MAGNETICS®
Division of Spang & Company

Technical Bulletin

BULLETIN CG-05

Frequently-Asked Questions About Magnetic Materials And Their Answers

It is recognized that courses in magnetic materials and their applications are limited in university offerings. Engineers who are getting into designs that require knowledge in this area often have questions about the science of magnetic materials and the variety of materials and geometries that are available. MAGNETICS has compiled this document for the benefit of those seeking answers to some of the most commonly-asked questions.

In many of the replies here, more extensive and detailed information is further available in other brochures; references are made to these other publications, and it is suggested that these be perused. For those individuals who don't know where to start, MAGNETICS Brochure APB-2 has a compilation of applications and the recommended materials or geometries for these applications.

INDEX OF KEY WORDS

INDEX OF KEY WORDS (arranged by subject)

1. QUESTION: How do you test ferrites for A_L? Explain why testing at 5 gauss is important.

ANSWER: Inductance is measured on a bridge with variable voltage and frequency. The flux density should be less than 10 gauss (1mT). Cores have to be properly mounted around the measuring coil, or for toroids, wound uniformly with the correct number of turns.

Testing at a low gauss level is important. Magnetic material characteristics change considerably at higher drive levels. Since all applications are different, it is necessary for manufacturers to normalize characteristics at a low level to insure a degree of consistency in measurement conditions. *Additional details on testing can be obtained from the Magnetic Materials Producers Asssociation, 8 South Michigan Ave., Suite 1000, Chicago, IL 60603, Phone (312) 456-5590, FAX (312) 580-0165. Ask for Brochure "MMPA SFG." You can also obtain a copy from Magnetics.*

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2. QUESTION: Why are cores not like magnets?

ANSWER: Permanent magnets are considered "hard" magnetic materials because their magnetism is **permanently** retained, a result that has been achieved by their manufacturing process. Cores are considered "soft" magnetic materials because they have magnetism only when wound with current-carrying wire. Hard magnets are fixed at one point on the B-H (or hysteresis) curve. Soft magnetic materials can be cyclicly driven along portions of their B-H curves, making them usable for transformers and inductors. MAGNETICS does not supply permanent magnets.

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3. QUESTION: What are effective core parameters?

ANSWER: Magnetic cores, particularly ferrites, come in a variety of geometries. In order to apply the many formulas that are used in calculations for designs, core physical parameters are calculated to minimize geometry effects. These parameters include items such as magnetic path length, effective areas and effective volume. *A good source of what these effective parameters are and how they are computed appears in the Magnetic Materials Producers Association (MMPA) publication "MMPA SFG". Contact: Magnetic Materials Producers Asssociation, 8 South Michigan Ave., Suite 1000, Chicago, IL 60603, Phone (312) 456-5590, FAX (312) 580-0165. You can also obtain a copy from Magnetics.*

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4. QUESTION: How does MAGNETICS measure toroid coating insulation and make certain guarantees?

ANSWER: Core finishes on toroids are measured for voltage breakdown by inserting the core between ***two*** weighted wire mesh pads. The force is adjusted to produce a uniform pressure of 10 psi, simulating winding pressure. The test is conducted using a 60Hz r.m.s. voltage. Consult the toroid product catalogs for specific finishes and their guaranteed voltage breakdowns. Users should be careful to note that their actual windings, especially when heavy wire is used, can cause mechanical stresses that are not present in the standard breakdown test; excessive stresses here can deform the coating, resulting in a lower-than-expected breakdown.

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5. QUESTION: Why is a corner radius important on a toroid?

ANSWER: A radius is important on a toroid because if the core has sharp edges, the wire insulation could be scraped during the rigorous winding operation. MAGNETICS takes special pains to insure that toroids have some radius. Ferrite toroid dies are made with a built-in radius, and cores are either deburred or tumbled to remove any sharp edges. Additionally, many cores are painted or coated to provide not only a more blunt corner radius, but also a smoother winding surface. Powder cores have a pressed radius on one side and a deburred radius on the other. As with ferrites, a coating provides additional edge coverage.

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6. QUESTION: What types of cores are used for transformers? What type for inductors?

ANSWER: Desirable materials for transformer cores are those that have a high flux density and keep the temperature rise within desirable limits. Strip materials have the highest flux density and are generally used at frequencies less than 20kHz. Above 20kHz, ferrites are desirable because the materials are designed to have low core losses (lower heat rise) at these higher frequencies.

For inductors, cores that have air gaps are desirable because they can maintain their constant permeability levels up to high dc or ac drive levels. Ferrites and strip wound cores can be gapped. Powder cores have a built-in distributed air gap.

MAGNETICS *brochures APB-2 and CG-02 are useful in narrowing down the selection of materials for various applications.*

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7. QUESTION: Why are A_L values provided for ferrites and powder cores and not for tape cores?

ANSWER: Tape wound cores are generally used in transformer or square loop applications in which the A_L is meaningless. The desirable characteristics are high flux density, low core losses, and in some cases high squareness in the B-H loop. In square B-H loop materials such as those used in tape wound cores, the permeability varies widely as the loop is traversed; a consistent and repeatable inductance measurement is not obtainable. Square loop materials are generally used for switching applications. In rounded B-H loop materials, such as ferrites and powder cores, the permeability is more constant along the loop. A_L is a measure of permeability at low drive levels, where the permeability is relatively stable in round loop materials.

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8. QUESTION: What is the best material to use?

ANSWER: There is no straight answer to this question, as selection depends on the application and application frequency. Any material selected is subject to tradeoffs. For instance, some materials may keep heat rise to a minimum and are expensive, but if one is willing to put up with more heat, perhaps a larger component or less costly one may do the job. The best material selection first depends on whether you have an inductor or a transformer application. From this point, the operating frequency and cost are important. Different materials are optimal at different frequency ranges, operating temperatures, and flux densities. After narrowing the core selection to particular types, it is advisable to sample the different ones that could meet the requirements, then make a final selection. *For additional information, refer to **MAGNETICS** brochures APB-2, CG-02, PS-01 or FC-S1.*

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9. QUESTION: How do you demagnetize a core?

ANSWER: Drive the core under 60 Hz conditions (saturating alternately in a positive and negative direction) then slowly reducing the drive level over several cycles until it is reduced to zero. This action will reduce the remanence point to the origin.

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10. QUESTION: What happens to cores if you go above the Curie temperature?

ANSWER: Curie temperature is that temperature at which a material loses all of its magnetic properties. Above the Curie temperature, the core loses its usefulness in an electronic circuit. Many cores have an insulated finish which would be ruined much before the Curie temperature is reached. It is best to consult the catalogs of those cores to see what the coating temperature limit is.

Strip-wound cores that do not have any insulated coatings may be affected because going through the Curie range can alter the magnetic characteristics when the cores are returned to operating temperature. Conventional strip-wound cores and powder cores generally have such high Curie temperatures (>450°C) that the materials may be damaged due to oxidation well below the Curie temperature. Manganese-zinc ferrites, on the other hand, will not be affected, except for the insulated coating on them. This is due to the low Curie temperatures (120°C to 250°C) of ferrites. Exceeding these temperatures is generally not high enough to alter the ceramic material structure. In general, the core's magnetic properties will be restored when the temperature is reduced to below the Curie temperature, as long as the material has not been oxidized.

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11. QUESTION: What is the maximum frequency at which you can operate a magnetic material?

ANSWER: First, this depends on the type of material. Strip-wound cores generally will have a maximum usable frequency lower than, say ferrites, because the resistivity is lower, resulting in higher eddy currents and higher core losses. The thinner the strip material, the higher the usable frequency. On the other hand, core losses depend on the operational flux density of the design; thus, by reducing the flux density, a higher operating frequency can be achieved. Often in power magnetics, it is not the saturation flux density (B_{sat}) of the material that limits the drive level, but rather the maximum tolerable losses at the specific operating frequency. *Consult the **MAGNETICS** catalogs to see the relationships among core losses, frequency and flux densities.*

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12. QUESTION: Why does one consider single layer windings on toroid cores?

ANSWER: Single layer windings are less costly to wind. The distributed capacitance is kept to a minimum; this maximizes the frequency response. Temperature rise due to copper loss is minimized. For common mode chokes, symmetry between the opposing windings is much easier to maintain when only 1 layer is used.

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13. QUESTION: What is a bifilar winding?

ANSWER: Two strands of wire, usually twisted together. The dual wire is then wound on the core or bobbin to produce two equal and parallel windings which take the place of one large single strand.

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14. QUESTION: WHAT IS THE RELATIVE COST OF DIFFERENT MAGNETIC MATERIALS?

ANSWER: Much of the cost is related to the basic cost of raw materials. In strip-wound materials that are made of nickel or cobalt, the nickel or cobalt is the determining factor. On the other extreme, a material made from silicon-iron where most of the composition is iron, the cost is on the low side. In between these two extremes are the variety of compositions that comprise the many types of materials and geometries. Material cost is a big factor in large cores, and not so on small cores. One must consider environmental and temperature conditions plus any trade-offs that result in the use of one material over the other. Relative costs can be compared as follows:

In powder cores, iron powder ranges from 1x - 3x
KOOL Mμ -- ”   ”   4x - 5x
High Flux -----------approx. 10x
MPP -------------------   ”   12x

In ferrites, F, P, R and J materials, roughly equivalent (1y)
W material------------1.25-1.75y
H material ----------- 1 .50-2.00y

Ferrite cost is a function of geometry:
Toroids ------------- least
E cores ------------ mid
Other shapes-------most

Probably the first place to start is to consider the application, then decide what materials should be investigated because some applications are more suited to the use of a particular core and/or material. ***MAGNETICS*** *Brochure APB-2 shows a basic listing of many applications and will enable the designer to zero in on one or two materials for his application.*

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15. QUESTION: What is the B-H (or Hysteresis) loop?

ANSWER: It defines the flux density of the material, coercive force, the amount of drive level required to saturate the core, and the permeability (or the ability to change the magnetic lines of force). The B-H loop changes with frequency and drive level. How a material reacts to the frequency and excitation level (current and voltage) is very important in determining its effectiveness to meet the needs of a particular application. Refer to the product catalogs for specific descriptions.

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16. QUESTION: Why do you put an air gap into cores?

ANSWER: Putting an air gap into a core, "tilts", or "shears" the B-H loop, making it possible to use the core at higher H levels, thus preventing early saturation of the core. Once a core saturates, the permeability is drastically reduced, hence the desirabilty, for many applications such as inductors, to delay this saturation. Air gaps give tighter control on inductance. ***MAGNETICS*** *brochure TWC-S5A describes this effect.*

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17. QUESTION: What is magnetostriction?

ANSWER: When a magnetic material is magnetized, a small change in dimension occurs. The relative change is in the order of several parts per million, and is called "magnetostriction". For applications like ultrasonic generators, the mechanical motion produced by magnetic excitation through magnetostriction is used to good advantage. In other applications, operating in the audible frequency range, an annoying audible hum is observed. For this reason, low magnetostrictive materials such as Permalloy 80, METGLAS 2714A, KOOL Mμ and MPP powder cores may be used for less audible operation.

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18. QUESTION: What is disaccommodation?

ANSWER: This phenomenon, occurring in ferrites, is the reduction of permeability with time after a core is demagnetized. This demagnetization can be caused by heating above the Curie point, by applying an alternating current of diminishing amplitude, or by mechanically shocking the core. In this phenomenon, the permeability increases towards its original value, then starts to decrease exponentially. If no extreme conditions are expected in the application, permeability changes will be small because most of the change has occurred during the first few months after manufacture of the core. High temperature accelerates the decrease in permeability. Disaccommodation is repeatable with each successive demagnetization; thus, it is not the same as aging.

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19. QUESTION: Why does the inductance of a ferrite toroid decrease after winding and potting?

ANSWER: Ferrite materials are susceptible to mechanical stress, both from winding the core and from encapsulation. High permeability materials are particularly affected. Suggested remedies: (1) after winding, bake and/or temperature-cycle, (2) thin out the epoxy used for encapsulation or dope with an inert material such as sand or ground mica, (3) cushion with tape,(4) silicone (RTV) dip the wound cores prior to potting. *For more details, see* ***MAGNETICS*** *article reprint "Common Mode Inductors for EMI Filters Require Careful Attention to Core Material Selection". Pages 6 and 7 in that article cover this subject in detail.*

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20. QUESTION: Why are actual core losses in gapped structures larger than calculated?

ANSWER: When calculating the core losses, it is assumed that the structure is homogeneous. In reality, when core halves are mated, there is leakage flux (fringing flux) at the mating surfaces, and the gap losses contribute to the total losses. Gap losses are caused by flux concentration in the core and eddy currents generated in the windings. When a core is gapped, this gap loss can drastically increase losses. Additionally, because the cross-sectional area of many core geometries is not uniform, local "hot spots" can develop at points where a smaller core area enables a higher local flux density, hence causing higher losses to occur at these points.

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21. QUESTION: What is the difference between nickel-zinc and manganese-zinc ferrites?

ANSWER: MnZn materials have a high permeability, while NiZn ferrites have low permeability. Manganese-zinc ferrites are used in applications where the operating frequency is less than 5MHz. Nickel-zinc ferrites have a higher resistivity and are used at frequencies from 2MHz to several hundred megahertz. The exception to this rule of thumb is common mode inductors where the impedance of MnZn materials makes it the best choice up to 70MHz and NiZn is recommended from 70MHz to several hundred GHz.

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22. QUESTION: How important is permeability in power materials?

ANSWER: Permeability is flux density, B, divided by drive level, H. Power materials are generally used for high frequency transformer applications. Generally, the important characteristics are high flux density and low core losses. Permeability is of less importance because of its variability over an operating flux range.

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23. QUESTION: Why is only the minimum A_L listed in the catalog?

ANSWER: Permeability (and A_L) varies with drive level. For power applications, there is no need to place a limit on the maximum A_L. A minimum A_L translates into maximum excitation current. See also Questions 1 and 7.

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24. QUESTION: How do I know the ferrite hardware will fit on the core?

ANSWER: Cores are manufactured to standards that have been agreed to in the industry. Tolerances have been assigned to the critical dimensions. Generally, hardware fit should not be a problem. The safest thing to do is to purchase the hardware and cores from the same source where possible. *For additional information on core standards, the Magnetic Material Producer's Association has these publications available:*

PC110-Pot Cores
TOR400-Toroid Cores
UEI300-U,E,and I Cores

MMPA address is 600 South Federal Street, Suite 400, Chicago, IL 60605, Phone (312) 922-6222, FAX (312) 922-2734.

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25. QUESTION: Can I get tighter dimensional tolerances in ferrites?

ANSWER: During the sintering operation, parts shrink to their final dimensions. Different material and processing techniques result in variance in this linear shrinkage which can range from 10 to 20% of the pressed dimensions (in finished parts, this could range from l-4%). Some dimensions cannot be held to a tighter tolerance. Dimensions that can be machined after firing can certainly be held to tighter tolerances.

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26. QUESTION: Can I get a custom ferrite part?

ANSWER: It is possible to get a custom part. Volumes of less than 500 pieces can be readily machined. Quantities over 20,000 are generally pressed from custom-built tools. Adjusting the heights of existing parts is a practical way to minimize machining and tooling costs.

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27. QUESTION: What is the proper clamping pressure in ferrites?

ANSWER: Generally, a recommended figure is about 700 kg/m^2 (100 lbs./sq. in.) of mating surface. *For specific recommended pressures for RM, PQ, EP and pot cores, consult the **MAGNETICS** Ferrite Catalog, FC-601.*
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28. QUESTION: What is the best core shape?

ANSWER: There is no "best shape." It depends on the application, space constraints, temperature limitations, winding capabilities, assembly, and a number of other factors; this means that compromises must be made. *For additional information on this subject, consult the **MAGNETICS** Ferrite Catalog where geometry considerations are covered in more detail. Brochure PS-01 also covers this subject.*
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29. QUESTION: Why do you flat-grind ferrite cores?

ANSWER: Cores are flat-ground because of the uneven surface produced during the firing process. It is important for mating surfaces to mate with a minimum air gap to keep the gap losses to a minimum and to achieve an optimum inductance.
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30. QUESTION: Why do cores get lapped? What is the surface finish?

ANSWER: Lapping is an additional production process used to decrease the effects of an air gap on mated surfaces. It is typically done on mated cores with material permeabilities of 5000 and greater in order to achieve the maximum A_L value for a given material. A mirror-like finish is the result. The typical surface finish for normally flat-ground surfaces is 25 micro-inches (.635 microns) and for lapped surfaces is 5 micro-inches (. 127 microns). Proper surface finish is not measured as a rule, but is maintained by monitoring the A_L.
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31. QUESTION: Why is the ferrite gapped tolerance not always ±3%?

ANSWER: Due to limitations of the machine performing the gapping, the smaller the gap, the harder it is to hold tight tolerances. As the A_L value increases, the gap gets smaller, hence the tolerance gets larger. As the gap gets smaller, the mechanical tolerance becomes proportionately larger, plus the influence of variation in the material permeability becomes greater. Thus, a gap specified by its A_L value yields a tighter tolerance than a gap specified by its physical dimensions.

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32. QUESTION: How do you glue ferrite cores?

ANSWER: Gluing should be done with thermosetting resin adhesives, in particular the epoxy resins. The available range is very large. Important factors in the choice are the required temperature and viscosity. The curing temperature must not be above the maximum temperature to which the assembly may be safely raised. As far as viscosity is concerned, if it is too high, application is difficult; if it is too low, the resin may run out of a poorly-fitted joint or may be absorbed by the porosity of the ferrite. Follow the manufacturer's instructions for a particular resin. Take care not to thermally shock ferrites; raising or lowering the core temperature too rapidly is dangerous. Ferrites will crack if changes in temperature exceed 5-10°C/min. In addition, care must be taken to match the adhesives' coefficient of thermal expansion (CTE) to that of the ferrite material. Otherwise, the resin may expand or contract more quickly than the bulk ferrite; the result can be cracks that will degrade the core.

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33. QUESTION: Why are ferrite toroid A_L tolerances wide and powder cores narrow?

ANSWER: Magnetic materials naturally have wide variations in permeability. Putting an air gap in the structure can have the effect of not only reducing permeability but dramatically reducing this variation. Powder cores have a distributed air gap; this results in a narrower inductance tolerance. Ferrite toroids do not have a distributed air gap and are thus subject to variations caused by normal processing. *For a complete description of the ferrite manufacturing process, consult the MMPA Soft Ferrite User's Guide, Publication number MMPA SFG. Magnetic Materials Producer's Association, 600 South Federal Street, Suite 400, Chicago, IL 60605.*

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34. QUESTION: Can you tighten electrical tolerances on ferrite toroids?

ANSWER: (see also question #33). While a production batch of ferrite toroids may have a wide tolerance, when required in rare instances, the cores can be graded into narrower inductance bands at a premium. Due to equipment limitations, this is not possible on all sizes. Check the factory for specific information and costs.
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35. QUESTION: What is the MAGNETICS specification for out of roundness on a ferrite toroid ?

ANSWER: Out of roundness is controlled by mandating that cores meet overall dimensional tolerances for OD and ID while keeping enough cross section to meet the specified A_L . *Refer to the* ***MAGNETICS*** *Ferrite Catalog FC-601 for toroid physical dimension tolerances.*
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36. QUESTION: What is the difference between nylon and polyester coatings for ferrite toroids?

ANSWER: They are similar. Nylon is thicker, and can stand temperatures up to 155°C. Polyester is good to about 200°C. Nylon finishes are generally applied to cores ranging in OD from 9 mm to 29 mm. Very large and very small cores are coated with a polyester finish. Voltage breakdown guarantee of nylon and polyester coatings is 500 volts. Nylon cushions better and is more resistant to solvents. Both finishes are held to the same electrical and mechanical specifications.
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37. QUESTION: What about availability of any other core coatings for ferrites?

ANSWER: Black lacquer is an inexpensive coating put on merely for the purpose of providing a smooth winding surface. It does not have any voltage breakdown guarantee. Size range is 7.6 mm. to 15.8 mm. in outside diameter. Parylene C is a vacuum deposited coating providing good resistance to moisture and organic solvents. Electrical characteristics are superior to other coatings. The size range is economically limited to outside diameters of 14mm or less.
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38. QUESTION: How do you determine the proper core size?

ANSWER: Two elements are useful in determining core size: core window (winding area) and core cross-sectional area. The product of these two elements (area product, or $W_a A_c$) relates to the power handling capability of a core. The larger the $W_a A_c$, the higher the power able to be handled. As operating frequency increases, the area product can be reduced, thus reducing the core size. **MAGNETICS** publishes the area products of all cores as a useful design tool.

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39. QUESTION: Can MAGNETICS press powder cores and ferrite toroids in different heights?

ANSWER: Many cores can be pressed to different heights. Dies are made so that the cavities can accommodate these different heights. Each core size is different, however. Consult the factory for specific questions on the sizes of interest, minimum quantities and price. One advantage this offers is the ability to produce other core sizes without the expense of additional tooling.

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40. QUESTION: In powder cores, why is actual inductance different from calculated?

ANSWER: MAGNETICS measures inductance in a Kelsall Permeameter Cup. *Actual* wound inductance outside a Kelsall Cup is greater than the value calculated due to leakage flux and flux developed in the winding. The difference depends on core size, permeability, core finish thickness, wire size and number of turns, *in addition to* the way windings are put on the core. The difference is negligible for turns greater than 500 and permeabilities 125µ and higher. The following table is a guide to the differences that one might experience:

No. of Turns	Actual L	No. of Turns	Actual L
1000	0%	100	+3.0%
500	+0. 5%	50	+5.0%
300	+1 .0%	25	+8.5%

The following formula can be used to approximate the leakage flux to add to the expected inductance. This formula was developed from historical data of cores tested at MAGNETICS. Be aware that this will only give an approximation based on evenly spaced windings. You might expect as much as ±50% deviation from this result.

$$L_{LK} = \frac{292 N^{1.065} A_e}{l_e \times 10^5}$$

where L_{LK}= leakage inductance (mH)
N= number of turns
A_e= core cross-section (cm²)
l_e= core magnetic path (cm)

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41. CONVERSION FACTORS:

MULTIPLY	BY	TO OBTAIN
Oersteds	2.0213	ampere-turns/inch
Oersteds	0.79577	ampere-turns/cm
Oersteds	79.577	ampere-turns/m
Ampere-turns/cm	1.2566	oersteds
Gausses	10^{-4}	teslas
Micro-inches	0.0254	microns

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