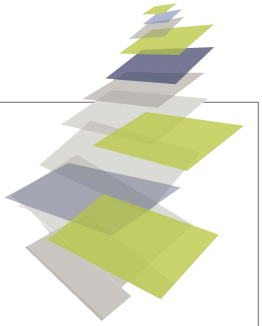

# Technical Paper

## Low Cost Method for Magnet Testing

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**Dexter at a Glance:**

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The Helmholtz coil test method is well suited to modern high coercivity magnet materials and can be implemented at relatively low cost. The theory behind the method is taught in physics books and has been presented in depth in numerous papers. This paper presents practical Helmholtz coil design and test techniques in a “cookbook” manner to promote their use.

### Why Test Magnets?

Modern high coercivity magnet materials have essentially a linear B vs. H relationship in a second quadrant plot. This means that they will recoil to the Br point if inserted into a closed magnetic path, or yoke. The practical significance of linear B vs. H is that magnets made from these materials may be charged prior to assembly without a magnetic penalty. This is fortunate since large assemblies and many newer magnet arrangements would be impossible to magnetize after assembly. Magnets for large spectrometers, focused flux assemblies and those which derive performance from continuous rotation of magnetic vectors must be magnetized and measured prior to assembly to realize their full potential. Multipole devices, such as motors and torque couplings, also perform better with magnets matched on the basis of test data.

The need for testing stems from the same factors that give these materials their desirable magnetic properties. Small particle size, high press pressures, strong orienting fields and critical heat treat cycles are needed to manufacture the magnets.

The best materials push the processes to the limits so variations can be expected. While all parties involved have an interest in keeping variations within published limits on a statistical basis, it is no wonder that properties vary from magnet to magnet and lot to lot. Magnet materials are also improving year after year, and unless this is recognized and compensated for, the performance of some devices may actually suffer.

Furthermore, high energy magnetizers and special magnetizing fixtures are needed to saturate the magnets. The high energy pulse heats the magnetizing coil and will result in less energy available for magnetization, or may damage the coil.

Testing magnets provides a benchmark for indication of these problems.

### Magnet Properties

Helmholtz coil output is proportional to the magnetic moment of the sample and the number of turns in the coil. The magnetic moment is defined as the intrinsic flux density per unit volume. It is a fundamental property of magnetic materials and is proportional to the product of pole strength, i.e. total polar flux, times the interpolar distance. If the unit of flux is the Maxwell, and length is in centimeters, the unit for the magnetic moment will be Maxwell–centimeters. This unit matches the units of the definition if intrinsic flux density, measured in Maxwells per square centimeter (Gauss), is multiplied by the volume in cubic centimeters.

Since the coil output is proportional to intrinsic flux density, all magnetic parameters for the magnet may be derived from the reading. The derivation is given later.

### Brief Helmholtz Theory

The Helmholtz coil magnet measuring system works on the basis of reciprocity; if a current (I) in a coil produces a specific axial magnetic field, then introducing that field to the coil will cause the current (I) to flow. The basic calibration constant is then amperes per gauss and it can be measured with a magnetometer to great accuracy. This calibration constant can also be calculated precisely, and reading accuracy will be better than one percent if reasonable care is used in making the coil.

The Helmholtz coil is much larger than the volume used for the test. It is composed of two identical layer wound coils with a specific geometry; the mean radius is equal

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to the mean coil spacing. When the coil is driven, this geometry results in a large volume in which uniform conditions exist. The same mathematics show that magnet placement during test is not extremely critical since each coil sees the net effect of both poles of the magnet. If the magnet is closer to one coil, that coil is cut by more flux, while the other coil is cut by less. However, the total flux seen by the two coils remains constant so long as the magnet is reasonably close to the center of the coil system.

### Fluxmeter Considerations

A fluxmeter is basically an integrating voltmeter. Since voltage is proportional to total flux and the number of turns per coil, the meter is scaled to display the Maxwell–turn product. To minimize fluxmeter drift and obtain reliable, repeatable readings, the Helmholtz coil should be designed to produce an output that will drive a fluxmeter to within a decade of the center of its reading range. The meter literature or manufacturer can help identify this value. This output should be produced when the typical magnet to be tested is rotated 180 degrees in the coil. Most meters will then perform well with inputs plus or minus two decades of the central value, which allows the coil to function with a broad range of magnet sizes and materials. When readings go beyond this central four decade range another coil size should be used.

A factor in favor of working on lower meter scales, using fewer coil turns, is reduced noise pickup. Some users with high turn coils and/or noisy environments have had to use two separated Helmholtz coils connected in series opposition for noise cancellation. The second coil must be located so it is not influenced by the magnet under test. When the coil produces very low outputs it may be necessary to orient the coil to null the influence of ambient fields, including that of the earth.

A Magnetic Instrumentation model 7387 was used in this work, but most modern fluxmeters will work well with the system described here. Equivalent models made by RFL, Steingroever, and Walker Scientific are good alternatives. External BCD output and reset jacks can be used to automate the test sequence and capture data for SPC analysis. Beware of meters that digitize and sum the analog coil signal to eliminate drift; the theory is good, but they are rate and threshold sensitive. Peak reading capability and decades for input of the area-turn product are nice features but they are not required for the test system described here.

### Making a Helmholtz Coil

Physically the Helmholtz coil is a pair of identical coils connected in series. The geometric relationship is precise; the mean radius of the coil bundles is equal to the mean coil spacing. For best performance, neither the width nor depth of the wound coil cross section should exceed 1/5 of the coil radius and the coil diameter should be at least 3 times the largest dimension of the part to be tested.

Fortunately, schedule 40 PVC pipe couplings have a geometry which makes them ideal and inexpensive coil form stock. With the information given above and some luck a useful and valid Helmholtz coil could be produced. However, planning the coil size so the output matches the fluxmeter mid-range will optimize performance. To select the proper geometry and calculate the coil constant the following information is needed:

- Typical magnet volume, cubic inches.
- Br of magnet material in Gauss.
- Mid-range of the fluxmeter.

Then as a first approximation:

$$\frac{\text{Br} * \text{Volume}}{\text{Meter mid-range}} * 18.5 = \frac{\text{Coil diameter}}{\text{Coil Turns}}$$

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Example:

16 MGOe SmCo Magnet disk
Br = 8200 gauss
Diameter = .500 inch
Length = .186 inch
Volume = .0365 cubic inch
Meter mid-range = 5 * 1e4
Diameter/turns = .11

PVC pipe coupling sizes are stated as the ID of the pipe they couple, so the mean diameter of a coil wound on them will be about 20 percent larger. Any PVC pipe coupling from 1.5 inch on up could be used for this coil. As an example, a 4 inch coupling allows a 4.8 inch mean coil diameter, and 50 turns of layer wound 22 AWG magnet wire per coil works well (5 layers of 10 turns). Slots for wire bundles can be cut on a lathe. The wire size is not critical but it should be large enough to keep resistance low. An odd number of winding layers should be used so the leads exit on opposite edges of the coil. The coil inner edge leads are then connected in series and the outer edge leads are trimmed and terminated with a convenient length of twisted pair and a banana plug.

### CALCULATION CONSTANT

From the foregoing information it can be seen that some constant relates coil output directly to the intrinsic flux density of the magnet. For the mixed units of gauss and inches the constant is:

$$.0541532 * \frac{\text{Coil diameter, mean}}{\text{Coil Turns}}$$

For example:
.0541532 * 4.8 / 50 = .0052

$$\text{Then: Bd (i)} = \text{Constant} * \frac{\text{MRR}}{\text{Part vol, cu in}}$$

Where MRR = Meter reading times the range. For the example a meter reading of 56.5 on the 1e3 range would be expected.

This constant can be confirmed or determined empirically with calibrated magnets, or by driving the coil with a DC power supply and measuring the induced field intensity with a magnetometer. The ratio of current to flux density is divided by 26.081 to obtain the calculation constant.

Where 26.081 = .0254^3 / (2e-7 * pi)

For the example 135.6 mA / gauss would be expected.

Calculated constants were within .5 percent of measured constants for all coil sizes we have made to date, from 1.5 inches to 24 inches diameter.

### MEASURING A MAGNET

1. Select a work area with a nonmagnetic table top away from magnetic materials or strong magnetic fields.
2. Place the coil on the table with an open end up.
3. Plug the Helmholtz coil into the fluxmeter.
4. Turn the fluxmeter on and let it warm up. Modern fluxmeters draw little power so it would be reasonable to leave them on all day to minimize instrument drift when testing parts.
5. Place a non-magnetic platform in the coil so the magnet will rest approximately at the mid-plane of the coil with the magnetic axis of the magnet in line with the coil axis.
6. Set fluxmeter switches to “normal”.
7. Set range switch as required for an on scale reading.
8. Adjust the drift control for a stable reading.
9. Place the magnet to be tested on the center of the platform.
10. Press the “Zero” or “Reset” button on the fluxmeter before each test. Note any residual reading (offset). (Fluxmeters may or may not reset exactly to zero).
11. Turn the magnet over.

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12. Note the fluxmeter reading. Try to work with positive readings.
13. Record the difference between the reading and any offset.
14. Record the fluxmeter range and the coil constant for each group of magnets tested.

The measurement technique described in this paper utilizes magnet rotation for best accuracy. This method reads the magnetic moment twice, and thereby averages out the "hot pole—cold pole" effect sometimes seen when the extraction method is used.

The extraction method is taught by most reference texts and may be used here, but the net reading must be doubled in the calculations described here. With the extraction method, step 11 above becomes "Move the magnet to a location where it no longer influences the fluxmeter reading." This will typically be 3 or more coil diameters away.

### CALCULATIONS

All magnet parameters are derived from the intrinsic flux density, Bd(i), using the recoil permeability and permeance coefficient values.

Bd(i) = constant * reading * range / volume of magnet.

Recoil permeability is found in published data for each grade of material. The permeance coefficient value, B/H slope, or load line, is determined by calculation from magnet geometry.

The permeance coefficient (PC) of a magnet is the value of the tangent of a line from the origin of the second quadrant curve, where B and H equal zero, through a point on the normal curve known as Bd and Hd. The value of recoil permeability, "Ur", is also the value of the slope of a line; Ur passes through the Bd, Hd and the Br, H = O points. These lines intersect at the Bd and Hd points so all other values can be calculated if the magnet is operating above its "knee" and the Bd, Hd, Ur and PC values are known.

The association of the permeance coefficient with the Bd, Hd operating points on the normal second quadrant curve implies that the PC is a magnet property. It is only a statement of how the geometry of a discrete magnet, or magnetic circuit influences the ratio of Bd to Hd.

PC = k * Lm / A * SQRT (pi * S/2)
K = 1.0 for ferrite, RECo, NdFeB, etc.,
0.7 for Alnico
Lm = magnetic length
A = area normal to Lm
S = surface area of magnet

For the example given earlier:
Ur = 1.04 (From published data)
P.C.= .982

All other parameters derive from the following:
Bd(i)= constant * MRR / volume
Br = Bd(i) * (Ur + PC) / (PC + 1)
Hd = Bd(i) / (PC + 1)
Bd = Bd(i) – Hd
MGOe(max) = Br^2 * 1e – 6/(4 * Ur)
Bd * Hd = Bd * Hd * 1e – 6
Hc(SL) = Br / Ur
MM= BD(i) * volume * 2.54^3

For the example:
Bd(i)= 8045 = .0052 * 56.5 * 1e3/ .0365
Br = 8207 gauss, residual flux density
Hd = 4057 Oe, operating point, normal
Bd = 3988 gauss, operating point, normal
MGOe(max) = 16.2 Mega Gauss- Oersteds,
(material energy product)
Bd * Hd = 16.2 Mega Gauss- Oersteds,
(operating energy product)
Hc(SL) = 7891 est of material coercivity
(straight line)
MM= 4815 Maxwell-Cm

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Note that the "straight line" value of Hc is calculated; the actual Hc will be different if the material has a "knee" in the second quadrant plot.

### TESTING UNKNOWN MAGNETS

When testing an "unknown" material an estimate of length factor and recoil permeability must be made. This requires some basic assumptions but mistakes are usually very apparent. First, does the material have low or high coercivity? If Helmholtz readings are reduced after two magnets are pushed together in opposition, the coercivity is low. If it is very difficult to get two like poles close to each other, the coercivity is high.

For high coercivity materials, the length factor is 1.0 and a recoil permeability of 1.1 can be tried. The recoil permeability for ceramic, rare earth and neodymium magnets falls in the narrow range of 1.02 to 1.15, so results using 1.1 should produce results within +/- 5 percent.

Low coercivity materials have a wider recoil permeability range. Readings and calculated parameters are also heavily influenced by where the P.C. intersects the second quadrant curve. If the intersection is below the "knee" of the normal curve, special techniques must be used, or test data will be only relative. Relative data allows grading based on comparison of readings with those of magnets known to be "good" or "bad" in an application.

Even some high coercivity magnet materials have a "knee" in their second quadrant curve. Check published curves at the operating temperature if the calculated PC is less than 1. Whenever the calculated load line intersects the normal second quadrant curve of a known material below the knee, or if the PC seems low for an unknown material, a "stack" test should be run.

### STACK TEST

The stack test is run on a sample composed of several magnets. This increases the total magnet length and the "Length / Area" ratio to cause the PC to intersect the normal curve above the knee. The test stack should be magnetized as a unit if possible. Stack, magnetize and measure the full stack first and then measure again after removing one magnet at a time.

When high coercivity magnets are stacked together they simulate a single longer magnet with a higher PC. When the stack is shortened the PC and the Bd decreases while the Hd increases. The second quadrant curve can be plotted by connecting data points obtained from a successively shorter stack of magnets. The line can be extended up to the vertical axis, where H = O, to find "Br". Extending the line to the horizontal axis, where B = O, has meaning only if the material has no knee in its second quadrant curve, then it represents the value for "Hc".

### FLUXMETERS VERSUS GAUSSMETERS

Close fitting search coils and Helmholtz coils measure properties of the whole magnet and readings are very repeatable. By contrast, gaussmeter test results are repeatable only when the probe is in a fixed relationship to a specific spot on a magnet. Gaussmeter readings are also difficult to relate to actual unit magnet properties unless complex fixtures are used.

### MAGNETIC LENGTH

Helmholtz coils readings are proportionate to the magnetic moment of the sample. The magnetic moment is a very precise quantity representing the product of pole strength and magnetic length of the sample. Pole strength is a measure of total flux at the pole; magnetic length is NOT the same as physical length.

We have been taught to use physical length as magnetic length in highly coercive materials (ferrite, RECo, NdFeB) and .7 times physical length when dealing with Alnicos. Actual magnetic length varies from about

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0.7 times the physical length in long and/or low coercivity magnets to .9999 times the physical length in short and/or high coercivity magnets, and may vary with the level of magnetization.

Magnetic parameters calculated from Helmholtz readings are quite accurate and repeatable when a magnet is saturated, operating above its “knee”, and correct assumptions about magnetic length are made. In fact, parameters obtained from Helmholtz readings are often more repeatable than those taken with a permeameter because the latter suffers from small physical air gaps between the pole pieces and the ends of the sample. This makes precise reproduction of plots on the same permeameter difficult, and a variety of instruments may give a variety of answers.

Because Bd(i) is obtained by dividing the magnetic moment by the volume of the sample, it is possible to evaluate this parameter for samples with irregular shapes with the Helmholtz system. Where shape is very complex, the sample volume may be obtained by volumetric displacement of a liquid, or by dividing weight by published density in pounds/cubic inch. Magnetic orientation may be found by rotating the sample for peak readings, or deduced from the vector sum of a series of orthogonal measurements with respect to some defined fiducials or surfaces. So, even if the magnetic length cannot be determined precisely, magnet quality can be judged on the basis of comparative Bd(i) values.

## SUMMARY

Helmholtz coil testing of permanent magnets is a convenient, low cost way to insure consistent and balanced device performance. The coils are easy to design, produce and calibrate. While calculations are simple, raw coil data can be used without further interpretation to monitor relative magnet quality and performance of magnetizing equipment. The coils can also be used for evaluation of off axis flux components in magnets for complex devices.

## REFERENCES

1. Ference, Lemon and Stephenson, “Analytical Experimental Physics”, University of Chicago Press.
2. D. L. Martin, “Permanent Magnet Characterization Measure-ments”, G.E. Technical Informa-tion Series Nbr 81CRD086, May 1981.
3. Nelson, Barale, Green and VanDyke, “The Lawrence Berkley Laboratory Magnetic-Moment Sorting System”, 9th Internati0nal Conference on Magnet Technology, Zurich, September, 1985.