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Magnet Handbook

This guide has been developed to provide the fundamental basics of magnetic materials, their properties, methods of manufacture, and costing so that the user has adequate knowledge when deciding what type or grade of material should be used in various applications.

The main purpose of magnets is to help in the conversion of energy:

Mechanical to Electrical, such as in generators, sensors and microphones
Electrical to Mechanical, such as in motors, actuators and loudspeakers
Mechanical to Mechanical, such as for couplings, bearing and holding devices

With such importance and the complexities of devices utilizing magnets, they are a relatively easy material to understand. There are only four major types of permanent magnet materials:

NdFeB, Neodymium or Neo Rare Earth
SmCo, Samarium Cobalt
$SrFe_2O_3$, Hard Ferrites or Ceramics
AlNiCo, Alnico magnets

Then, there are only 4 major magnetic performance properties:

Br, Residual Induction. The magnetic flux that remains permanently in a magnet
Hc and **Hci**, Coercivity. The Susceptibility for demagnetization of the magnet
BH_{max}, Energy Product, The total energy stored in a magnet (BrxHc)
T, Temperature Stability. Reversible, irreversible, max working and Curie temps.

The Four Families of Permanent Magnets

	Ferrite	Alnico	SmCo		NdFeB			
Property	Ceramic 8	Alnico 5	REC-20	REC-26	B10N	N52	N45SH	N38EH
B_r (kG)	4.0	12.5	9.0	10.5	6.8	6.9	8.25	13.1
α (%/°C)	-0.18	-0.02	-0.05	-0.03	-0.12	-0.12	-0.12	-0.12
$(BH)_{max}$ MGOe	3.8	5.5	20	26	10	52	45	38
H_{ci} (kOe)	3.3	0.64	20+	10+	9	14.8	13.7	12.6
H_{ci} as temp falls	Worse	Better	Better	Better	Better	Better	Better	Better
H_s (kOe)	10	3	20	30	5.4	10.5	12.5	11.3
T_c (°C)	450	890	727	825	310	310	310	310
Electrical conductivity	Poor	Good	Good	Good	Poor	Good	Good	Good

Notes : The quantity α is the reversible temperature coefficient of B_r.
The field required to saturate is H_s.

Magnetic Materials Introduction

Ferrites Commonly known as Ceramics, have been in production since the 1950's. They are primarily made from Iron Oxide (FeO) and the addition of Sr and Ba through a calcining process. They are the least expensive and most common of all magnet materials. Primary grades are C1, C5 and C8. They are mostly used in motors and sensors.

Alnico These are one of the oldest commercially available magnets and have been developed from earlier versions of magnetic steels. Primary composition is Al, Ni and Co, hence the name. Although they have a high remanent induction, they have relatively low magnetic values because of their easy of demagnetization. However, they are resistant to heat and have good mechanical features. Common applications are in measuring instruments and high temperature processes such as holding devices in heat treat furnaces.

Samarium Cobalt They belong to the rare earth family because of the Sm and Co elements in their composition. Magnetic properties are high and they have very good temperature characteristics. They are also more expensive than the other magnet materials. They come mostly in two grades: $SmCo_5$ and Sm_2Co_{17}, also known as SmCo 1:5 and 2:17. Common uses are in aerospace, military and medical industries.

Neodymium Also known as Neo, these are the strongest and most controversial magnets. They are in the rare earth family because of the Nd, B, Dy, Ga elements in their composition. A relatively new group of commercial magnets, they are controversial because they are the only magnets that have been patented for both composition and processing. The patent and licensing issues are important and will be discussed later in this guide.

Bonded Magnets All of the above materials are available as bonded grades by either extrusion, compression, calendaring or injection molding processes. The magnetic properties are lower because they sometimes lose their anisotropy and they are not fully dense due to the introduction of resins and epoxies. The main advantage to this group is that they can be made in complex shapes and can be insert, over-molded and co-molded with other materials.

Magnetics Terminology

Ag Area of the air gap, or the cross sectional area of the air gap perpendicular to the flux path, is the average cross sectional area of that portion of the air gap within which the application interaction occurs, Area is measured in sq. cm. in a plane normal to the central flux line of the air gap.

Am Area of the magnet, is the cross sectional area of the magnet perpendicular to the central flux line, measured in sq. cm. at any point along its length. In design, Am is usually considered the area at the neutral section of the magnet.

B Magnetic induction, is the magnetic field induced by a field strength, H, at a given point. It is the vector sum, at each point within the substance, of the magnetic field strength and resultant intrinsic induction. Magnetic induction is the flux per unit area normal to the direction of the magnetic path.

Bd Remanent induction, is any magnetic induction that remains in a magnetic material after removal of an applied saturating magnetic field, Hs. (Bd is the magnetic induction at any point on the demagnetization curve; measured in gauss.)

Bd/Hd Slope of the operating line, is the ratio of the remanent induction, Bd, to a demagnetizing force, Hd. It is also referred to as the permeance coefficient, shear line, load line and unit permeance.

BdHd Energy product, indicates the energy that a magnetic material can supply to an external magnetic circuit when operating at any point on its demagnetization curve; measured in megagauss-oersteds.

(BH)max Maximum energy product, is the maximum product of (BdHd) which can be obtained on the demagnetization curve.

Bis (or J) Saturation intrinsic induction, is the maximum intrinsic induction possible in a material.

Magnetics Terminology

Bg Magnetic induction in the air gap, is the average value of magnetic induction over the area of the air gap, Ag; or it is the magnetic induction measured at a specific point within the air gap; measured in gauss.

Bi (or J) Intrinsic induction, is the contribution of the magnetic material to the total magnetic induction, B. It is the vector difference between the magnetic induction in the material and the magnetic induction that would exist in a vacuum under the same field strength, H. This relation is expressed by the equation:

$$Bi = B - H$$

Bi = intrinsic induction in gauss
B = magnetic induction in gauss
H = field strength in oersteds.

Bm Recoil induction, is the magnetic induction that remains in a magnetic material after magnetizing and conditioning for final use; measured in gauss.

Bo Magnetic induction, at the point of the maximum energy product (BH) max; measured in gauss.

Br Residual induction (or flux density), is the magnetic induction corresponding to zero magnetizing force in a magnetic material after saturation in a closed circuit; measured in gauss.

f Reluctance factor, accounts for the apparent magnetic circuit reluctance. This factor is required due to the treatment of Hm and Hg as constants.

F Leakage factor, accounts for flux leakage from the magnetic circuit. It is the ratio between the magnetic flux at the magnet neutral section and the average flux present in the air gap.

$$F = (BmAm)/(BgAg)$$

Magnetics Terminology

F Magnetomotive force, (magnetic potential difference), is the line integral of the field strength, H, between any two points, p_1 and p_2.

$$F = \int_{p2}^{p1} H \, dl$$

F = magnetomotive force in gilberts
H = field strength in oersteds
dl = an element of length between the two points, in centimeters.

H Magnetic field strength, (magnetizing or demagnetizing force), is the measure of the vector magnetic quantity that determines the ability of an electric current, or a magnetic body, to induce a magnetic field at a given point; measured in oersteds.

Hc Coercive force of a material, is equal to the demagnetizing force required to reduce residual induction, B, to zero in a magnetic field after magnetizing to saturation; measured in oersteds.

Hci Intrinsic coercive force of a material, indicates its resistance to demagnetization. It is equal to the demagnetizing force which reduces the intrinsic induction, Bi, in the material to zero after magnetizing to saturation; measured in oersteds.

Hd is that value of H corresponding to the remanent induction, Bd; measured in oersteds.

Hm is that value of H corresponding to the recoil induction, Bm; measured in oersteds.

Ho is the magnetic field strength at the point of the maximum energy product (BH)max; measured in oersteds.

Magnetics Terminology

Hs Net effective magnetizing force, is the magnetizing force required in the material, to magnetize to saturation measured in oersteds.

J, see Bi, Intrinsic induction.

Js, see Bis Saturation intrinsic induction.

lg Length of the air gap, is the length of the path of the central flux line of the air gap; measured in centimeters.

lm Length of the magnet, is the total length of magnet material traversed in one complete revolution of the center line of the magnetic circuit; measured in centimeters.

lm/D Dimension ratio, is the ratio of the length of a magnet to its diameter, or the diameter of a circle of equivalent cross-sectional area. For simple geometries, such as bars and rods, the dimension ratio is related to the slope of the operating line of the magnet, Bd/Hd.

P Permeance, is the reciprocal of the reluctance, R, measured in maxwells per gilbert.

R Reluctance, is somewhat analogous to electrical resistance. It is the quantity that determines the magnetic flux, f, resulting from a given magnetomotive force, F.

$$\boxed{R = F/\Phi}$$

R = reluctance, in gilberts per Maxwell
F = magnetomotive force, in gilberts
Φ = flux, in Maxwells

Magnetics Terminology

Tc, Curie temperature, is the transition temperature above which a material loses its magnet properties.

Tmax Maximum service temperature, is the maximum temperature to which the magnet may be exposed with no significant long range instability or structural changes.

Vg Air gap volume, is the useful volume of air or non-magnetic material between magnetic poles; measured in cubiccentimeters.

μ **permeability**, is the general term used to express various relationships between magnetic induction, B, and the field strength, H.

μ**re recoil permeability**, is the average slope of the recoil hysteresis loop. Also known as a minor loop.

Φ **magnetic flux**, is a contrived but measurable concept that has evolved in an attempt to describe the “flow” of a magnetic field. Mathematically, it is the surface integral of the normal component of the magnetic induction, B, over an area, A.

A closed circuit condition exists when the external flux path of a permanent magnet is confined with high permeability material.

The demagnetization curve is the second (or fourth) quadrant of a major hysteresis loop. Points on this curve are designated by the coordinates Bd and Hd

A Fluxmeter is an instrument that measures the change of flux linkage with a search coil.

The Gauss is the unit of magnetic induction, B, in the cgs electromagnetic system. One gauss is equal to one maxwell per square centimeter.

Magnetics Terminology

A Gaussmeter is an instrument that measures the instantaneous value of magnetic induction, B. Its principle of operation is usually based on one of the following: the Hall-effect, nuclear magnetic resonance (NMR), or the rotating coil principle.

The Gilbert is the unit of magnetomotive force, F, in the cgs electromagnetic system.

A Hysteresis loop is a closed curve obtained for a material by plotting (usually to rectangular coordinates) corresponding values of magnetic induction, B, for ordinates and magnetizing force, H, for abscissa when the material is passing through a complete cycle between definite limits of either magnetizing force, H, or magnetic induction, B.

Irreversible losses are defined as partial demagnetization of the magnet, caused by exposure to high or low temperatures external fields or other factors. These losses are recoverable by remagnetization. Magnets can be stabilized against irreversible losses by partial demagnetization induced by temperature cycles or by external magnetic fields

A keeper is a piece (or pieces) of soft iron that is placed on or between the pole faces of a permanent magnet to decrease the reluctance of the air gap and thereby reduce the flux leakage from the magnet. It also makes the magnet less susceptible to demagnetizing influences.

Leakage flux is flux, Φ, whose path is outside the useful or intended magnetic circuit; measured in maxwells.

The major hysteresis loop of a material is the closed loop obtained when the material is cycled between positive and negative saturation.

The Maxwell is the unit of magnetic flux in the cgs electromagnetic system. One maxwell is one line of magnetic flux.

Magnetics Terminology

The neutral section of a permanent magnet is defined by a plane passing through the magnet perpendicular to its central flux line at the point of maximum flux.

The Oersted is the unit of magnetic field strength, H, in the cgs electromagnetic system. One oersted equals a magnetomotive force of one gilbert per centimeter of flux path.

An open circuit condition exists when a magnetized magnet is by itself with no external flux path of high permeability material.

The operating line for a given permanent magnet circuit is a straight line passing through the origin of the demagnetization curve with a slope of negative Bd/Hd. (Also known as permeance coefficient line.)

The operating point of a permanent magnet is that point on a demagnetization curve defined by the coordinates (BdHd) or that point within the demagnetization curve defined by the coordinates (BmHm).

An oriented (anisotropic) material is one that has better magnetic properties in a given direction.

A permeameter is an instrument that can measure, and often record, the magnetic characteristics of a specimen.

Reversible temperature coefficients are changes in flux which occur with temperature change. These are spontaneously regained when the temperature is returned to its original point.

Magnetic saturation of a material exists when an increase in magnetizing force, H, does not cause an increase in the intrinsic magnetic induction, B, of the material.

Magnetics Terminology

A search coil is a coiled conductor, usually of known area and number of turns, that is used with a fluxmeter to measure the change of flux linkage with the coil.

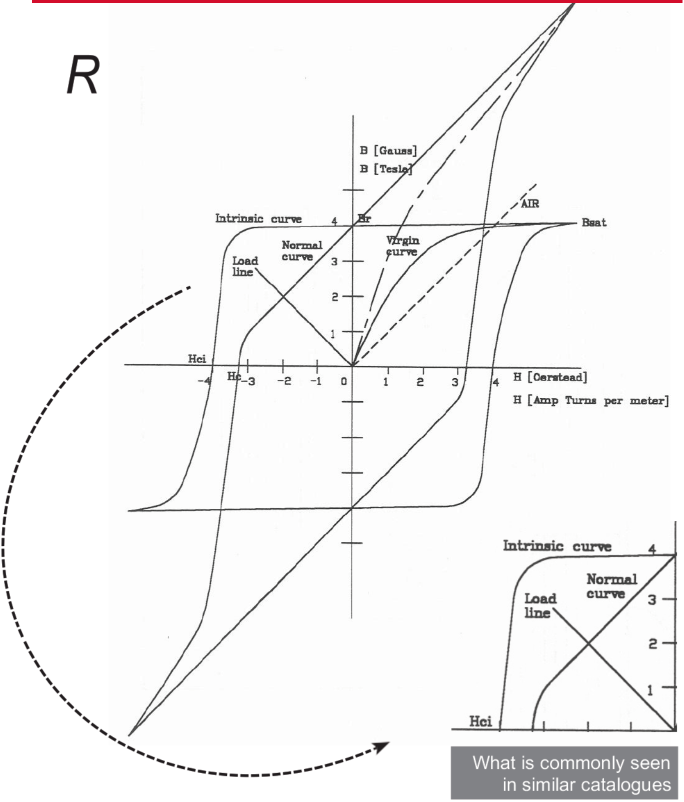
The temperature coefficient is a factor which describes the reversible change in a magnetic property with a change in temperature. The magnetic property spontaneously returns when the temperature is cycled to its original point. It usually is expressed as the percentage change per unit of temperature.

An unoriented (isotropic) material has equal magnetic properties in all directions.

Conversions

Designation	CGS	SI	Conversion
H	Oersted (Oe)	A/m	1A/m = 12.57 x 10^3 Oe
B	Gauss (G)	Tesla (T)	1 T = 10,000 G
Φ	Maxwell (M)	Weber (Wb)	1 Wb = 10^8 M
F	Gilbert	Amp-turn	1 A-t = 1.256 Gilbert
BH	MGOe	Joule/m^3	1 J/m^3 = .1257 x 10^6 GOe

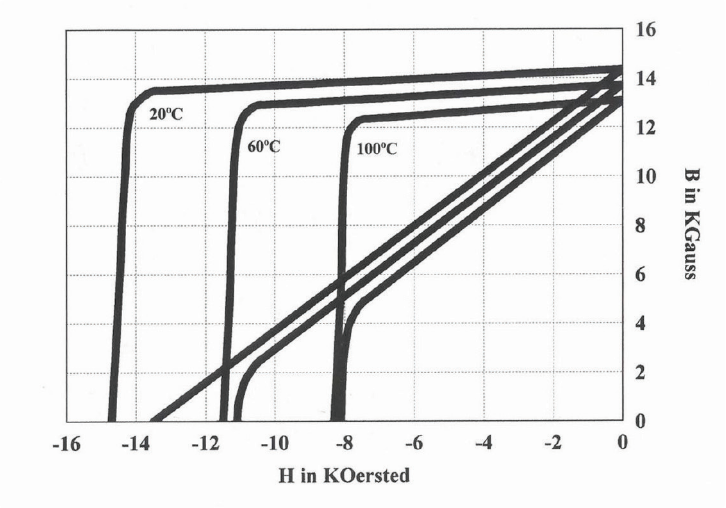
Hysteresis and Demagnetization Curves



What is commonly seen in similar catalogues

Our technical experts are on hand to help you understand the contents of this guide more thoroughly, please contact us for assistance using the details shown on the back cover

NdFeB Magnet Grade at Various Temperatures



NdFeB loses approximately 0.11 % Br for every degree C above 20°C
This is called the Reversible Temperature Coefficient.

Magnet Materials

Materials	Typical Shapes	Pro	Con
Cast Alnico AlNiCo	Rods, Bars, U shape and other cast type	High Br High working T Good T coef.	Very Low Hc High cost High L/D Requires Cast
Sintered Alnico AlNiCo	Powder pressed to shape	Complex shapes High Br, T	Requires Tool High cost Low market
Ceramic/Ferrite $SrFe_2O_3$	Blocks, Rings, Arcs, Discs	Most flux for $ High usage Low corrosion	Low Br Requires tool Simple shapes
Samarium Cobalt SmCo	Blocks, Rings, Discs Arcs, Segments	No corrosion Very low T coef Stable, No tool	Very expensive Simple shapes High Co content
Neodymium NdFeB	Blocks, Rings, Discs Arcs, Segments	Highest magnetic properties No tooling	Corrodes Low working T Difficult to Mag
Bonded Grades All materials	Difficult geometries Can be insert molded or overmolded	Complex shapes Various resins	High toolings Low magnetics High volumes

Highest Properties of Each Magnetic Material

Material	Br	Hc	Hci	(BH)max	ΔBr/ΔT
$SrFe_2O_3$	4000	3600	4100	4.0	-.18
Alnico 5	12700	640	650	5.5	-.02
Alnico 9	10500	1500	1520	10.5	-.02
$SmCo_5$	10000	9500	12500	24.0	-.03
Sm_2Co_{17}	11300	8000	>9000	28.0	-.03
NdFeB	14600	11750	>12000	54.0	-.11
NdFeB (AH)	12200	11800	>33000	38.0	-.11
MnAlC	5500	2500	>2500	5.5	-.11

- These materials do not include bonded types
- The greatest advances in magnetics are being done in the area of Neo
- Neo is becoming stronger and with a higher working temperature
- New methods of manufacturing are being developed

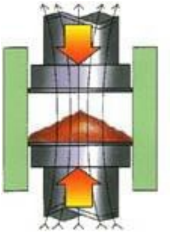
Manufacturing Process

Depending on the type of material, the following processes are used to manufacture permanent magnets:

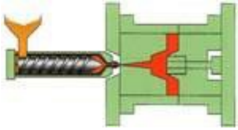
Sintering The sintering process involves compacting fine powders at high pressures in an aligning magnetic field, then sintering it into a solid shape. After sintering, the "ingot" is rough and must be machined to achieve close tolerances. The complexity of shapes that can be pressed using this process is limited. Neodymium and Samarium cobalt powders are compressed to form magnets by:

- **Isostatic pressing** The powder is compacted with the same force from all directions. These magnets have the highest possible magnetic values because of the higher density achieved using this technique.
- **Compressing in tools**:
  1. Transverse Field Pressing. The powder is compacted at right angles to the magnetic flux. These magnets have a weaker field compared to the isostatic pressed ones, but stronger compared to the parallel pressed magnets.
  2. Parallel Compressing. The powder is compacted parallel to the magnetic field.

Compression Molding This method is commonly used to make NdFeB magnets using melt spun Nd powders that are epoxy coated. The powders are compacted and then heat cured for the epoxy to perform the binding function. These magnets are typically isotropic.



Manufacturing Process



Injection Molding Neodymium, Samarium Cobalt, and Ferrite Materials can be manufactured by injection molding. Common binders for injection molding are polyamides. The advantage of using this method is the possibility to get a better tolerance directly from the tool with no required heat treatment, and the magnets can be produced in complex shapes. They can be combined with other materials for over-molding or insert molding.

Casting This process is used for manufacturing Alnico. Process is similar to the casting of other metals. Parts are formed in sand casts which can be complex.

Calendering and Extruding Flexible NdFeB and Ferrite magnets with Nitrile rubber binders are made using this method. The process is similar to that for vinyl sheets. Parts are later die cut or stamped from sheets of various thicknesses.

NdFeB Coatings

Properties	Organic: E-Coat	Metallic: Nickel Plating
Application Type	Immersion Electrodeposition Epoxy/ Urethane Water Based	Immersion Barrel Electroplate Electroless
Pretreat Process	Alkaline Clean Acid Etch/Passivate	Alkaline Clean Electroclean Acid Etch/Activate
Thickness	15-25 m (0.6-1.0 mil)	10-50 m (0.4-2.0 mil)
Uniformity (Flatness/Edges)	Excellent 20% Edge Loss	Good 50% Edge Gain
Durability	Good Pencil 2H-4H	Excellent 300-1000 V_{100}
Temp and Humidity at 85°C and 85% RH	250 Hours	Over 1200 Hours

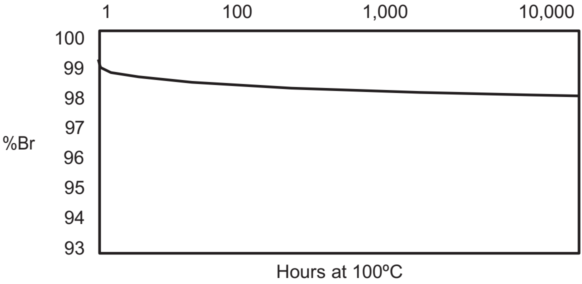
Things to consider when specifying coatings:

- Platings can be electroless Zn, Ni, Ni-Cu-Ni, Cu-Ni
- Must have 100% corrosion protection
- Protect against oxidation at high temperatures
- Encapsulate all magnetic particles
- Chip and crack resistance
- Determine functional properties: bonding of magnet, dielectric, oils
- Coatings will have different appearance. Epoxy coat can be many colors

Adverse Effects on Magnetic Performance

Time

The effect of time on modern permanent magnets is minimal. Magnets will see changes immediately after magnetization. These changes, known as “magnetic creep”, occur as less stable domains are affected by fluctuations in thermal or magnetic energy, even in a thermally stable environment. This variation is reduced as the number of unstable domains decreases. Rare Earth magnets are less likely to experience this effect because of their high coercivity. Studies have shown that a newly magnetized magnet will lose only a minor percent of its flux as a function of age.



Adverse Effects on Magnetic Performance

Reversible Losses

These are losses that are recovered when the magnet returns to its original temperature. Reversible losses cannot be eliminated by magnet stabilization. Reversible losses are described by the Reversible Temperature Coefficient, -%Br/°C, shown in the table below. These losses vary for different magnet materials and are not always linear as the temperature increases. For example, a NdFeB magnet with a -.11 reversible loss will have 11% less magnetic flux at 120°C than at 20°C.

Material	Tc of Br	Tc of Hc
Neodymium	-0.11	-0.60
Samarium cobalt	-0.03	-0.30
Ferrite	-0.18	+0.30

Reversible temperature coefficients of Br and Hc

Magnetic materials have a wide range of working temperatures. The following chart list the various materials and their maximum working temperature. NdFeB material comes in many different heat tolerances but as the heat tolerance increases the maximum available flux density decreases:

Material	Maximum Working Temperature	
	°C	°F
Ceramic	400	752
Alnico	540	1004
SmCo 1,5	260	500
SmCo 2, 17	350	662
NdFeB N	80	176
NdFeB M	100	212
NdFeB H	120	248
NdFeB SH	150	302
NdFeB UH	180	356
NdFeB EH	200	392

Machining of Magnets

Sintered Samarium Cobalt and Ferrite magnets exhibit small cracks within the material that occur during the sintering process. Provided that the cracks do not extend more than halfway through a section, they do not normally affect the operation of the magnet. This is also true for small chips that may occur during machining and handling of these magnets, especially on sharp edges. Magnets may be tumbled to break edges. This is done to avoid “feathering” of sharp edges due to the brittle nature of magnets and is also done for better adhesion of plating or coatings. Because of these inherent material characteristics, it is not advisable to use any permanent magnet material as a structural component of an assembly.

Sintered Neodymium, Samarium Cobalt and Ferrite magnets are machined by grinding, which may affect the magnet cost. Maintaining simple geometries and wide tolerances is therefore desirable from an economic point of view. Generally, tolerances less than 0.125mm will result in higher costs, regardless of the size of the part. Rectangular or round sections are preferable to complex shapes. Square holes and very small holes (less than 6.35mm) are difficult to machine and should be avoided.

Handling of Magnets

- Personnel wearing pacemakers must not handle magnets.
- Magnets should be kept away from sensitive electronic equipment and credit cards with magnet stripes.
- Modern magnet materials are extremely strong magnetically and somewhat weak mechanically. Therefore, packaging should be carefully considered.
- Any person required to handle magnets should be appropriately trained about the potential dangers of handling magnets. Training can be provided by Bunting.
- Injury is possible to personnel, and magnets themselves can easily get damaged if allowed to snap towards each other, or if nearby metal objects are allowed to be attracted to the magnets.
- Materials with low coercive forces such Alnico must be carefully handled and stored when received in a magnetized condition. When stored, these magnets should be maintained on a "keeper", which provides a closed loop protecting the magnet from adverse fields. Bringing together like poles in repulsion can lead to irreversible, although remagnetizable, losses.
- Samarium Cobalt magnets must be carefully handled and stored due to the extremely brittle nature in the material.
- Uncoated Neodymium magnets should be stored in a way to minimize the risk of corrosion.
- Magnetized magnets are considered Hazardous Materials when transporting by air and the stray flux must meet IATA guidelines.
- NdFeB materials, when in powder form, will self combust in air. Therefore, careful attention is required when handling this material.

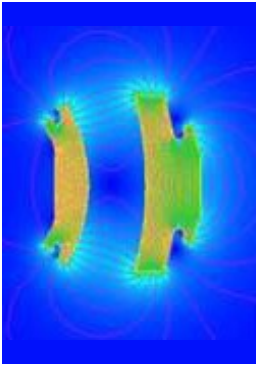
Bunting has many years of expertise in handling magnetic materials.
For any questions, please do not hesitate to contact us.

Full contact details for Bunting are inside the back of the handbook.

Magnetization Process

To make a magnet “magnetic” it must be exposed to a strong external magnetic field. This field reorganizes the magnet’s domain structure and leaves the magnet with a remanent magnetization (Br). If a magnet is isotropic, the remanent magnetization has the same direction as the external field. Meanwhile, an anisotropic magnet can only be magnetized in its anisotropy direction.

The most common method of magnetizing is to let a very short current pulse go through a conductor or a coil. The short pulse is generated from a magnetization machine, which is basically a powerful capacitor together with a controller. Different materials require different lengths of current pulse. The resistivity of a material provides a prediction of what the magnetization pulse should look like. A material with high resistivity can be magnetized with a pulse of a few micro seconds, while a more conductive material may need several hundreds of a second longer pulse. Also, the volume of a magnet is of importance for the length of the current pulse.



During the magnetizing process, Eddy Currents are produced in an electrical conducting material. Eddy Currents create a magnetic field which is in the opposite direction of the applied field.

Besides various pulse lengths, different materials need different strengths of the magnetizing field. Coercive force (intrinsic) is the property of the material that decides what magnetic field strength that is needed for the magnetization. Axial and diametrical magnetization can be made in standard inductors, i.e. solenoids. However, radial, multiple pole, or any other complex magnetization has to be done in a specially built magnetization fixture.

Magnetizing and Testing Equipment

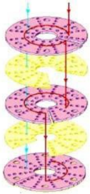
Magnetizers:

Capacitive Discharge

Direct Current

Half Cycle

Permanent Magnet

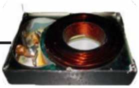


Fixtures:

Wire Wound Multipole

Solid Copper Plate

Wire Wound Solenoids



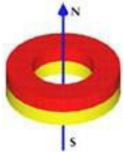
Testing:

Fluxmeter Coil

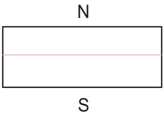
Gaussmeter

Permeameter

Magnetization Types



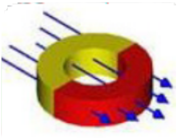
AXIAL



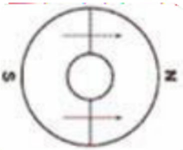
LATERAL

MULTIPOLE

RADIAL



DIAMETRAL



Testing Magnets

A test method or combination of test methods should be based upon the criticality of the requirement, and the cost and ease of performing tests. Ideally, the test results should be able to be directly translated into a functional performance of the magnet. A sampling plan should be specified which inspects the parameters that are critical to the application. Sampling plans can be found in the MMPA 01-100 guidelines.

Hysteresis, Permeameter, BH Curve

B-H curves describe the magnetic properties at a specific temperature. B-H curves may be plotted with the use of a Permeameter. In order to plot a B-H curve, a sample of a specific size must be used and then cycled through a magnetization/demagnetization cycle. This test is expensive to perform due to the length of time required to complete. The test is destructive to the sample piece in many cases, and is not practical to perform on a large sample of finished magnets. However, when magnets are machined from a larger block, the supplier may be requested to provide B-H curves for the starting raw stock of magnet material. The B-H test will essentially provide you the demag properties.

Total Flux

Using a test set up consisting of a Helmholtz coil pair connected to a Fluxmeter, total flux measurements can be made to obtain total dipole moments, and interpolated to obtain close estimates of Br, Hc, and BHmax. The inside diameter of the coils should be at least three times the largest dimension of the magnet for accurate results. The angle of orientation of the magnet can also be determined using this method. This is a quick, repeatable and reliable test, and one that is not overly sensitive to magnet placement within the coil.

Flux Density

Flux density measurements are made using a Gaussmeter and an appropriate probe. The probe contains a Hall Effect device whose voltage output is proportional to the flux density. There are two types of probes: Axial, which measures the flux parallel to the probe holder and Transversal, which measures the flux perpendicular to the probe holder. The position of the probe related to the magnet must be exactly the same between each sample. This can be simplified by using a fixing device.

Testing Magnets

Pull Force

The pull of magnets is proportional to B (flux density) squared. Variations in B occur due to variations in the inherent properties of the magnet itself, as well as environmental effects such as temperature, composition and condition of the material that the magnet is being tested on. Since B decays exponentially from a zero air gap, small inadvertently introduced air gaps between the magnet and the test material can have a large effect on the measured pull. It is therefore recommended that the test is performed with a small air gap. To achieve the best accuracy on the measurements, the test should be made with various air gaps.

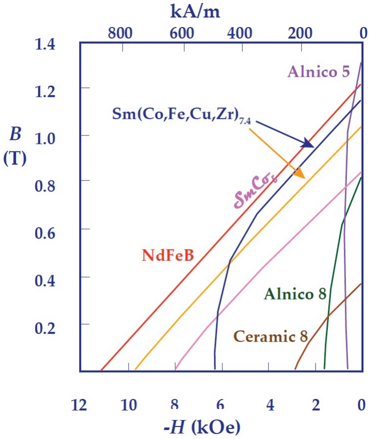


Figure 6 — Comparison of Rare Earth magnets with some older magnet types. B,H demagnetization curves of average commercial magnets.

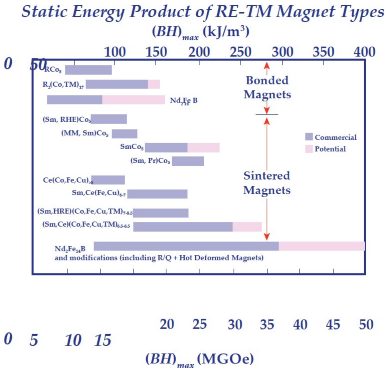


Figure 9 — Energy products available from different rare-earth magnet types in production in 1989.

Examples of the reversible behavior of the useful flux at elevated temperatures are given in Figure 10 for representative rare earth permanent magnets up to their respective limits of utility. As mentioned before, this temperature dependence can be reduced by judicious HRE alloying additions.

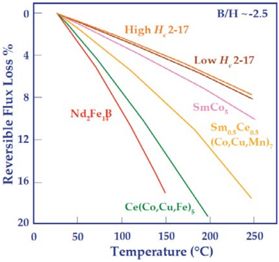


Figure 10 — Reversible flux versus temperature plots for several Rare Earth Permanent Magnet materials. (Measured in open circuit at B/H ≈ -2.5 after thermal pre-stabilization. D. Li et al., 1988.)

BUNTING LOCATIONS:

BUNTING - NEWTON
500 S. SPENCER ROAD
P.O. BOX 468
NEWTON, KANSAS 67114
USA

BUNTING - CHICAGO
1150 HOWARD STREET
ELK GROVE VILLAGE, IL 60007
USA

BUNTING - DUBOIS
12 INDUSTRIAL DRIVE
DUBOIS, PA 15801
USA

BUNTING - BERKHAMSTED
NORTHBRIDGE ROAD,
BERKHAMSTED, HERTFORDSHIRE, HP4 1EH
UK

BUNTING - REDDITCH
BURNT MEADOW ROAD, NORTH MOONS MOAT,
REDDITCH, WORCESTERSHIRE, B98 9PA
UK

BUNTING - CHINA
NORDIC INDUSTRIAL PARK CO., LTD.
A3 BUILDING, 89 JINCHUANN ROAD
ZHENHAI, NINGBO 315221
CHINA

Our technical experts are on hand to help you understand the contents of this guide more thoroughly, please feel free to contact us for assistance.

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