Specify Saturation Properties of Ferrite Cores to Prevent Field Failure

by

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Abstract

Not all ferrites are equivalent, especially their saturation flux density properties. Today's trend for name brand ferrite companies to have their products private labeled for them by low cost bidders around the world rather than manufacture their own ferrites necessitates the importance of specifying saturation properties. Circuit currents typically escalate and spike when the core of a magnetic component saturate. These high currents typically cause other circuit components (semiconductor switches, diodes, capacitors) to fail well before any permanent damage occurs to the magnetic component. Because no permanent damage occurs to the magnetic component the true root cause for these failures often goes undetected. Component engineers meticulously specify dimensions, inductance and power loss but typically neglect the saturation properties of the magnetic component and their cores. This paper proposes a simple, fast and inexpensive method of measuring the saturation properties of magnetic components and their cores and offers a simple technique for determining the saturation specification for a ferrite core.

Introduction

"Equivalent" ferrite cores manufactured by different suppliers in different plant locations around the world are typically "equivalent" only in dimensions, inductance index (A_L value) and maybe even in core loss but often have dissimilar saturation characteristics. Engineers in our magnetics industry usually neglect to specify saturation requirements of magnetic cores and the components they are used in. Users typically qualify ferrite cores from a specific supplier by testing samples in their application. If the supplied samples function properly, do not saturate and have acceptable temperature rise, the supplier's part number is approved and added to the approved vendor list which signals that the buyers may purchase this part number from this approved supplier. This process is adequate as long as the supplier continues to manufactures the production volumes using the same raw material sources, same recipe, same process and same equipment. In today's globalized world, production quantities of "qualified" part numbers are often private labeled for one ferrite manufacturer by another ferrite manufacturer. The result of this is that "qualified" part numbers are commonly being manufactured from different raw material sources, in different equipment and processes, and in different countries from where the original "qualified" samples had been manufactured. These production volumes often have saturation properties that are dissimilar to the samples the user qualified. Users can easily know if the production volumes are manufactured in a different location from were the original samples had been manufactured by comparing certificate of origin receipts of the original samples vs. each production volume shipment received. The dimensions, A_L values and even core losses of each production shipment

may all be within the specified tolerances but the saturation properties are most often dissimilar when compared to the original sample.

The saturation properties of a magnetic core are equally if not more important than dimensions, A_L value and core loss and should also be specified measured and monitored. In many applications if the core saturates, the inductance and impedance of the component decreases and causes the circuit currents to escalate. Excessive currents can cause other circuit components (semiconductor switches, diodes, capacitors) to fail. The saturated core is hard to determine as the root cause since this failure mode typically exhibits no permanent damage to the ferrite core and the magnetic component. The core and magnetic component still exhibit dimensions, A_L values and even core losses all within the specified tolerances.

The Saturation Property

A magnetic material is saturated when increases in magnetizing force (H) no longer appreciably increase the magnetic induction (B). Saturation flux density (Bs) is the value of magnetic flux density when the material reaches its limit with respect to the number of flux lines per unit area it can efficiently conduct. Hysteresis curves show the relationship between a magnetizing force (H) and the resultant magnetic induction (B).
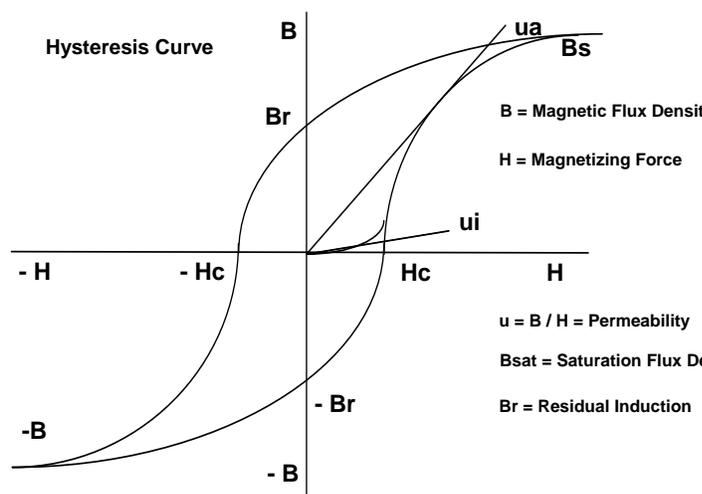

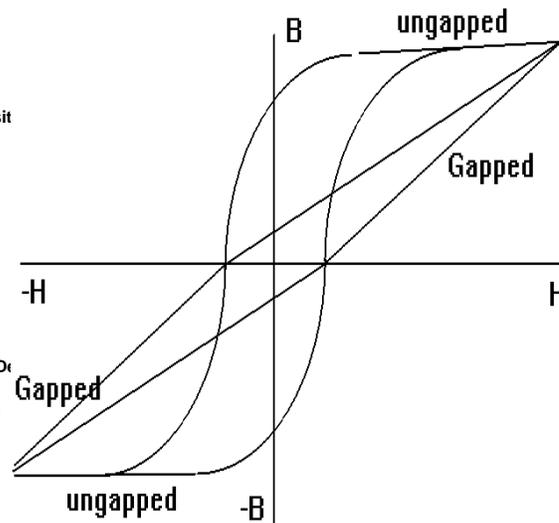Figure 1A   Figure 1B

The slope of flux density (B) divided by magnetizing force (H) is the effective permeability. Permeability is a materials ability to conduct magnetic flux relative to air and is proportional to a components inductance. Note that as the material saturates the slope of B/H decreases, thus the inductance of a component decreases. Introducing an air gap in the magnetic flux path sheers the hysteresis loop so that it requires more magnetizing force to saturate the core. The more air gap introduced into the flux path the lower the permeability (ratio of B/H). Note that the saturation flux density is unchanged even though a gapped core requires more magnetizing force before reaching saturation.[1]

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A ferrite core's saturation properties are a direct result of the ferrite's composition and their final sintered density. Many variables contribute to a ferrite core's final sintered density. Raw materials from one source may be less pure and more reactive than raw materials from a different source. Every ferrite manufacturer around the world has a unique process. Some wet mix, others dry mix. Some calcine (homogenize by pre-heating powder to ~1000 degrees) in rotary calciners, other may use car kilns or batch kilns to calcine. The calcined material may be in the form of powder, agglomerated pellets or calendered ribbon dependent upon the manufacturers preference. Each ferrite manufacturer has their own unique milling process and each chooses to mill particles to a unique size. Smaller particle sizes are more reactive and therefore the pressed parts can be sintered at lower temperatures or for shorter time compared to ferrite grades that are milled to a larger particle size that must be sintered at higher temperatures or for longer times. Each ferrite manufacturer spray dries pressable powder to a unique agglomerate size with a unique binder and binder content. Each ferrite manufacturer, powder compacts their pressable powder to a unique pressed density with planned shrinkage to compliment their chosen process methods. Finally some manufacturers use continuous kilns while others use more controllable batch or elevator kilns that have advanced capabilities that cannot be duplicated in continuous kilns. To further complicate process consistency between manufacturers is the fact that there are many equipment manufacturers in each part of our world that offer unique machines that result in unique product properties regardless of all the chosen methods.

It is difficult to compare published saturation flux densities (Bs) between manufacturers because each manufacturer specifies saturation flux density (Bs) driven to different magnetizing forces (H) measured on different size and shape test specimens. Since ferrite manufacturers publish saturation flux density (Bs) at very high magnetizing forces (H) were the materials are driven well into saturation, this published data fails to portray differences between material grades at practical levels were the materials begin to saturate, before or near the point were the hysteresis loop closes.

Measuring Saturation Properties

Monitoring the saturation properties of ferrite core by measuring hysteresis curves in a production environment is not practical since the equipment required to drive large or gapped cores into saturation and the sophisticated equipment required to integrate the voltage wave-form which distorts as saturation is approached is very expensive. Measuring hysteresis curves requires a primary coil to drive the magnetizing current and a secondary coil to sense the flux density. Many inductors have only one winding. To measure a hysteresis curve for quality control purposes, the cores would have to be assembled with a primary and a secondary test coil, and then reassembled with just the one coil for the inductor application.

An adequate and cost effective measure of saturation is to simply measure the inductance on an LCR meter and increase a dc bias current until the inductance decreases. When the core saturates the inductance abruptly decreases. Large and small, gapped and ungapped cores can be

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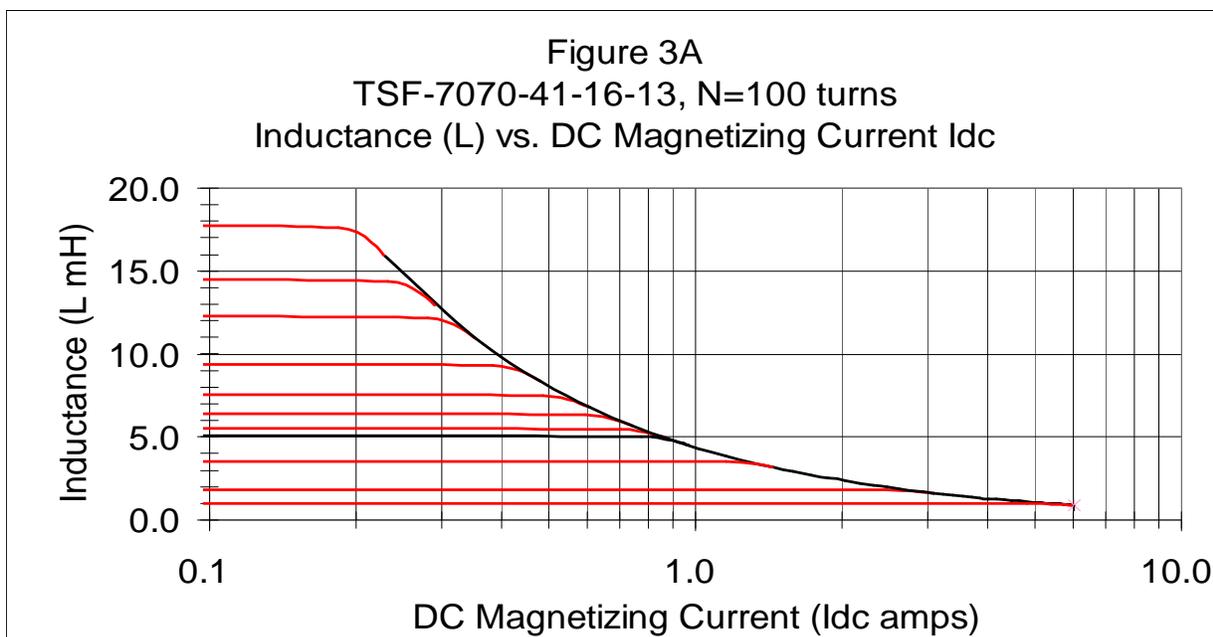by George G. Orenchak

measured in this manor using a single coil and a relatively inexpensive LCR meter with a dc bias current. Wayne Kerr Electronics model 3265/5A, /10A, /20A or /25A dc bias units paired with their 3255B inductance analyzer or 3260B precision magnetics analyzer are easy to use.
As many as 5 of their 3265/25A dc bias units can be used in parallel to achieve up to 125 amps of dc bias current.[2]


Figure 2

Determining a Core's DC Current Bias Capability

Inductance (L in mH) vs. I_{dc} for several different center leg gap depths on an E21 (41-16-13) size core in TSF-7070 material and measured with a 100-turn coil are shown in figure 3A. With only a few data points a curve made from the tangents of the knees of these curves can be used to identify the capability of this core size to support a given I_{dc} with a 100 turn coil if center leg gapped to any specific Inductance (L) value. The curve made with the point's tangent to the knee of each curve for the different gap depths is an inverse-exponential relationship.

Figure 3A
TSF-7070-41-16-13, N=100 turns
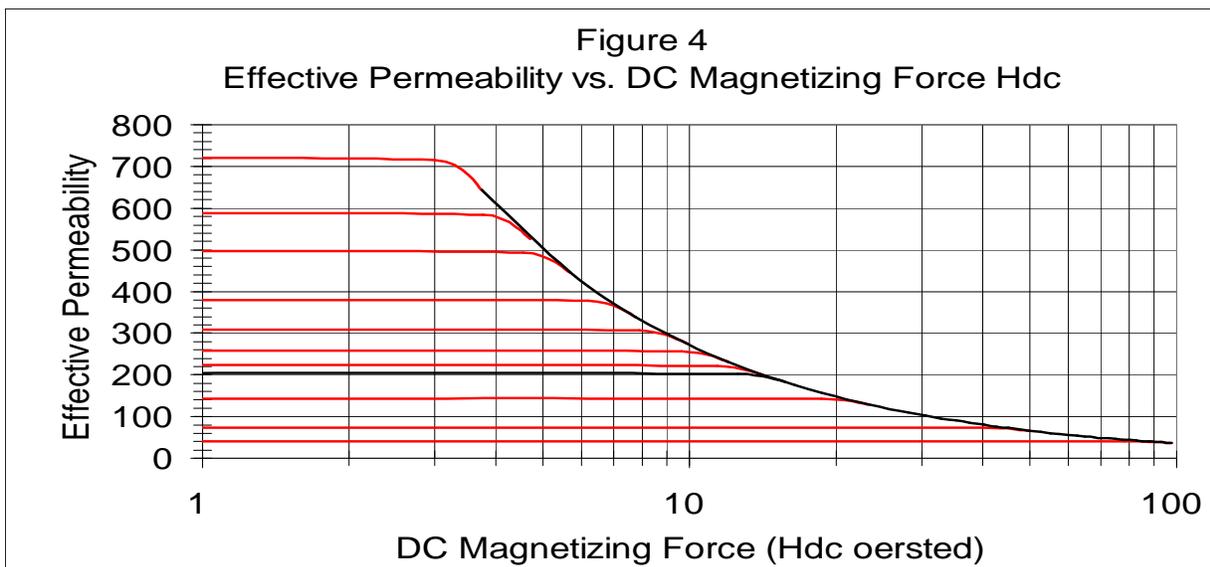Inductance (L) vs. DC Magnetizing Current Idc

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By converting the vertical axis from inductance (L in mH) to inductance index (A_L values in nH/N^2) and the horizontal axis from I_{dc} to ampere-turns (NI_{dc}), the data collected on this core size with this 100 turn count can be used to predict the capability this core size regardless of the turn count. Inductance index (A_L values in nH/N^2) vs. ampere turns (NI_{dc}) for several different center leg gap depths on an E21 (41-16-13) size core in TSF-7070 material are shown in figure 3B.

Figure 3B
TSF-7070-41-16-13
Inductance Index (AL) vs. NIdc (amper turns)
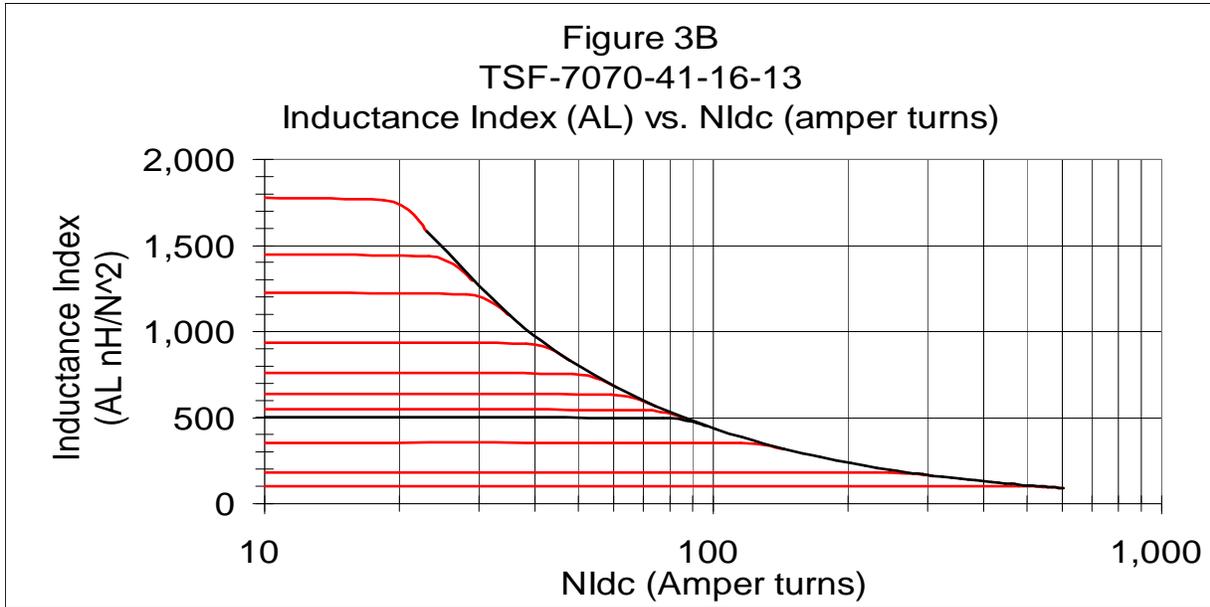
By converting the vertical axis from A_L value to effective permeability and the horizontal axis from ampere turns (NI_{dc}) to magnetizing force (H) the data collected on this core size can be used to predict the capability of any center leg gapped core size and shape (figure 4).[3]

Figure 4
Effective Permeability vs. DC Magnetizing Force Hdc

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$\mu_e = (A_L N^2)/(4 \Pi A_e 10^{-9}/L_e)$
$H_{dc} = 0.4 \Pi NI_{dc}/L_e$

A_L = Inductance Index (nH/N^2)
N = number of turns
H_{dc} = magnetizing force in oersteds
L_e = magnetic path length in cm
I_{dc} = dc current in amps
Π = Ratio of a circle's circumference to its diameter (3.14159•••)

Pitfalls - Theory vs. Reality

The dc bias capability of cores with non-uniform cross sectional core area throughout the magnetic path can be conservatively estimated by using such core's minimum cross sectional core area. This minimum core area will saturate first and at a lower magnetizing force than portions within the magnetic path that have larger cross sectional area and the inductance will roll-off into saturation a slower than a core with uniform cross sectional area. Using the smallest cross sectional area in the flux path is a fair and conservative approach.

A core with a distributed gap, such as when a non-magnetic material is assembled between all the mating surfaces of a two piece core set, typically is capable of supporting a different magnitude of magnetizing force compared to a core set with a recess ground center leg gap when both core sets are gapped to the same A_L value. This is because fringing flux that intersects the winding, increasing the inductance value is less when the gap is distributed. Since the fringing flux intersecting the coil increases the inductance, this causes the distributed gap to be mechanically smaller than a center leg gapped core set if both are gaped to the same A_L value. The deeper center leg gap shears the hysteresis loop more than the shallower gap. More magnetizing current is needed to saturate a core set with the deeper center leg gap compared to the core set with the shallower distributed gap. This same fringing flux issue causes differences due to winding construction to also cause variations between calculated values and practical results measured on components. The more flux lines that stray and intersect the winding, the deeper the gap needs to be for the same A_L value. As the gap deepens the hysteresis loop shears further and the more magnetizing current is required to reach saturation.

Figure 5
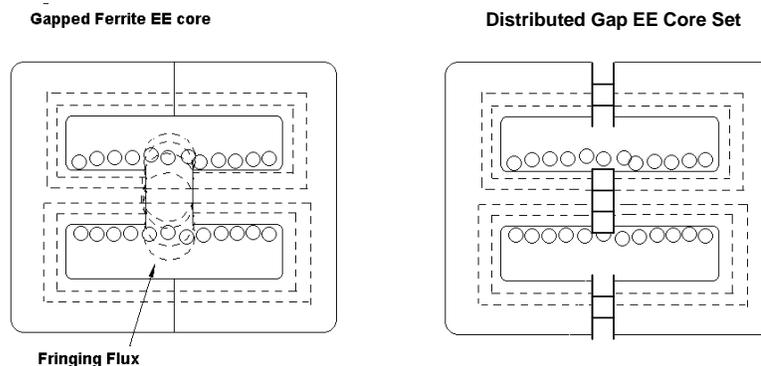
Gapped Ferrite EE core   Distributed Gap EE Core Set

Fringing Flux

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Spreadsheet Tool to Ease the Job of Specifying Bias Current

TSC Ferrite International has characterized the saturation properties of each of their ferrite material grades by determining the dc current biasing capability for cores center leg gapped to various effective permeabilties per the method described above. Furthermore TSC Ferrite International has developed a mathematical model of the effective permeability vs. dc magnetizing force for each of their material grades and has used this mathematical model to develop an easy to use tool in the form of an excel spreadsheet. [4] Users can enter the material grade, core size, A_L value and turn count of their design and the spread sheet returns the dc current for a 10% inductance roll-off such a component will support.

Example of the Excel Spread sheet

DC Bias Analysis

Type in material grade & part size in blue at A10& B10

Enter your turn count and Inductance Index (AL) in blue at cells A27 & B27 and read the maximum dc current for no more than 10% inductance roll off in cell E27

7070 41-16-13

Enter Your Turn Count N	Enter Your Inductance Index (AL) (nH/N^2)	Inductance with no Idc mH	Effective Permeability Ue	Inductance at 10% Rolloff mH	Maximum Idc for 10% or < Inductance Rolloff Idc max. (amps)	DC Magnetizing Force (H) Oersteds	Mechanical gap depth Inches
100	485	4.850	197	4.365	1.001	16.22	0.0147

This excel spreadsheet tool should be used to easily specify the inductance with dc current amplitude for all magnetic components that could saturate.

Summary

To prevent failures caused by the saturation of substituted or private labeled ferrite cores, it is prudent to specify, measure and monitor the saturation properties of all ferrite cores and the components they are used in. An easy, practical and affordable method to measure the saturation properties of ferrite cores is to measure inductance with a dc current bias. The inductance will not decrease unless the dc current applied pushes the core into saturation. Mathematical models of the effective permeability vs. dc magnetizing force for each ferrite material grade are used to easily determine the maximum dc bias current any particular core, (shape, size, A_L value) can handle before the core saturates. These methods can be used to easily and quickly specify the dc bias current for every ferrite core and magnetic part number.

Acknowledgement

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