Theory

To understand which effects are studied in this lab, the formulae used will be expanded on, to explain the individual variables and their meaning. Firstly, in ferromagnetic materials, the unpaired electron spins line up parallel with each other over small volumes called domains. The electron spins produce a magnetic field and as a result each domain acts like a magnet. Domains, which vary in size, are generally not aligned with each other so a sample of ferromagnetic material normally produces no net magnetic field. An external magnetic field can cause the magnetic domains to line up with each other. The sum of the internal magnetic fields which come from the alignment of the electron spins can be stronger than the external magnetic field which produces the alignment. The effective multiplication of the external field produces a net field which is often expressed in terms of the relative permeability μ_r.

$$\mu_r = \frac{B}{H * \mu_0} \qquad (1)$$

Therefore, the magnetic permeability describes the relative increase or decrease in the net magnetic field of a magnetized object in an external magnetic field.

where μ_0 is the relative permeability of a vacuum which is $1.25663706212*10^{-6}$ +- $1.5*10^{-10}$ H/m and H is the magnetic field strength in units A/m. For a vacuum $\mu_r = 1$ (relative to itself of course), and μ_r is roughly 1 for any non-ferro magnetic material. However, μ_r can range widely for ferro magnetics like iron or steel. However, the change in the magnetic field is also dependent on the magnetic history of the sample and not only on H. If we start with an unmagnetized ferromagnetic core and apply an increasing H, by increasing I, the induced magnetic field (= B in units of Tesla) will follow the initial magnetization curve. If the current in the magnetizing coil is then reduced to zero, some domains remain aligned and the field at this point is called the remanence (= B_r) and is the reason why when turning off the power the iron sample was hard to remove from the yoke during the experiment. For this reason, remanence is also called residual magnetism and it is the reason why magnetic hard disk drives work. To reduce the magnetization to zero the current must be reversed to produce a negative H value H_c the coercive force. If enough domains have been reversed to cancel the effect of those aligned, then the material is demagnetized again. The coercive force describes the ability to resist this reversing of domains. H_c is the intensity of a magnetic field required to make these changes. If the current is periodically reversed the material will follow the hysteresis loop.

This cyclic behaviour is called hysteresis and results from a kind of internal friction as the domains change. As the domains are changed energy is lost to heat. It can be shown that the heat produced with each complete cycle, in $J*m^{-3}$, equals the area of the loop. The power dissipation in the sample is therefore given by the product of the area of the hysteresis loop, the volume of the sample being magnetized V (= volume using the magnetized length and cross-sectional area), and the frequency f with which the loop is cycled.

$$P = A * V * f \qquad (2)$$

The power loss P is in units of J/s or Watts. “A” represents the area within the hysteresis loop and f is in Hz or 1/T if T is the period of each cycle measured in seconds.

The shape of the hysteresis curve and the size of B_r and H_c determine a material's suitability for an application. For example, to make a permanent magnet or for use in magnetic memory (hard drive or magnetic strip on a credit card) a large H_c is desirable so that the material is not easily demagnetized. For generators, motors, and transformers the hysteresis curve should be tall and thin indicating that powerful magnetic fields are obtained with small magnetizing currents and H_c values are small so that the field is easily reversed. The small loop area is indicating low energy loss.

$$H = \frac{n_1}{L * S} * V_s \qquad (3)$$

The voltage Vs is the source voltage in V, and its resistance is S in ohm. Eq. 3 holds true assuming the material of the core is the same everywhere. L is the magnetized length of the material which amplifies the field. In the case of the iron same the magnetized length goes through the yoke as well because it too is made of iron. Therefore, the magnetized length for steel and iron varies greatly. n_1 is the number of turns for the first coil wrapped around the yoke.

$$B = \frac{R * C}{n_2 * A_c} * V_c \qquad (4)$$

Eq. 4 is used to calculate the induced magnetic field B. R is the resistance of the resistor in the circuit in ohm and C is the capacitance of the capacitor in Farad. n_2 represents the number of turns for the second coil wrapped around the sample material. A_c is the cross-sectional area of the sample which is calculated using measurements of height and width of the sample.

To calculate errors of measurements and when adding values with error in the form of z = x + y the following equation is used to propagate the error of x and y.

$$\Delta z = [(\Delta x)^2 + (\Delta y)^2]^{1/2} \qquad (5)$$

Delta z is the new absolute error of the sum of x and y. Delta x and y are the absolute errors of x and y. To propagate errors with calculations involving multiplication and division the following equation is used.

$$\frac{\Delta z}{z} = [\frac{\Delta x^2}{x^2} + \frac{\Delta y^2}{y^2}]^{1/2} \qquad (6)$$

This equation gives the relative error for z when z = x*y. INSERT also uses the relative error for x and y by dividing the absolute error by its value.