Lake Shore CRYOTRONICS
a DwyerOmega brand

Measuring Permanent Magnet Characteristics with a Fluxmeter and Helmholtz Coil

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General

Measurement of magnetic moment with a fluxmeter and a Helmholtz coil is a convenient way to test permanent magnet materials. Other values such as operating flux density (B_d), operating field strength (H_d), coercive force (H_c), residual flux density (B_r), and maximum energy product (BH_{max}) can be derived from the measured moment value. Although this method is not as accurate as hysteresisgraph measurement, the measurement process is easy, values are useful and reliable, and equipment cost is substantially less.

Making the Moment Measurement

Features of Lake Shore's Model 480 Fluxmeter and Helmholtz coil simplify the measurement process. The Model 480 Fluxmeter automatically retrieves coil resistance and Helmholtz constant from a PROM in the coil connector at power-up. Only two fluxmeter settings are needed: RANGE and selection of units in MOMENT = weber·centimeters.

When used with a Helmholtz coil, a fluxmeter provides a value for the magnetic moment of a test sample when the magnet is placed between the coils in alignment with the coil axis and rotated 180 degrees or withdrawn. The Model 480 easily accommodates magnetic moment measurement with single sample extraction, double extraction with sample rotation, or rotation of the sample within the coil. Reliable measurement is more a function of consistent adherence to a documented test procedure and operator comfort with the measurement method than selecting a superior test method. Record this value for use in subsequent calculations. The fluxmeter and Helmholtz coil can also be used with a non-magnetic sample fixture to ensure consistent testing of samples in series.



Model 480 Fluxmeter



FH-6 Helmholtz Coil

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Recoil Permeability and Permeance Coefficient Values

In addition to the measured magnetic moment value, recoil permeability (μ_{rec}) and permeance coefficient (B_d/H_d) values for the tested magnet are required for subsequent calculations. Recoil permeability is available from the magnet vendor specification sheet. Permeance coefficient is a function of magnet geometry such as length and diameter. The specific permeance coefficient for a particular magnet can be obtained from published equations or charts; for example, see Rollin J. Parker's *Advances in Permanent Magnetism* (John Wiley and Sons, 1990). The magnetic length used in these formulas is not always the physical length of the magnet. For constant cross-section, high coercivity magnets, magnetic and physical lengths can be assumed to be equal. For alnico magnets, magnetic length is about 70% of the magnet's physical length.

Figure 1 is a graphical representation of the formulas that follow:

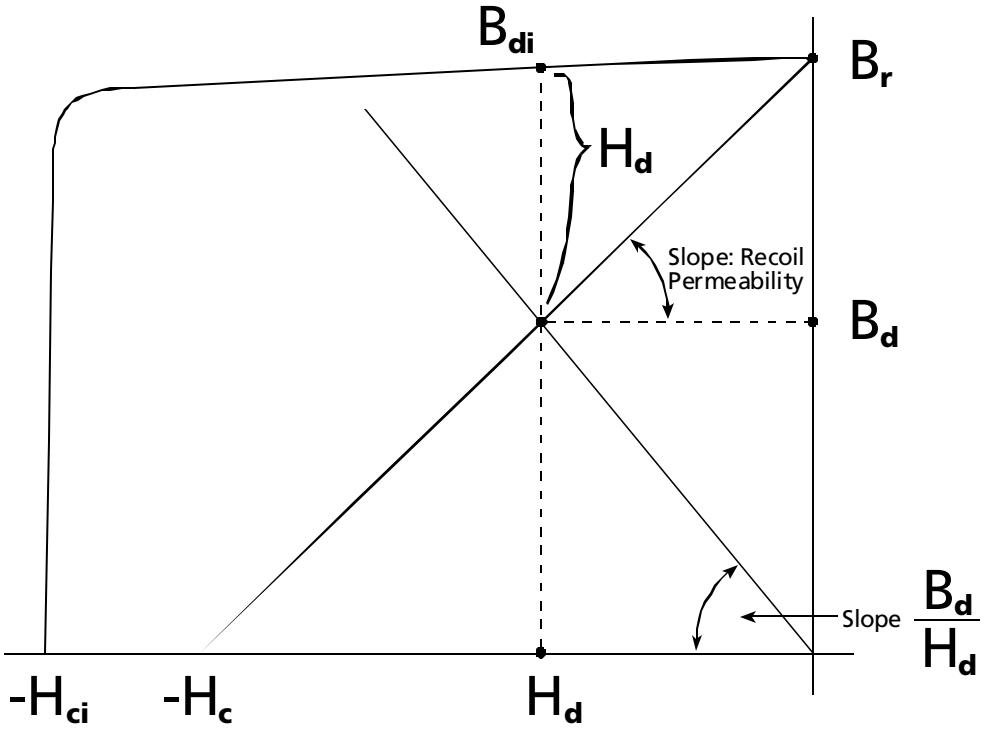


Figure 1: The second quadrant

Deriving Intrinsic Flux Density

The magnetic moment of interest in permanent magnet testing is generally defined as the intrinsic flux density per unit volume of magnet. Based on the magnetic moment measurement and measured magnet volume, intrinsic flux density, B_{di}, can be calculated.

$$B_{di} = \frac{\text{Moment}}{\text{Volume}} = \frac{\text{weber} \cdot \text{cm}}{\text{cm}^3} = \frac{\text{weber}}{\text{cm}^2}$$

For convenience in calculations, convert webers per cm^2 to gauss:

$$B_{di} = \frac{\text{Moment}}{\text{Volume}} = \frac{\text{weber} \cdot \text{cm}}{\text{cm}^3} \times 10^8 = \text{gauss}$$

Calculate Normal Operating Point (Field Strength)

$$H_d = \frac{B_{di}}{(\text{PermeanceCoeff} + 1)} \qquad \textit{(oersteds)}$$

Calculate Normal Operating Point (Flux Density)

$$B_d = B_{di} - H_d \qquad \textit{(gauss)}$$

Calculate Residual Flux Density

$$B_r = \frac{B_{di}(\text{RecoilPerm} + \text{PermeanceCoeff})}{(\text{PermeanceCoeff} + 1)} \qquad \textit{(gauss)}$$

Calculate coercive force (straight line approximation)
This value will be inaccurate if the magnet material exhibits a substantial knee in the second quadrant.

μ_{rec} = Recoil Permeability

$$H_c \cong \frac{B_r}{\mu_{rec}} \qquad \textit{(oersteds)}$$

Calculate Magnet Maximum Energy Product

$$(BH)_{max} = \frac{B_r^2}{4\mu_{rec}} \qquad \textit{(gauss•oersted)}$$

Example
Actual measured and calculated values for a grade 27 neodymium-iron-boron magnet are shown below. The magnet is 0.375 inches in diameter by 0.125 inches long for a magnet volume of 0.226 cm^3.

The vendor values are:
H_c = 9650 oersteds
B_r = 10850 gauss
BH_{max} = 27 x 10^6 gauss•oersteds
Recoil Permeability = 1.1

Based on a length to diameter ratio of 0.333, the permeance coefficient is 0.861.

Using a Model 480 Fluxmeter and FH-6 Helmholtz coil, the sample's magnetic moment is measured:

m = 23.26 μ weber•cm

B_{di} = [23.26 x 10^{-6} wb•cm / 0.226 cm^3] x 10^8 = 10,292 gauss

H_d = 10,292 / (0.861 + 1) = 5530 oersteds

B_d = 10,292 – 5530 = 4762 gauss

$B_dH_d = 26.33 \times 10^6$ gauss•oersteds (operating energy product)

$B_r = [10{,}292\ (1.1 + 0.861)] / (0.861 + 1) = 10{,}845$ gauss

$H_c \approx 10845 / 1.1 = 9859$ oersteds

Designing and Fabricating a Helmholtz Coil

Lake Shore's Helmholtz coils are easy to use and include factory calibration. For applications where local fabrication of a coil set is preferred, design parameters to construct, wind, and calibrate a Helmholtz coil are included here. Final coil diameter is often determined by available materials. Engineering plastics are very expensive for coil diameters exceeding 4 inches. Some heavy schedule PVC drainpipe can be adapted to construct a double coil form. Figure 2 illustrates design rules relative to coil and test sample size.

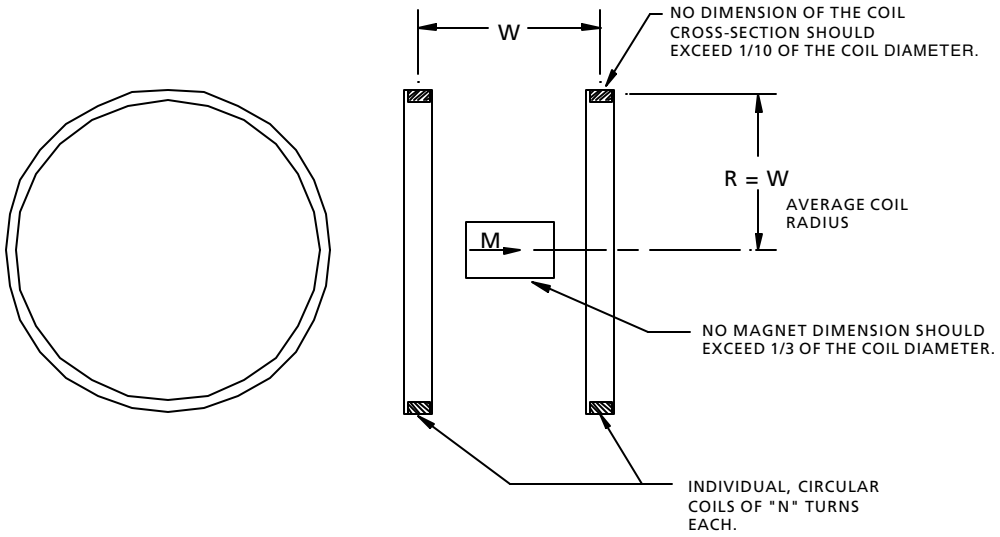


Figure 2: Helmholtz coil design rules

The Helmholtz coil constant, K, for a locally fabricated coil can either be calculated using the following formulas or measured. The calculated value offers accuracy of 5 to 10% when the coils are wound with normal care. Helmholtz constants are expressed in weber·centimeters per volt·second, which can be reduced to centimeters; the Model 480 Fluxmeter is designed for input of the Helmholtz coil constant in centimeters.

N = Number of Turns in Each Coil

R = Average Coil Radius

If "R" is in centimeters,

$$K = 1.397\frac{R}{N} \qquad \text{(cm)}$$

If "R" is in inches,

$$K = 3.548\frac{R}{N} \qquad \text{(cm)}$$

For greater accuracy, the Helmholtz constant can be derived from a gaussmeter reading of the magnetic field generated when a DC current is applied to the coil. CAUTION: Ensure that the applied current does not exceed the rating for the size of the coil wire. Accuracy depends on the instruments used and the care taken in orienting the gaussmeter probe in the center of the coil set. Accuracy to better than 1% is possible. Accurate measurement of the field generated per current supplied results in a value sometimes referred to as coil sensitivity. If coil sensitivity is expressed as gauss per ampere,

$$K = \frac{1.256}{\text{coil sens.}} \qquad \text{(cm)}$$

If the coil sensitivity is in millitesla per ampere,

$$K = \frac{0.1256}{\text{coil sens.}} \qquad \text{(cm)}$$

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