Amuneal Shielding

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seconds to 1-2 Amps, held for 15 seconds, and then ramped down slowly over 15 seconds to zero amps (total cycle time: 45 seconds). From the literature[5] and our experience, repeating the cycle three times will optimize demagnetization. Additional cycles beyond that tend to have little, if any, benefit.

By utilizing the material characteristics of CRYOPERM™ 10 and careful adherence to magnetic shield design rules, it is possible to design and fabricate high performance magnetic shields for low temperature applications.

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4. Patrick Phelan, “Final Report: Measurement of Thermal Conductivity of Magnetic Samples at Cryogenic Temperatures”, Arizona State University, November 20, 2001

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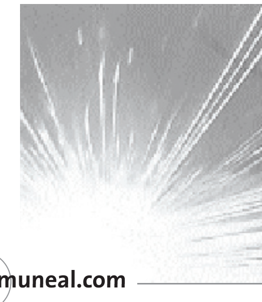

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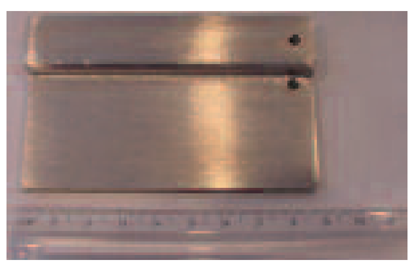
Amuneal's Cryoperm™ Magnetic Shielding

by Larry Maltin, President Technical Products, Amuneal Manufacturing Corporation, larrym@amuneal.com

Over the past five decades, an improved understanding of the characteristics and magnetic behavior of Iron-Nickel alloys have made them one of the most versatile of the soft magnetic materials. Originally limited to concerns for high permeability and low coercive force at room temperature, new alloys have been developed to meet high permeability requirements at cryogenic temperatures.[1]

The increasing development of SQUID (Superconducting QUantum Interference Device) based electronics technology has further led to wide-ranging industrial and scientific applications that require magnetic shielding at cryogenic temperatures. These include clinical instruments for biomagnetics, basic research in material characteristics, measurement of the cosmic microwave background radiation and the latest developments in SQUID Microscopy.



Prototype Cryoperm™ 10 Shield for PCB-mounted SQUID Array for the South Pole Telescope (Lawrence Berkeley National Laboratory)

As a result of a growing need for high permeability magnetic shielding at low temperature, CRYOPERM™ 10 was developed by Vacuumschmelze GmbH.[3] CRYOPERM™ 10 has high initial and maximum permeability as compared with AMUMETAL™, a standard 80% Nickel-Iron high-permeability alloy for shielding applications at room temperature. CRYOPERM™ 10 is available in standard sheet thicknesses of 0.02" (0.5mm), 0.040" (1.0mm) and 0.060" (1.5mm), and has allowed scientists and engineers to design the most cost-effective shielding for their specific low temperature application.

Magnetic and Physical Properties

Table 1 lists the typical properties of CRYOPERM™ 10 at 4.2K and 77.3K, based on measurement of fully annealed 0.004" (0.1mm) thick toroids. After fabrication, CRYOPERM™ 10 shields are hydrogen annealed at a special cycle to maximize performance at their specific application temperature.

Table 1. Typical properties of CRYOPERM 10 at 4.2K/77.3K

Saturation polarization at 10 A/cm		T	0.9
Permeability at 4 mA/cm (μ_4)	static	-	70000
	50Hz		65000
Maximum Permeability μmax	static	-	250000
	50Hz		160000
Static coercivity Hc		A/cm	0.012
Flux density at 0.1 A/cm (B0.1)		T	0.80
Remanence flux density		-	0.55
Remanence ratio Br/B0.1		T	0.7
Density		g/cm^3	8.7
Electrical resistivity	20˚C	$\Omega.mm^2/m$	0.45/0.35
	77.3 K		
Curie temperature		˚C	430

Magnetic Characteristics

Figures 2 and 3 illustrate the static hysteresis loop as well as the static and 50Hz permeability-field strength curves for CRYOPERM™ 10. These are mean-value curves measured on toroidal cores (strip thickness of 0.004" (0.1mm) at 4.2K and 77.3K. Figure 3 includes a static µH measured on 0.040" (1.0mm) thick solid CRYOPERM™ 10 rings at 77.3K.

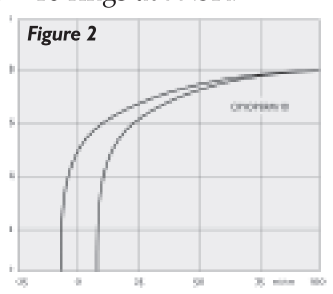


Figure 2

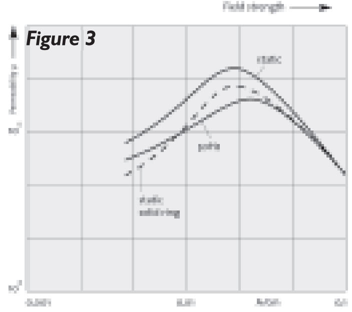


Figure 3

Coefficient of Thermal Expansion

Measurements for CRYOPERM™ 10 Coefficient of Thermal Expansion (CTE) were taken with a "dilatometer" at a starting temperature of -135°C. The -105°C value is influenced by the "starting effect", and is most likely low since the setup "settles" from the starting temperature. While there is no specific data for temperatures below -105°C, the range of values provides an indication of CTE at lower temperatures.

Coefficient of Thermal Expansion from -105° to

Teemperature (°C)	CTE (10^{-6})
- 105.9	10.193
- 053.0	11.463
- 000.5	11.925
050.5	13.074
101.4	13.095
151.4	13.900
200.9	13.979
251.0	14.851
300.8	15.198
350.7	15.830

Thermal Conductivity

Table 2. CRYOPERM Sample annealed for use at 4.2 K

Temperature (K)	Conductivity (W/m-K)
67.5	13.11
100.6	14.18
128.2	15.20
159.0	16.27
198.1	17.44
240.1	19.32

Table 3. CRYOPERM Sample annealed for use at 77.3 K

Temperature (K)	Conductivity (W/m-K)
69.1	13.11
101.3	14.09
134.1	14.67
168.3	15.51
206.4	16.60
241.0	22.63

Recent industry-sponsored research was done at Arizona State University to measure both the in-plane and thru-plane thermal conductivity of CRYOPERM™ 10 to determine if the material was isotropic.[4]

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Amuneal's Cryoperm™ Magnetic Shielding

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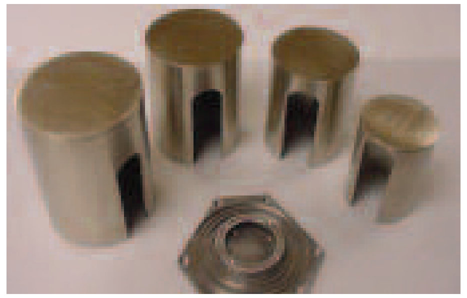
The tests were performed on two different types of CRYOPERM™ 10 samples...one annealed for use at 4.2K, and the second annealed for use at 77.3K. The results of the tests are shown in Tables 2 and 3 (page 50).

Shield Design Criteria

There are several magnetic shield design criteria which are essential in optimizing shield performance at low temperature:[6]

Material: Wherever possible, CRYOPERM™ 10 should be used where the shield itself will be at cryogenic temperature. In cases of very large shields however, it may be more cost-effective to use a thicker room temperature alloy like AMUMETAL™ in one or more layers to achieve equivalent shielding of a thinner CRYOPERM™ 10 shield.

Shape: Magnetic flux lines don't like to turn sharp corners. Rounded shields like cylinders are better at redirecting lines of flux than rectangular shields. Keeping the geometry of a shield simple maximizes a low reluctance path for magnetic flux.



Multi-Layer Magnetic Shield Asembly to study nonlinearity associated with intrinsic magnetic characteristics of superconductors. Alternate layers of CRYOPERM™ 10 and AMUMETAL installed on ultra-low-carbon-steel base. (University of Maryland Physics Dept.)

Size: The magnetic shield should be designed to envelop the device that is being shielded as closely as possible. The smaller the "effective radius" of a shield, the better will be its performance.

Dual-layer AMUMETAL™ Magnetic Shield for Spallation Neutron Source cryomodule (Thomas Jefferson National Accelerator Facility)

Continuity: Whenever a shield is constructed from two or more pieces, it should be designed to ensure magnetic continuity. This includes lids, overlapped corners and seams, and opening tabulations. Maintaining continuity ensures a low reluctance path for magnetic flux to ensure optimum shielding.

Shield Dimensions and Openings: When one or both ends of a shield must remain open, or if it requires openings in its side, then the diameter of these openings becomes critical to shield performance. For shields with open ends, the "rule of thumb" is that the shield should overhang the device by a distance equal or greater than the radius of the cylinder. "End effects" are minimized in shields with a length-to-diameter ratio greater than 4:1, which approach the attenuation calculated for an infinitely long cylinder.[7]

CRYOPERM™ 10 Magnetic shield Assembly for test cryostate (BESSY GmbH Berlin)

Likewise, the diameter of holes in the side of a shield is critical, since magnetic flux can extend into the cylinder a distance equal to five times the diameter. For shields with large diameter openings, tabulations can be designed to reduce the magnetic flux in the shield at the region(s) of the openings.

Multi-layer Shields: For some low-temperature shielding applications, a single-layer shield cannot provide the required level of attenuation. In such cases, multi-layer "nested" shields utilize spacing/air gaps between the layers to achieve significant shielding factors. Where space limitations prevent a multi-layer shield around the cryogenic device, a single layer CRYOPERM™ 10 shield can be combined with a room temperature shield around the dewar to achieve the required attenuation.

Formula for Demagnetization

Demagnetization of a magnetic shield, whether fabricated from AMUMETAL™ for room temperature applications, or CRYOPERM™ 10 for cryogenic temperatures, is particularly important in shielding against static magnetic fields. Ideally, a factory-annealed magnetic shield should be demagnetized after delivery to the location where the shield is installed. A recommended formula for cylinder demagnetization is:

$$H = \frac{N \times I}{C}$$

Where: H = Magnetization Field in A/cm; N = Number of coil windings along length of the cylinder; I = Current in Amperes, and C = Outer Circumference of the cylinder in cm.

Four-layer AMUMETAL hinged-door Magnetic Shield Assembly for SQUID Microscope (California Institute of Technology)

Using a VARIAC, the current should be ramped up slowly over 15

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