EEC Terminology Guide

1:5 --- An intermetallic compound comprised of two or more elements including Sm and Co. "1:5" is the atomic ratio between rare earth elements (Sm and Gd) and the transition metal, cobalt.

2:17 --- An intermetallic compound comprised of five or more elements including Sm, Fe, Cu, Zr, and Co. "2:17" is the atomic ratio between rare earth elements (Sm and Gd) and the transition metals including Fe, Cu, Zr, and Co.

Air gap --- A non-magnetic discontinuity in a ferro-magnetic circuit. For example, the space between the poles of a magnet, even if the space is filled with brass or wood or any other non-magnetic material, is nevertheless called an air gap.

Anisotropic --- Having properties which are dependent upon direction within the material.

Anisotropic magnet --- A magnet with a preferred direction of magnetic orientation.

B_d x H_d, or **Energy Product** --- Indicates the energy density that a magnetic material can supply to an external magnetic circuit when operating at the (B_d, H_d) point on its demagnetization curve; measured in mega Gauss-Oersteds (MGOe) or kilo Joules per cubic meter (kJ/m^3).

B_d/H_d, or **Slope of the operating line** --- The ratio of magnetic induction, B_d, to a demagnetizing field, H_d. It is also known as the permeance coefficient or load line.

B_g, Magnetic induction in the air gap --- The average value of magnetic induction over the area of the air gap, A_g. It is also defined as the magnetic induction measured at a specific point within the air gap; measured in Gauss or Tesla.

BH Loop --- A hysteresis loop across four quadrants.

$(BH)_{max}$ or **Maximum Energy Product** --- The maximum product of (B_d X H_d) which can be obtained on the extrinsic demagnetization curve, i.e., in the second quadrant of the hysteresis loop.

B_i (or J), or **Intrinsic induction ---** The contribution of the magnetic material to the total magnetic induction, B. It is the vector difference between magnetic induction in the material and magnetic induction that would exist in a vacuum under the same field, H.

B_r or **Residual induction** --- The magnetic induction which corresponds to zero applied field (magnetizing force) in a magnetic material after saturation in a closed circuit (in a permeameter); measured in Gauss or Tesla.

Closed circuit condition --- Exists when the external flux path of a permanent magnet is confined within flux conducting material.

Coercive force, Hc --- The value of demagnetizing force that reduces the B field in a magnet to zero. It is measured in Oersteds (Oe) or kilo Amperes per meter (kA/m).

Curie temperature (Tc) --- The temperature, above which ferromagnetic materials become paramagnetic, and lose their permanent magnetic properties.

Demagnetization curve --- Second quadrant curve of the hysteresis loop.

Demagnetized --- A magnet can be either thermally or field demagnetized. Thermal demagnetization can be achieved by heating the magnets above the Curie temperature. (Heating a magnet can be easily done for any kind of magnet.) Thermal demagnetization of NdFeB magnets is easily accomplished due to a relatively low Curie temperature compared to SmCo magnets. For Sm-Co magnets, proper heat-treatment is needed to recover the microstructure needed for optimum magnetic properties. Field demagnetization can be achieved by exposure to a continually decreasing sinusoidal AC field.

Direction of magnetization --- Refers to the "easy axis" or the axis of choice for the direction of alignment. Most rings are aligned axially so the direction of magnetization is through the axis (or thickness). Other possibilities for rings would include "across the diameter" and "radial".

Electromagnet --- Magnetic behavior induced in a magnet by electric current flowing through a conductor. The electrical conductor may be copper wire, plate, or strips of foil and may exist with a permeable material such as steel to conduct or guide the field to desired areas. The magnetic field exists only as long as current flows through the coil.

Finite Element Analysis (**FEA**) --- A computer-generated model designed to show the expected magnetic performance of a magnet or magnet assembly without having to build the empirical version.

Flux --- Flux is represented conceptually as "magnetic lines of force" which pass perpendicularly through a surface. Flux is measured in Maxwell or relative flux units.

Flux loss --- Generally, flux loss refers to the change (loss) in magnetic strength of a magnet, which occurs as a result of temperature stabilization. This is also known as irreversible loss. Once it occurs, the only way to regain the flux loss is to re-magnetize the magnet. Under normal circumstances, flux loss is limited to a few percent.

Flux meter --- An instrument that measures the change of flux linkage with a search coil. The current in the search coil caused by relative motion with the magnet is integrated (totalized). Using a calibrated coil allows calculation of field and magnet properties.

Gauss --- The unit of magnetic flux density, or induction, B, in CGS system.

Gaussmeter --- 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.

GHz --- 1,000,000,000 Hz (giga Hertz).

Hall Effect transducer --- A device that produces a voltage output dependent upon an applied DC voltage and an incident magnetic field. The magnitude of the output is a function of and proportional to the field strength and the angle of incidence with the Hall device. This type of sensor is often used to provide an output signal for use in a Gaussmeter to measure the incident magnetic induction B.

Hard magnetic material --- Permanent magnet material that has an intrinsic coercivity about 300 Oersteds.

H_c, Coercive Force, or **Coercivity** --- Is equal to the demagnetizing field required to reduce the B field in the magnet to zero after the magnet has been fully saturated; measured in Oersteds or A/m.

H_{ci}, Intrinsic Coercive Force, or **Intrinsic Coercivity** --- Represents the ability of the magnetic materials to resist demagnetization. It is equal to the demagnetizing field that reduces the B field in the magnet to zero (from saturation); measured in Oersteds or A/m.

Hysteresis and Hysteresis Loss – Hysteresis is the tendency of a magnetic material to retain its magnetization. Hysteresis causes the graph of magnetic flux density versus magnetizing force to form a loop rather than a line. The area of the loop represents the difference between energy stored and energy released per unit volume of material per cycle. This difference is called hysteresis loss. It is one of two major loss mechanisms in inductor cores; the other is eddy current loss. Hysteresis loss is measured at low frequency to distinguish it from eddy current loss.

Hysteresis Loop – A closed curve obtained for a material by plotting (usually to rectangular coordinates) corresponding values of magnetic induction, B, for ordinate 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. If the material is not "driven" to saturation, it is said to be on a minor loop.

Hysteresisgraph – An instrument that draws hysteresis loops; also called a permeameter.

Hz – Frequency in units of Hertz (cycles per second).

Induction Curve, or **Normal demagnetization curve** – A graph depicting the relationship between induction, B, and applied field (magnetizing force), H, where B corresponds to the sum of the externally applied field, H, and the magnetic flux from the magnetic material, B_i.

Intrinsic Demagnetization Curve --- The hysteresis loop corresponding to B_i versus H where B_i is the magnetization resulting from only the magnetic material.

Irreversible Flux Loss --- Defined as partial demagnetization of the magnet, caused by exposure to high temperatures, external demagnetizing fields or other factors. These losses can be recovered by re-magnetization. Magnets can be stabilized to remove irreversible losses by partial demagnetization induced by temperature cycles or by external magnetic fields.

Iso/axial press --- Refers to the method of alignment that is used during the pressing operation. In isostatic pressing, the pressure is applied uniformly in all directions. In axial pressing, pressure is applied parallel to the direction of alignment. Most rings are axially pressed.

Isostatic Pressing --- This method of pressing provides a higher degree of alignment (compared to axial pressing). Better alignment translates to higher magnetic properties. Using the same powder, for example, axial pressing would yield 24 MGOe magnets and isostatic pressing would yield 27 MGOe magnets.

Isotropic Magnets --- A magnet whose magnetic properties are the same in any direction, and which can therefore be magnetized in any direction.

J --- See B_i or Intrinsic induction

Joule --- SI unit for energy

kHz --- 1,000 Hz (kilo Hertz)

kilo Gauss --- 1 kilo Gauss is equal to 1,000 Gauss.

Knee (of the demagnetization curve) --- In the second quadrant of the hysteresis loop, some magnetic material such as ferrite and rare earth magnets exhibit a distinct "knee" or rapid change in slope of the intrinsic curve. The location of the knee is of interest to designers because if the magnet operates below the knee, irreversible loss of magnetic output occurs.

Leakage flux; Leakage field --- A portion of the flux that does not pass through the air gap, or useful part of the magnetic circuit.

Load line --- Graphical representation of the permeance coefficient of a magnet or a magnetic circuit. The load line is a straight line which originates from B = 0 through the point B_d/H_d in the second quadrant of the demagnetization of the hysteresis loop. The slope is a function of magnet geometry. Also known as the working point.

Magnet wire --- Copper or aluminum wire with electrical insulating material applied to the surface to prevent continuity between adjacent turns in a winding. Magnet wire is typically used to fabricate coils in electromagnets.

Magnetic circuit --- The combination of magnet, permeable flux carriers, and air gaps through or around which the magnetic flux flows.

Magnetic flux --- A contrived but measurable concept that has evolved in order to describe the "flow" of a magnetic field. Unlike electric current where there is an actual flow of electrons, a magnetic field is the result of the energy state of a series of magnetic domains. Conceptually, one could imagine that the sequential change of energy state as the result of an applied field represents a "flow".

Magnetic path --- The route that magnetic flux follows in a magnetic circuit.

Magnetizing field (H) --- An applied magnetic field used to drive another material to a condition of being magnetized. It may be applied by current through a coil of wire or by using permanent magnets to generate the applied field.

Magneto Motive Force (MMF) --- Most commonly produced by a current flowing through a coil of wire where its magnitude is proportional to the current, and to the number of turns.

Magnetostriction It is the property of a ferromagnetic material to change shape when subjected to a magnetic field. The expansion and contraction of a magnet with changing magnetic flux density. It is the change of length divided by original length (a dimensionless number) and is measured at the saturation flux density. Magneto-striction causes audible sound if it is sufficiently large and if the applied field is AC and is in the audible frequency range, e.g. 50 or 60 Hz.

Maximum energy product (BH_{max}) --- The product of B_d and H_d that yields a maximum. See also, "BH_{max}".

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

MGOe --- Stands for Mega Gauss Oersteds. MGOe is the English unit of measurement used to state the energy product or $(BH)_{max}$ of a magnet. The corresponding SI (metric) unit is kJ/m^3 (kilo Joules per cubic meter).

MHz --- 1,000,000 Hz (mega Hertz)

Mil --- 0.001 inch or one thousandths of an inch.

MMF --- see Magneto-motive force.

Mu-metal --- A nickel-iron alloy typically containing more than 65% nickel used for shielding magnetic flux. The name of the material refers to the Greek letter, μ (mu), which is the symbol for magnetic permeability. Mu-metal has a high value of magnetic permeability.

Net permeability --- The permeability of a magnetic circuit when all materials, air gaps, and applied MMFs are taken into account; it is the same as effective permaeability.

Oersted, Oe --- The unit of applied magnetic field strength, H, in the cgs electromagnetic system. One oersted equals a magneto motive force of one Gilbert per centimeter of flux path. 1 Oe = $10^3/4\pi$ A/m = 79.5775 A/m

Ohm (Ω) --- Unit of electrical resistance.

Open circuit condition --- Exists when a magnetized magnet is isolated from ferro-magnetic components that are commonly found in the magnetic circuit.

Operating line (Load line) --- 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 B_d/H_d. Although the slope is negative, by convention the values are usually referred to in the absolute value of the slope. (Also known as permeance coefficient line.)

Operating point --- That point on a demagnetization curve defined by the coordinates (B_d/H_d).

0 TC ("zero" TC) --- Refers to the magnet material that is said to be fully temperature-compensated, i.e., the fundamental magnetic properties exhibit very minute (as little as –0.001% per degree C) change over the functional temperature range of the magnet application.

Permalloy --- 4-79 Molybdenum Permalloy. A high permeability alloy of 4% molybdenum, 79% nickel, 17% iron used to make tape-wound and laminated cores and other components in a magnetic circuit. See Mu-Metal.

Permanent Magnet Material --- Any type of ferro-magnetic material, which once having been magnetized, shows definite resistance to external demagnetizing forces, i.e., requires a high demagnetizing force to remove the residual magnetism.

Permeability --- The ratio of the ability of a material to carry magnetic flux in comparison to air or a vacuum, the permeability of which is, by definition, one.

Permeability of free space --- The permeability of a volume occupied by a vacuum; sometimes called the magnetic constant.

Permeability, Initial --- The limit of incremental permeability as a changing unbiased magnetizing force approaches zero.

Permeability, Normal --- The ratio of the normal induction to the corresponding magnetizing force.

Permeability, Recoil --- The ratio of change in flux density as a function of incremental change in applied field (H) in the vicinity of H = 0. It has no dimensions in either the MKSA or CGS system.

Permeameter --- See Hysteresisgraph.

Permeance --- The reciprocal of the reluctance, R, measured in Maxwells per Gilbert.

Permeance Coefficient (P_c) --- Also known as the "load line" or operating point of a magnet. The P_c is affected by the dimensions of the magnet and the associated magnetic circuit.

Plotting --- Method of producing a graphical display of the measurement of the magnetic field as a function of position or location.

Pole pieces --- Generally, parts made of ferro-magnetic material, which are used to conduct the flux generated by permanent magnets. For TWT magnets, pole pieces are generally round with ODs and IDs.

Poles, North and South magnetic --- The north pole of a magnet corresponds with the north geographic pole of the earth (which is actually, by definition, a magnetic south pole), and the south pole of a magnet corresponds with the south geographic pole of the earth. The north-seeking pole of a compass or of a magnet is designated by the letter "N", and the other pole by the letter "S". The N (north) pole of the magnet will attract the S (south) pole of another magnet: unlike poles attract. The N (north) pole of the magnet will repel the north-seeking pole of a compass and vice versa.

Polymer bonded magnets --- Magnet powder is mixed with a polymer such as epoxy to form a carrier matrix. The magnets are molded by compression, extrusion, or injection into a certain shape. Solidification occurs by curing instead of sintering.

Powder confirmation --- A series of tests used to verify that a powder batch provides the magnetic properties it was designed to provide.

Quenching --- A rapid cooling process which follows sintering or solid solutioning.

Rare Earths --- A family of ~~periodic~~ elements in the periodic table having ~~with~~ an atomic number from 57 to 71, and including 21 and 39. They are also known as the lanthanide series, which includes lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, scandium, and yttrium.

Remanence (B_r) --- The magnetic induction remaining in a material when the magnetizing field has been reduced to zero; also called "remanent induction".

Return path --- A magnet typically forms only part of the magnetic circuit. Soft magnetic material such as iron or various steels are used to carry or channel the magnetic flux to the gap or working region for interaction with other components. This conductor of magnetic flux is referred to as the return path. It is usually designed to minimize fringing and leakage flux.

Reversible Temperature Coefficient (RTC) --- The reversible temperature coefficient (RTC) is the measure of the rate at which the field strength of a magnet changes with temperature. Standard magnet grades, like 1:5-18 and 2:17-27 have RTC of -0.04%/°C and -0.035%/°C, respectively. Fully temperature compensated magnets like 1:5TC-9 and 2:17TC-16, are known as 0TC. These magnets have RTC of -0.001%/°C (essentially zero).

Saturation --- Exists when an increase in magnetizing force, H, does not cause a corresponding increase in the intrinsic magnetic induction, B_i, of the material; i.e. the magnet is "full' of magnetizing force.

Saturation flux density --- The flux density at which a magnet saturates.

Search coil --- A coil conductor, usually of known area and number of turns, used with a flux meter to measure the change of flux linkage with the coil.

Second quadrant curve --- The second quadrant curve is the demagnetization portion of the hysteresis loop created with a permeameter. In a permeameter, magnets are magnetized to saturation in the first quadrant and then demagnetized to plot the second quadrant curve. The second quadrant curve is the intrinsic curve starting at B_r and ending at H_{ci}. From this intrinsic curve, the extrinsic (normal) curve is calculated to derive the line which extends from B_r to H_c.

Sintering --- The process used to densify green powder compacts after initial compaction. Sintering occurs at elevated temperatures, typically between 1100 and 1200°C.

Soft magnetic material --- Ferromagnetic material with high flux conducting capability (permeability) and very low intrinsic coercivity. Most of the commercial soft materials have an intrinsic coercivity less than 10 Oe.

Solution, or **Solid Solution** --- A homogenization process done at elevated temperatures in order to obtain a single, uniform phase, such as Sm_2TM_{17} phase; homogenization is generally followed by a fast quench to "freeze" the single phase. Solution temperature and a rapid quench after solution are critical to achieve good magnetic properties for SmCo 2:17 magnets.

Square Loop --- Refers to an intrinsic hysteresis loop with a rectangular shape.

Stability --- The ability to resist demagnetizing influences encountered in the operating environment. These demagnetizing influences can be caused by high or low temperatures or by external magnetic fields.

Temperature Coefficient (TC) --- A factor that describes the reversible change in any material property as a function of a change in temperature. The material property spontaneously returns when the temperature returns to its original point so long as a limit is not exceeded. It is usually measured as the percentage change per unit of temperature over a specified temperature range.

Temperature stabilization --- After manufacturing, many types of hard and soft magnetic material can be thermally cycled to remove irreversible changes that occur the first time temperature extremes are encountered.

Tesla --- SI unit for magnetic flux density, defined by Faraday's law. One Tesla is equal to a Volt-second per square meter per turn. One Tesla equals 10,000 Gauss.

T_{max}, **T_m**, or **Maximum service temperature** --- The maximum temperature to which the magnet may be exposed with no significant long-range instability or structural changes. A proposed magnetic definition is that the normal hysteresis curve is a straight line in the second quadrant up to the T_{max} temperature; the line begins to show curvature (a "knee") once T_{max} is exceeded.