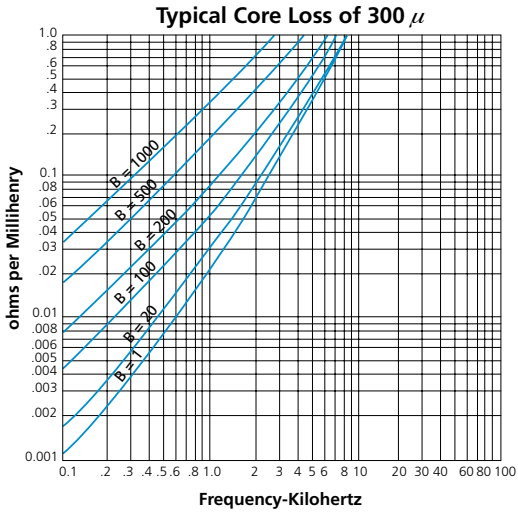
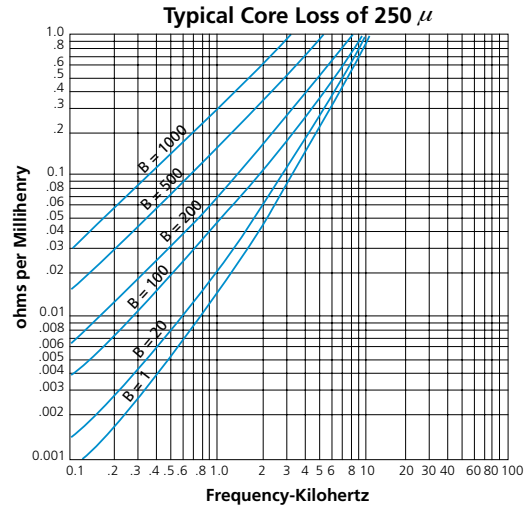
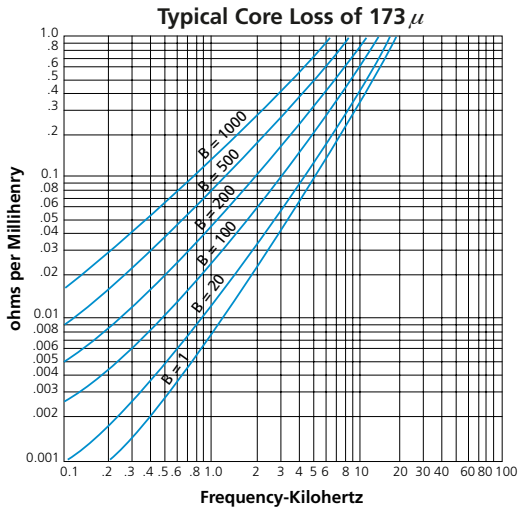
¹-Legg, V.E., "Magnetic Measurements at Low Flux Densities Using the A-C Bridge," *The Bell System Technical Journal*, Vol. 15, January, 1936, pp. 39-63.

Charts showing the typical core loss resistance in ohms per millihenry for each permeability material are found on pages 11 and 12.

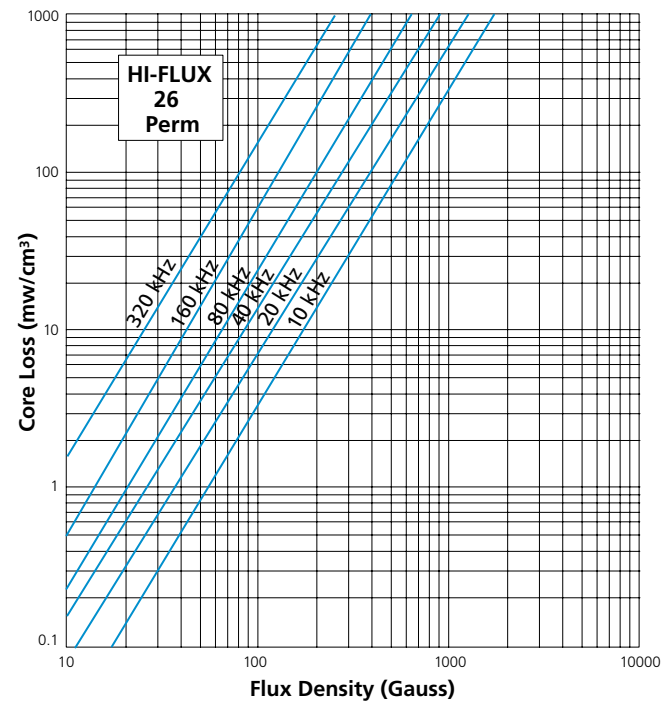
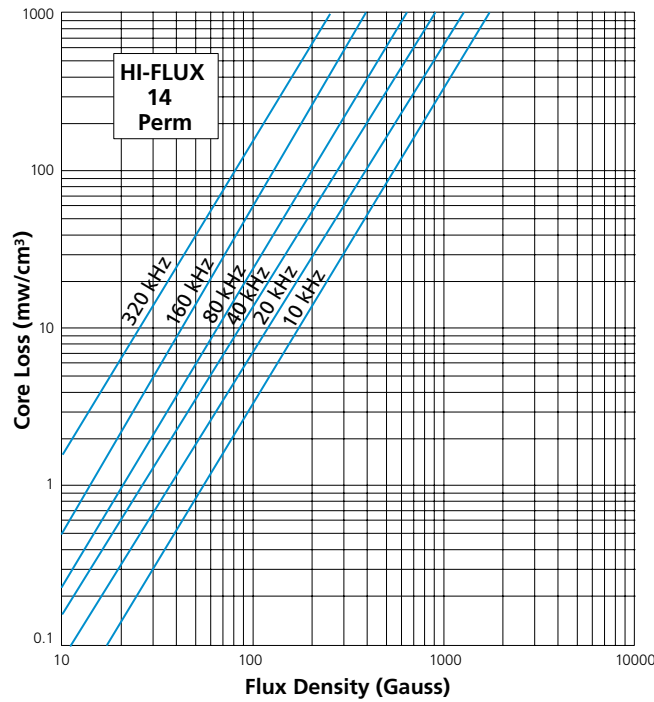
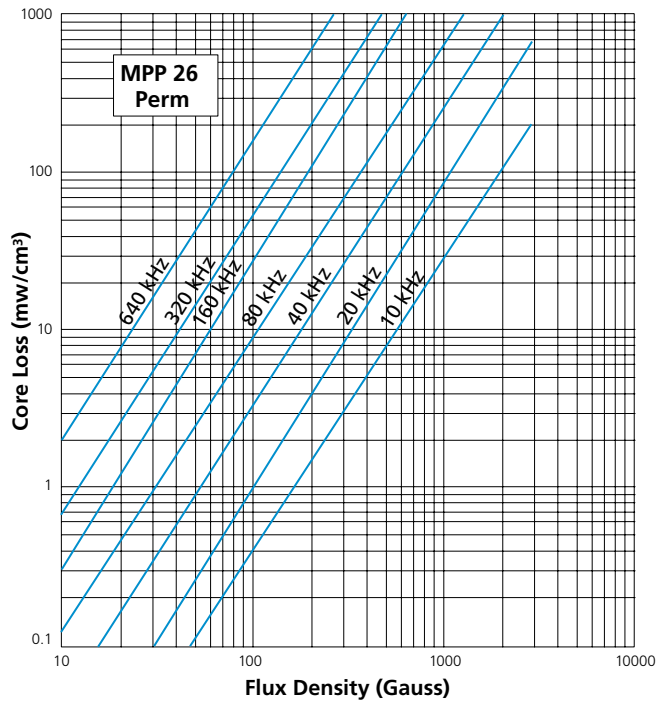
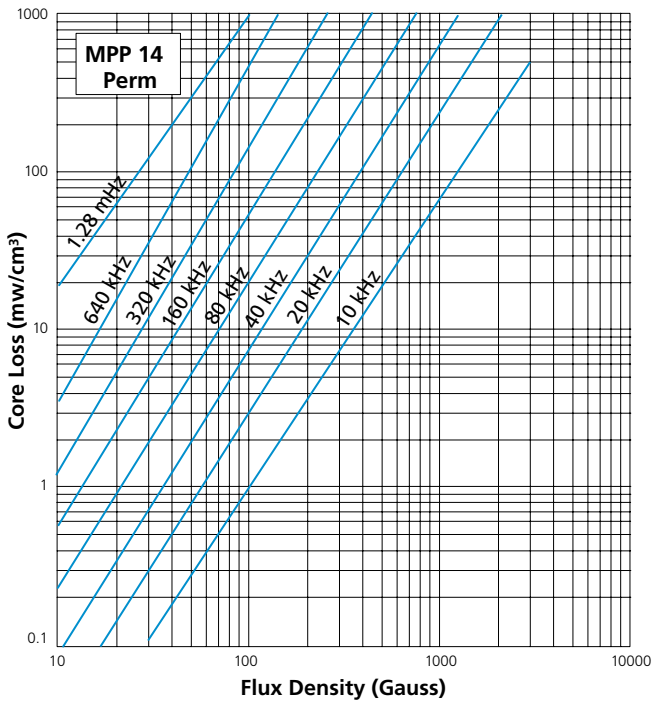
MPP Core Loss (Ohms per Millihenry)



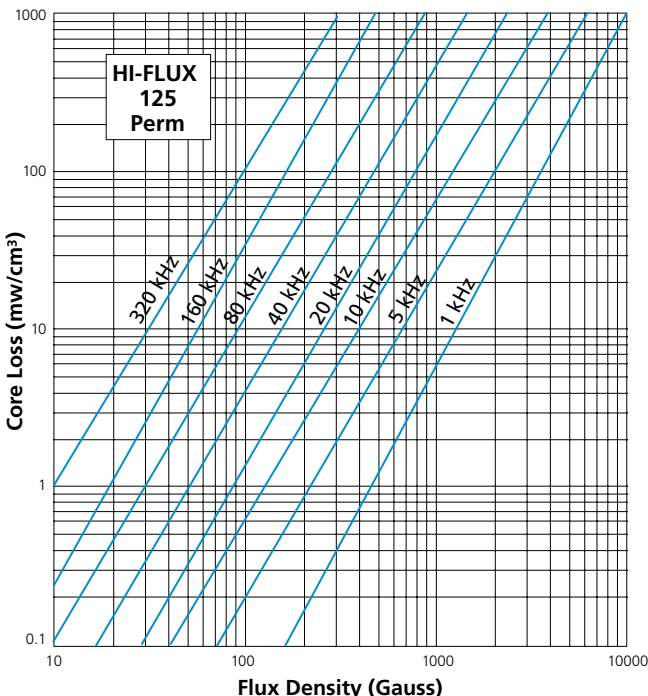
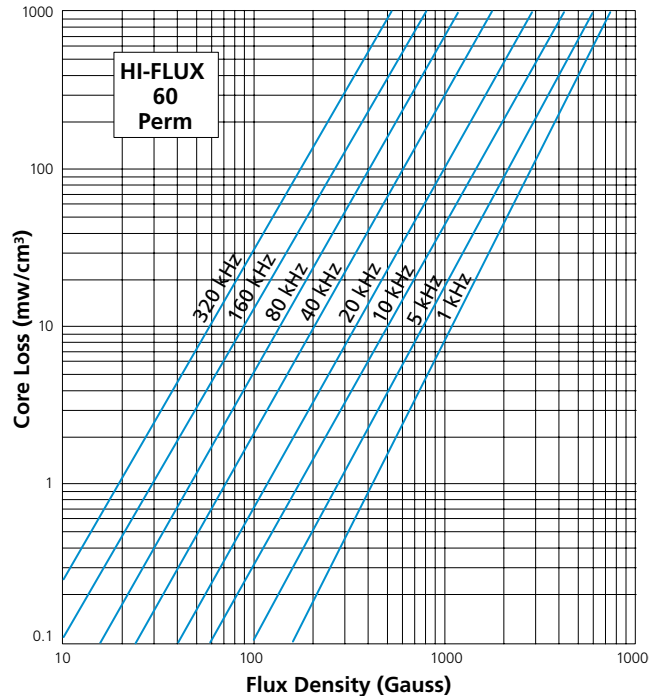
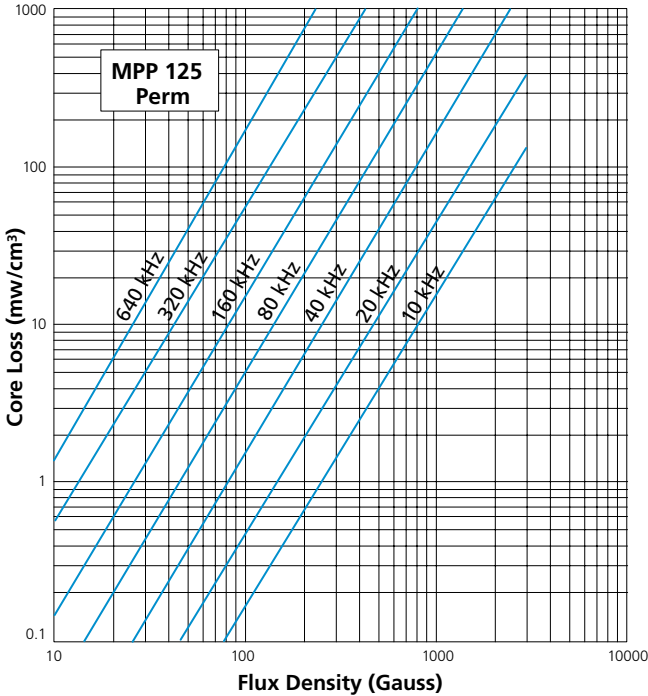
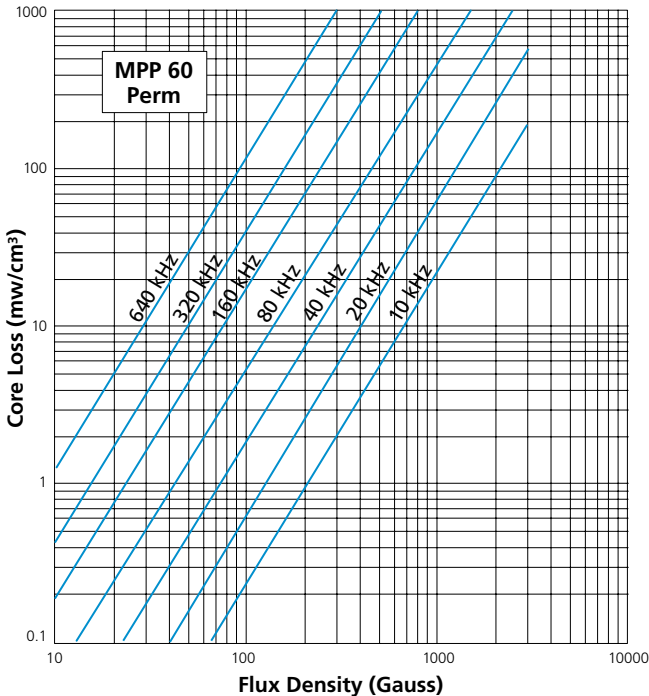
MPP Core Loss (Ohms per Millihenry)



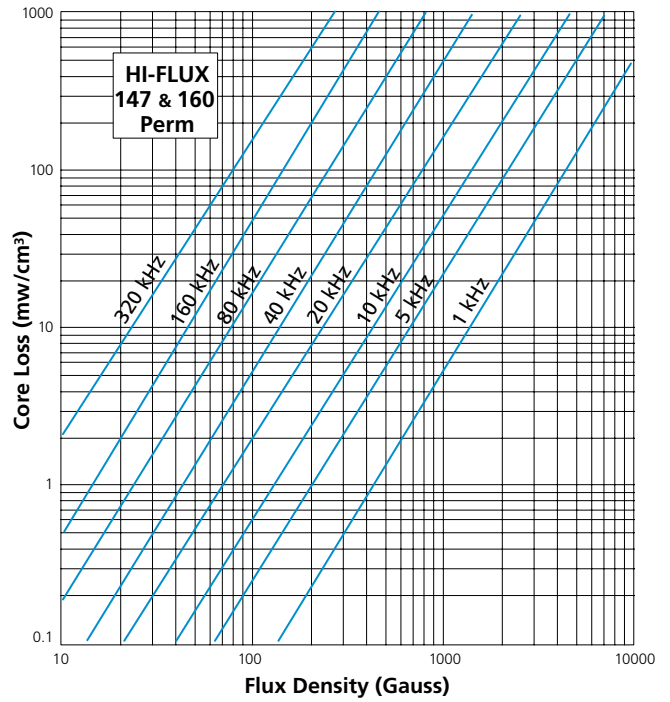
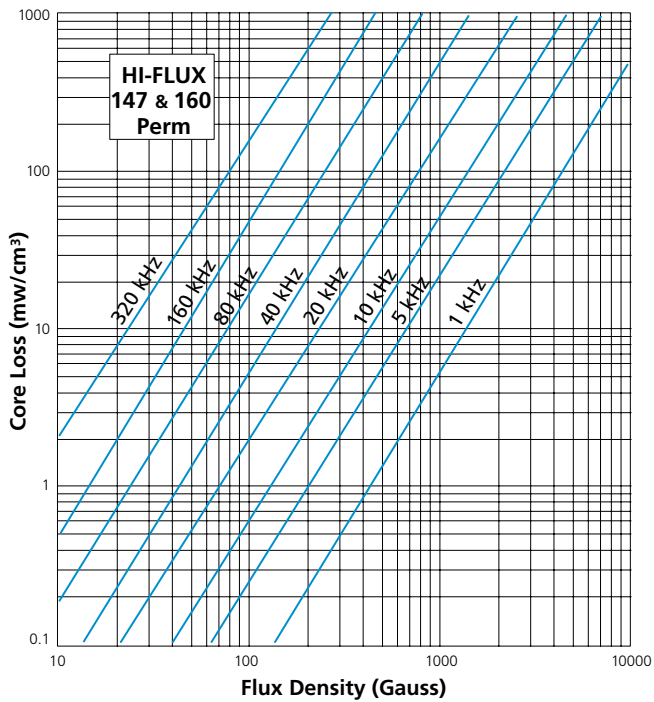
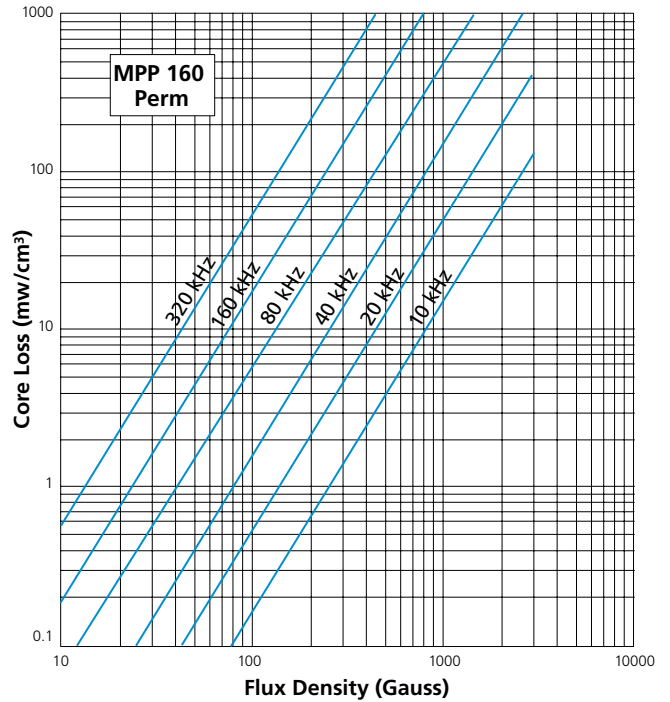
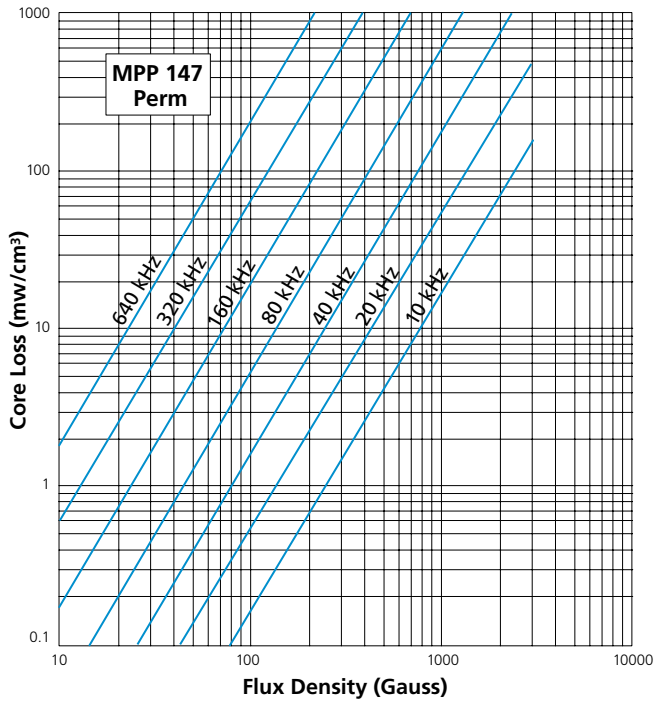
Typical Core Loss Curves



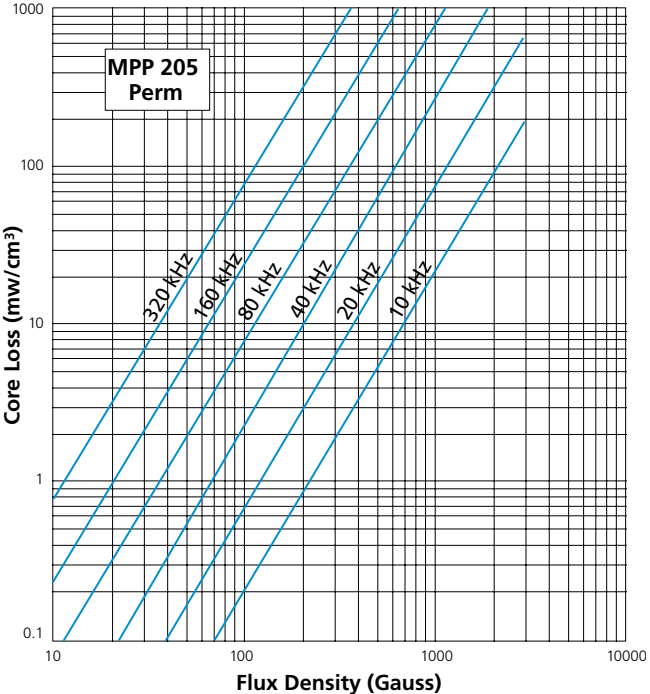
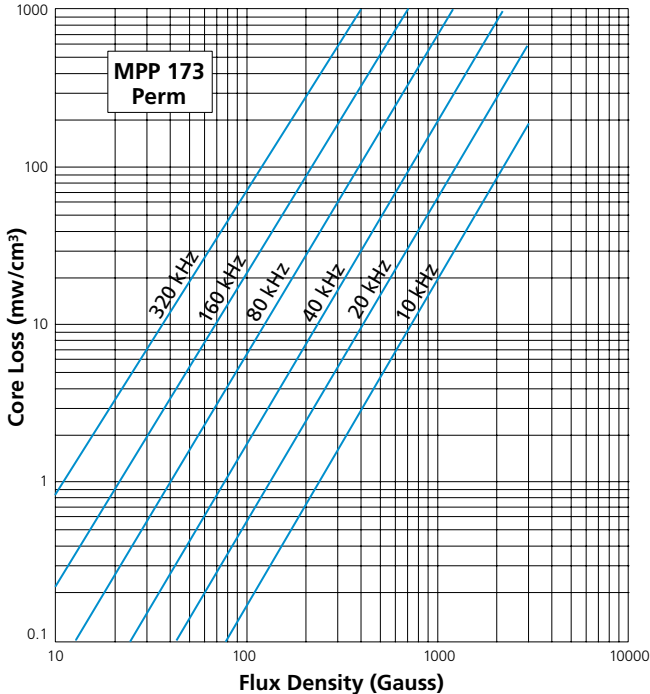
Typical Core Loss Curves



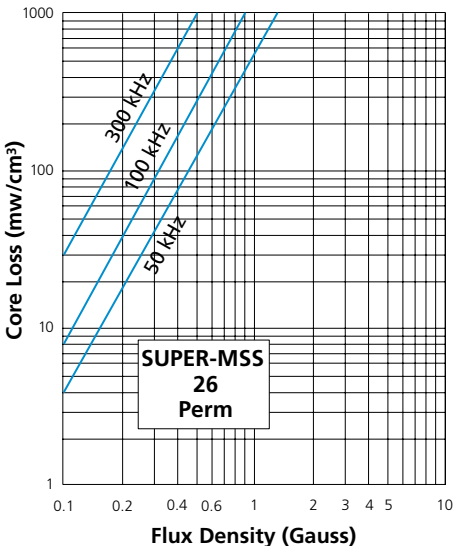
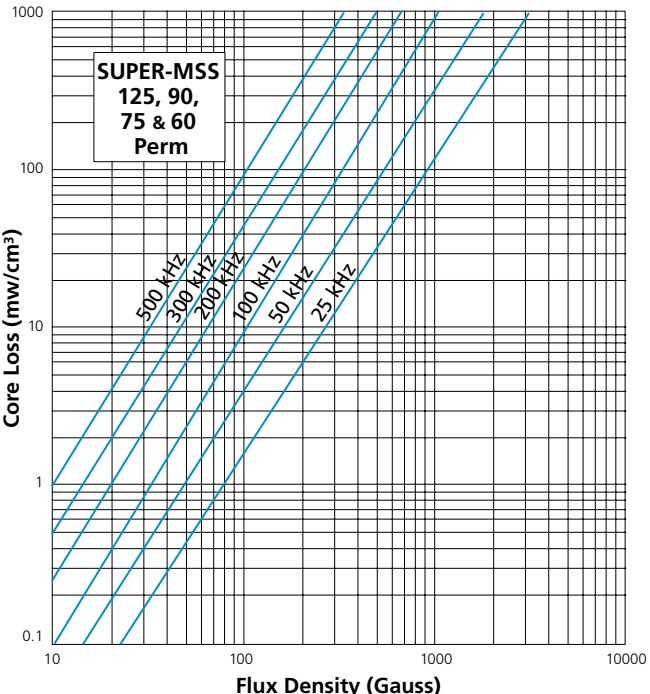
Typical Core Loss Curves



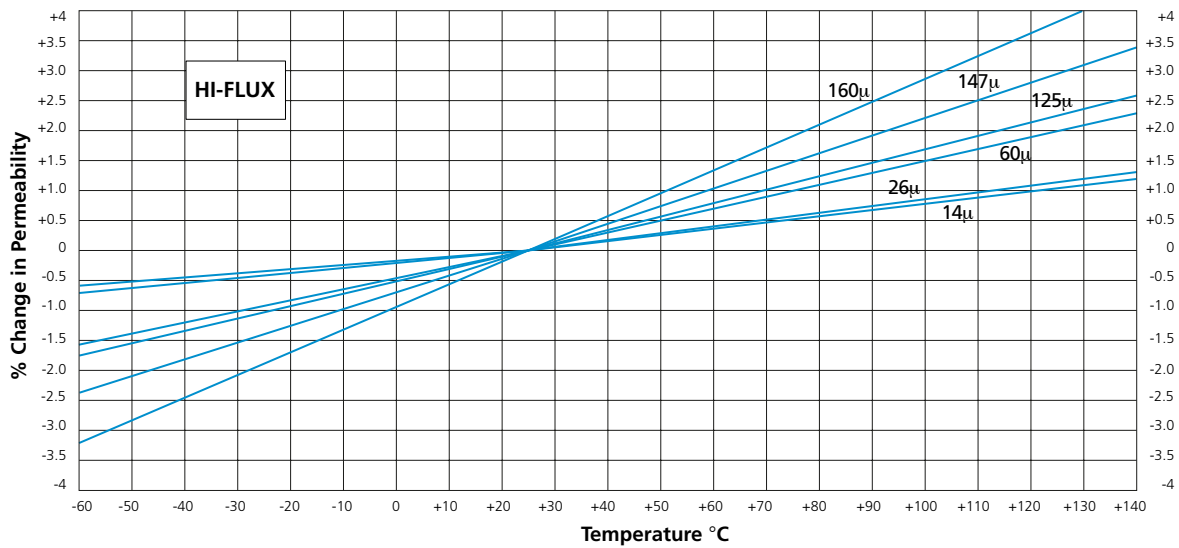
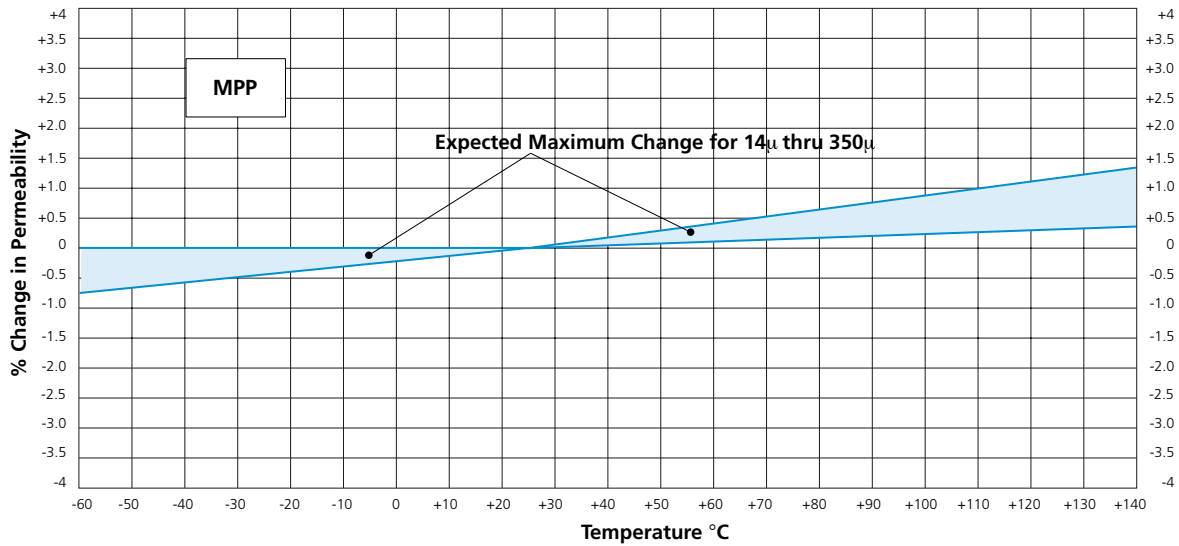
Typical Core Loss Curves



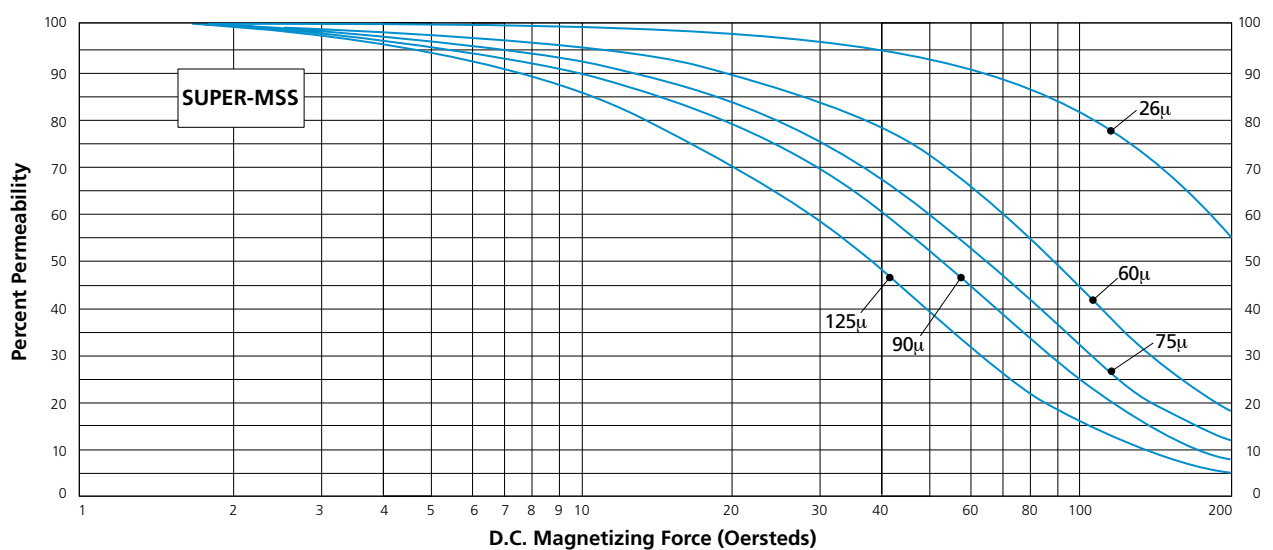
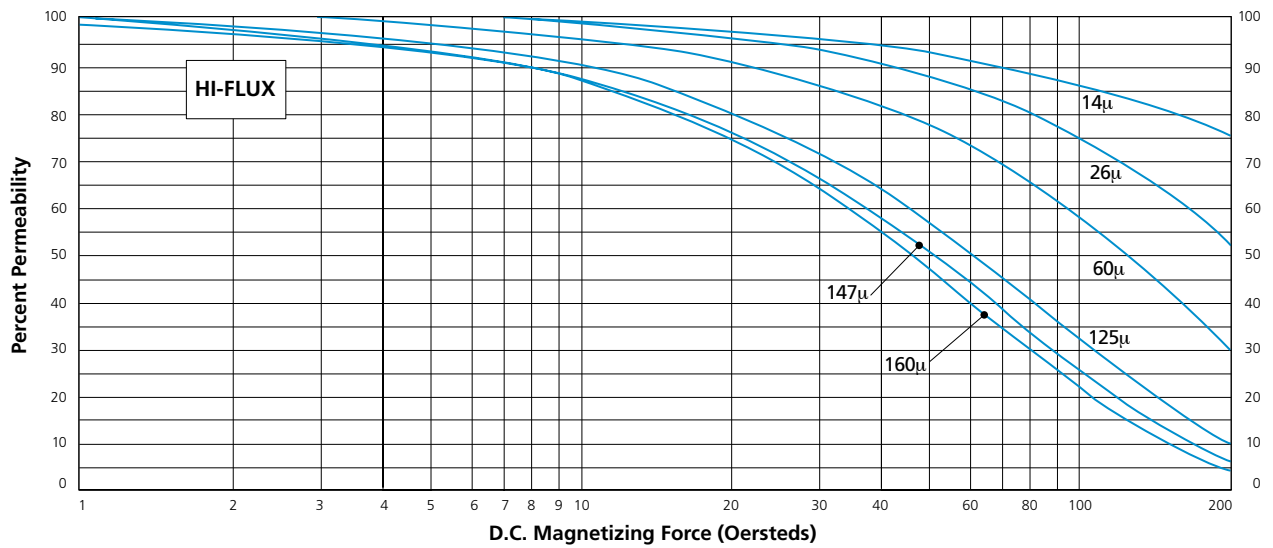
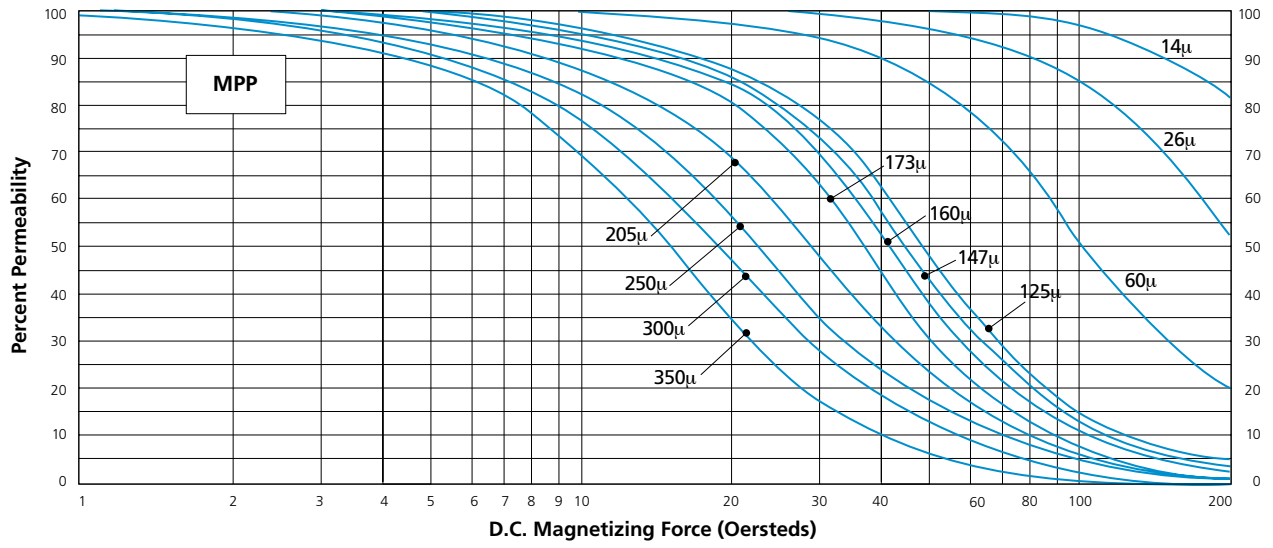
These Permeabilities do not apply to HI-FLUX.



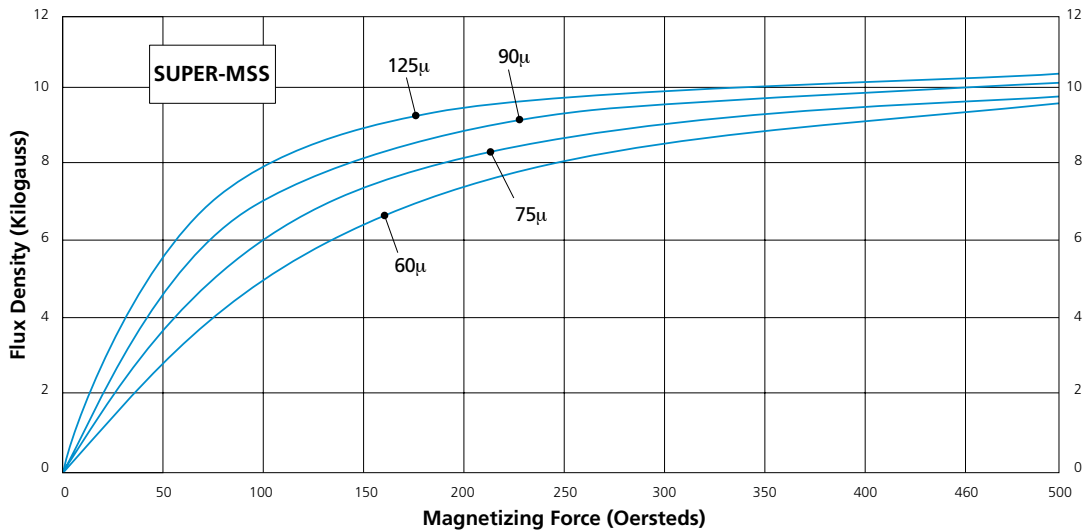
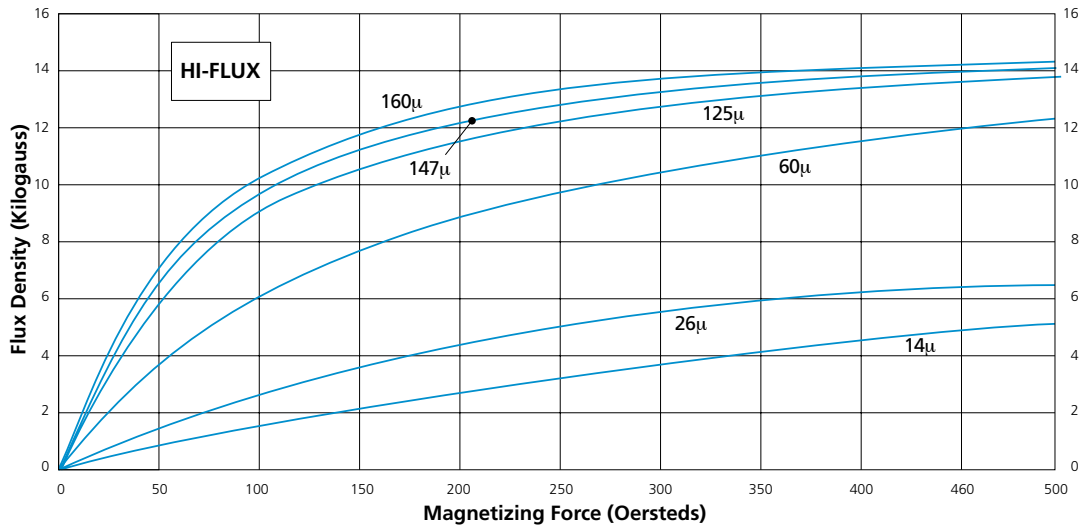
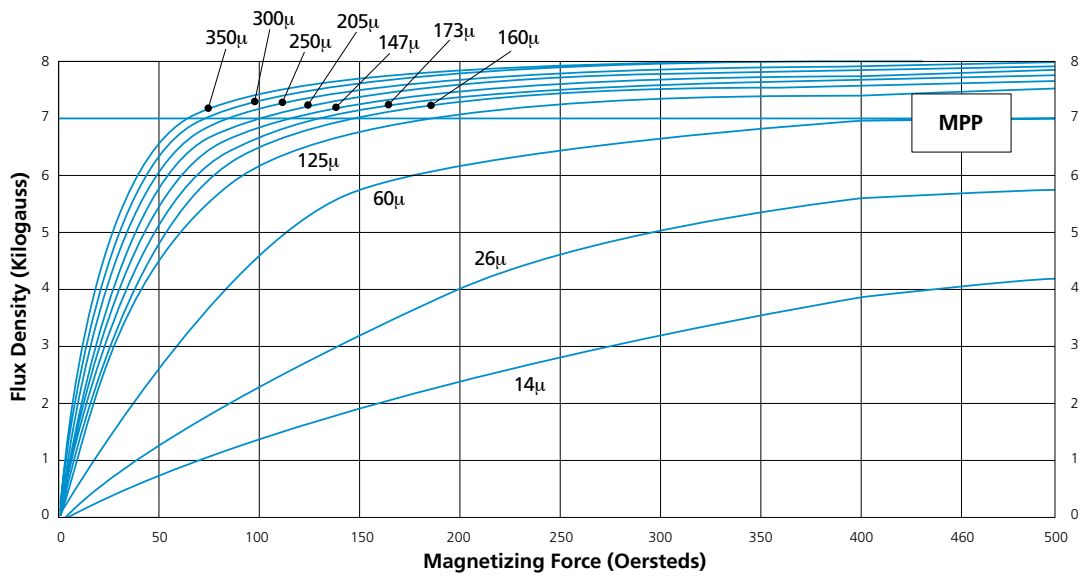
Typical Permeability vs. Temperature



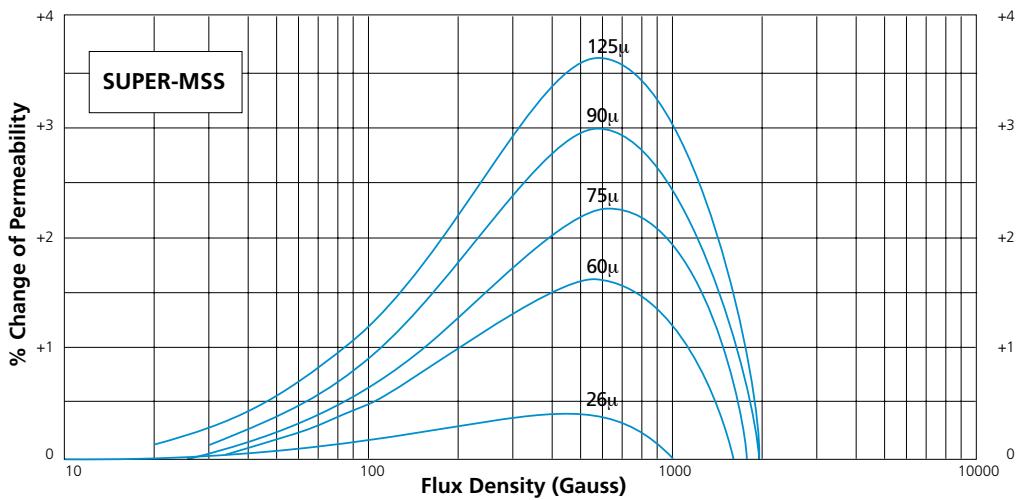
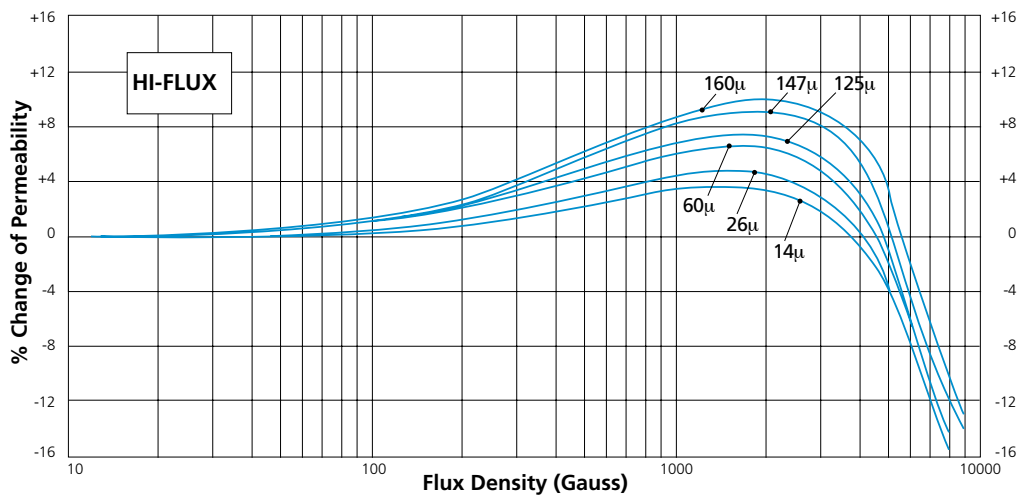
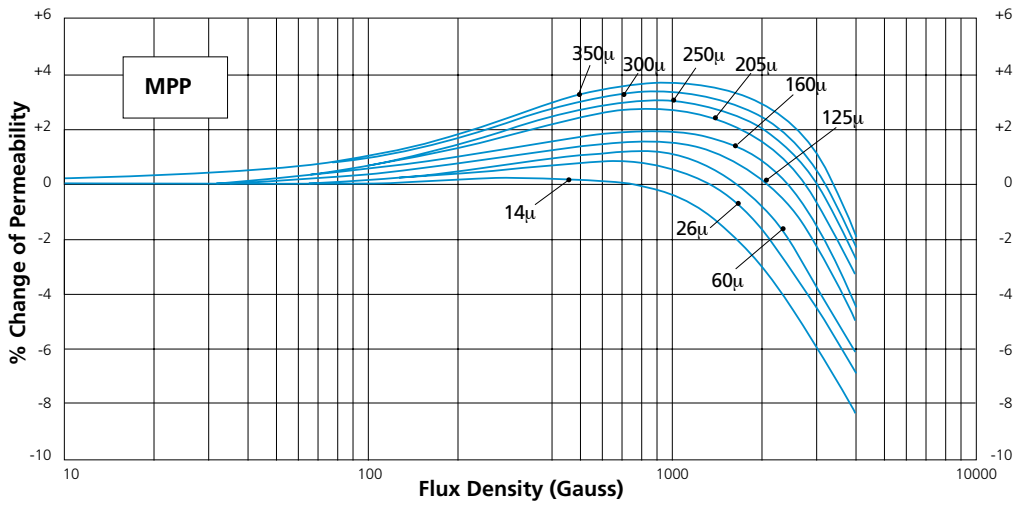
Typical Incremental Permeability vs. D.C. Bias



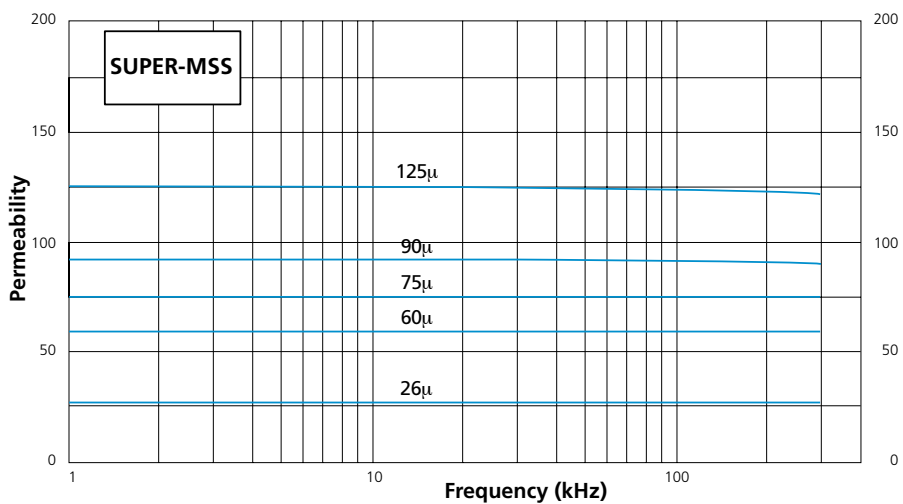
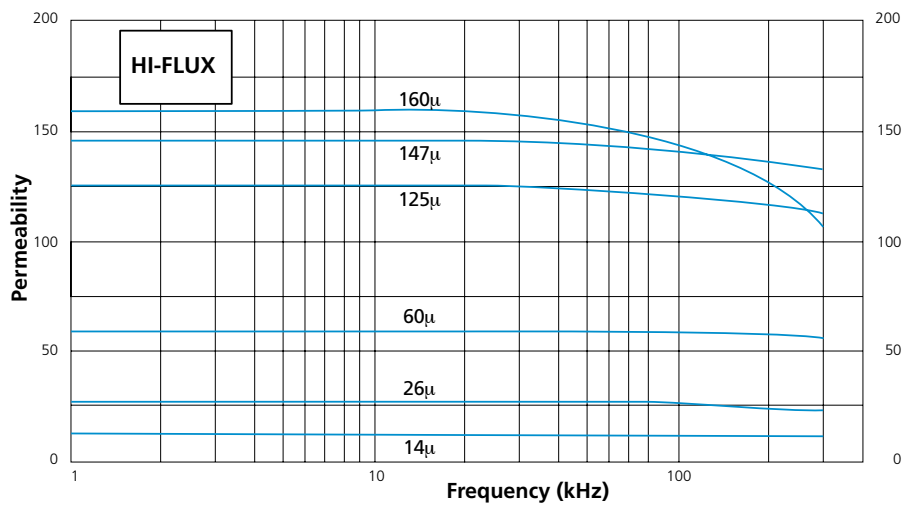
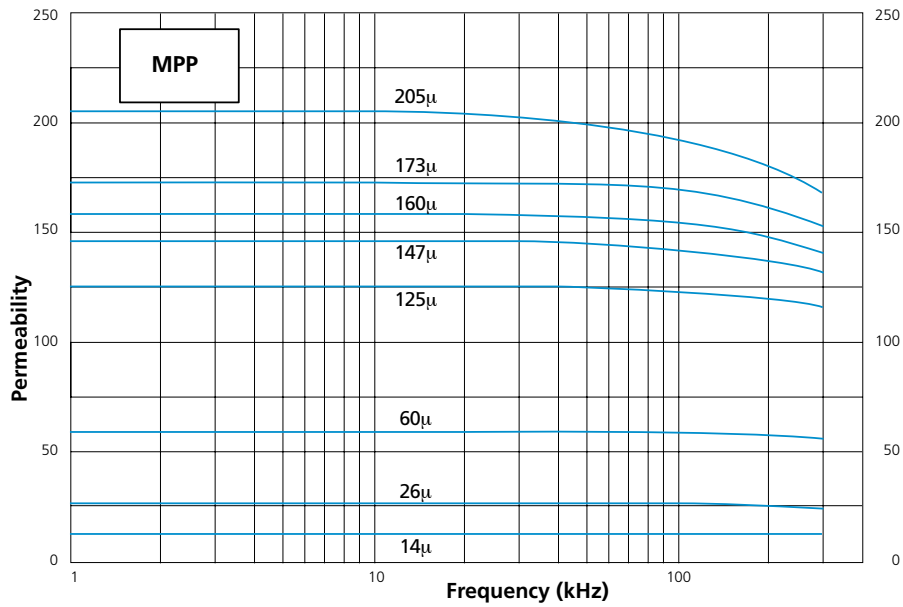
Normal Magnetization Curves



Normal Permeability vs. Flux Density



Typical Permeability vs. Frequency



Limited Warranty and Exclusive Remedy

Arnold Magnetics Ltd. warrants that these products conform to industry standards specific herein and will be free from defects in material and workmanship. THIS WARRANTY IS EXPRESSLY GIVEN IN LIEU OF ANY AND ALL OTHER EXPRESS OR IMPLIED WARRANTIES, INCLUDING ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, AND IN LIEU OF ANY OTHER OBLIGATION ON THE PART OF ARNOLD MAGNETICS LTD. Arnold Magnetics Ltd. will, at its option, repair or replace free of charge (excluding all shipping and handling costs) any products which have not been subject to misuse, abuse, or modification and which in its sole determination were not manufactured in compliance with the warranty given above.

THE REMEDY PROVIDED FOR HEREIN SHALL BE THE EXCLUSIVE REMEDY FOR ANY BREACH OF WARRANTY OR ANY CLAIM ARISING IN ANY WAY OUT OF THE MANUFACTURE, SALE, OR USE OF THESE PRODUCTS. In no event shall Arnold Magnetics Ltd. and its parent company, SPS Technologies, Inc., be liable for consequential, incidental or any other damages of any nature whatsoever except those specifically provided herein for any breach of warranty or any claim arising in any way out of the manufacture, sale, or use of these products. No other person is authorized by Arnold Magnetics Ltd. to give any other warranty, written or oral, pertaining to the products.

& RUSSIA

ASIA-PACIFIC

Arnold Magnetics (HK) Ltd
Unit 5, 10Fl., Kingsford Industrial Centre
13 Wang Hoi Road
Kowloon Bay, Hong Kong
Tel: (+852) 3106-3737
Fax: (+852) 3105-1955
Email: info@amlsz.com

EUROPE, AFRICA & RUSSIA

Swift Levick Magnets Ltd.
High Hazels Road
Barlborough Links, Barlborough
Derbyshire S43 4TZ United Kingdom
Tel: (+44) 1246-570500
Fax: (+44) 1246-573000
Email: slmsales@arnoldmagnetics.com

NORTH & SOUTH AMERICA

Arnold
Linden Ave.
Rochester, NY 14625-2764 USA
Tel: 800-593-9127
International: (+1) 585-385-9010
Fax: (+1) 585-385-9017
Email: info@arnoldmagnetics.com



ARNOLD MAGNETICS LTD

Bldg. D-6, Xin Tang Industrial Zone
Baishixia, Fuyong Town, Baoan County, Shenzhen, PRC
Tel: (+86) 755-2739-1771 • Fax: (+86) 755-2738-3210
Email: info@amlsz.com

www.arnoldmagnetics.com