Design to “Boost” Inductance under Direct Current Bias Conditions

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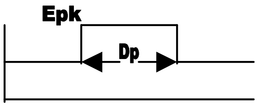
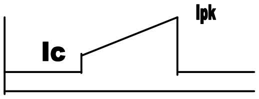
Abstract: Magnetic theory with a small alternating magnetizing force supper imposed on a static magnetizing force is briefly explained with the use of hysteresis loops. The purpose and creation of the Hanna curve design approach is explained. An improved soft ferrite material named "Boost" is introduced and output inductor design examples using the new material and the Hanna curve approach are given.

Certain applications require a component to provide a minimum inductance to filter out unwanted pulse waveforms while passing direct current. For example the pulses created by switching transistors can be removed by an output inductor so that a clean dc output signal is obtained. The minimum inductance needed to remove the pulse can be calculated as follows.



Voltage Waveform

Inductance = Epk Dp / (Ipk – Ic)



Current Waveform

Understanding some magnetic theory is helpful when designing the inductor component. A hysteresis loop is a curve showing the relationship between magnetizing force (H) and the resultant magnetic induction (B) (Fig. 1). Saturation (B_s) 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. Fig. 1 shows small operational hysteresis loops for a small ac signal (the size of the unwanted pulse waveforms) within the major material hysteresis loop for an ungapped core structure. The first small loop has no direct current bias so it operates well below saturation near the major material loop’s origin. The effective permeability (the slope of B/H) is high. Permeability is the ability of a material to conduct magnetic flux and is important because it is proportional to the components inductance. As the dc bias current is increased the operational hysteresis loop is pushed up the major material hysteresis loop. As it nears saturation the effective permeability (the slope of B/H) decreases (rolls off). Introducing a gap in the magnetic path length of the core structure causes the material’s major hysteresis loop to shear over so that it requires more magnetizing force before saturating. The effective permeability with no dc is a little less due to the gap but the core is able to support much more dc magnetizing force (H) before the effective permeability (B/H slope) decreases. The deeper the gap the more the major loop shears over. The core design becomes a balance of gapping the core enough to shear the loop over far enough to support the dc magnetizing force while keeping the effective permeability high so that the core size and coil turn count are no larger than necessary.

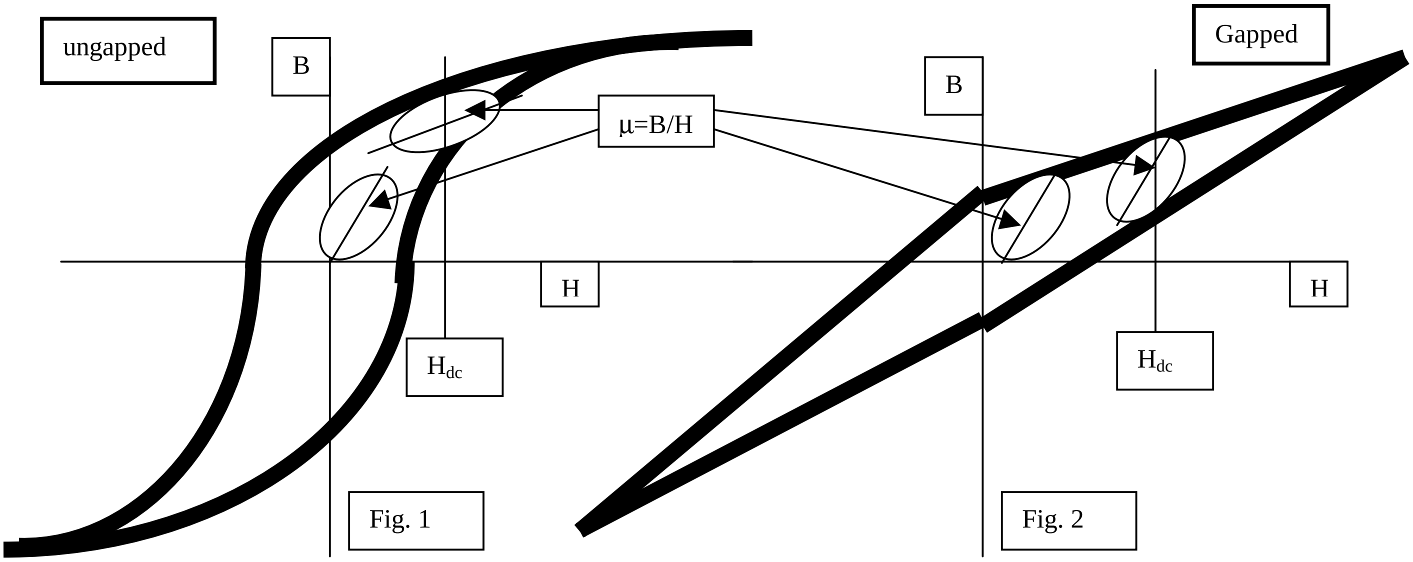


Fig. 1

Fig. 2

“Boost” is a new material grade available from TSC Ferrite International. It has been designed to handle more dc magnetizing force before the inductance rolls off. Inductance Indexes (A_L values in nH/N^2) vs. NI_{dc} for several different gap depths on an E21 (41-16-13) size core in Boost material are shown in fig.3. 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 NI_{dc} if gapped to any specific A_L value. The curve made with the points tangent to the knee of each curve for the different gap depths is an exponential relationship.

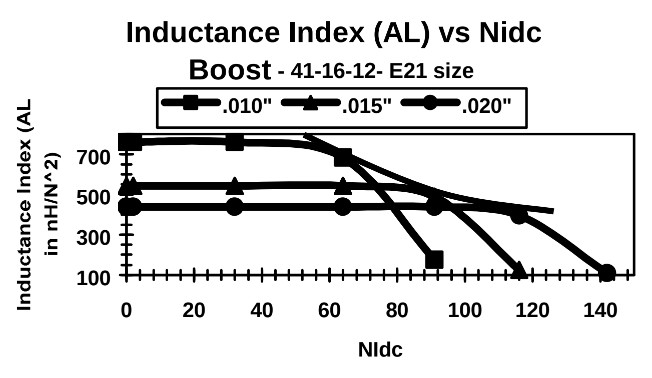


Fig. #3

By converting the vertical axis from A_L value to effective permeability and the horizontal axis from NI_{dc} to magnetizing force (H) the data collected on this core size can be used to predict the capability of any core size and shape. (see Fig. #4)

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

$H = 0.4\Pi NI_{dc}/L_e$

A_L = Inductance Index (nH/N^2)
N = number of turns
H = magnetizing force in oersteds
L_e = magnetic path length in cm
I_{dc} = dc current in amps

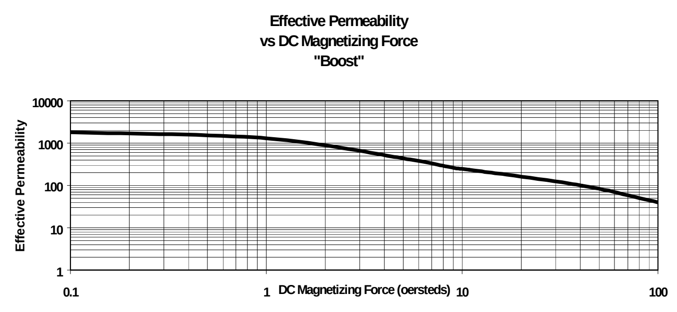


Fig #4

The data can also be used to create a design tool known as a “Hanna curve” by plotting the inductance (L) times the square of the direct current (I_{dc}^2) divided by the core volume V_e vs. the dc magnetizing force (H_{dc}) where the inductance value rolls-off. A gap factor curve which is the core gap divided by the core’s magnetic path length vs. the dc magnetizing force (H_{dc}) where the inductance value rolls-off is also useful (see Fig. #5). Together these two curves are used to select a core size, calculate the coil turns and determine the core’s gap depth.

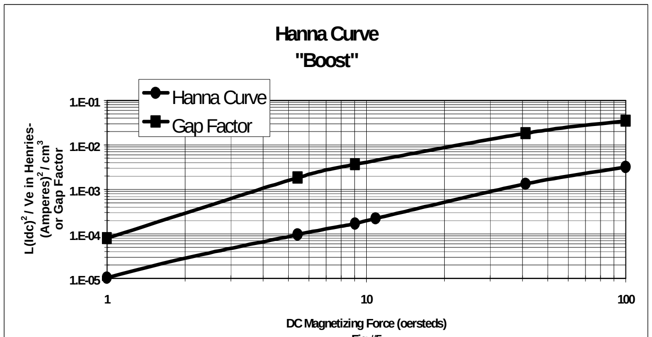


Fig #5

Calculate $L(Idc)^2$ / Ve in Henries-$Amperes^2/cm^3$

Read DC Magnetizing force (H in oersteds) at the value where ($L(Idc)^2$ / Ve) intersects Hanna Curve

CalculateTurns N = (H Le) / (0.4 π Idc)

Calculate Gap = (Gap Factor) (Le / 2.54)

L = desired Inductance in Henries
Idc = dc bias current in amps
Ve = effective core volume in cm^3
N = turns on coil
H = magnetizing force in oersteds from Hanna Curve
Le = magnetic path length in cm
Gap = core gap in inches
Gap Factor = value from gap factor curve at same DC Magnetizing Force as Hanna curve

The following tables show examples of inductor designs for 1 millihenry with 1.0 dc amp using the Hanna curve and gap factor curve for the new "Boost" material. The 25-10-06 is the standard EE2425 core size. The 25-10-13 is double thick to show how a larger cross sectional area reduces the turns and the required gap depth. The 25-16-06 has longer legs, longer winding window length and a longer magnetic path length. It is not the best choice because it requires more coil turns and a deeper gap.

Part #	Le	Ae	Ve	Wa	L	Idc
TSF-7070-25-10-13	4.899	0.787	3.856	0.850	0.001	1.0
TSF-7070-25-16-06	7.408	0.399	2.954	1.652	0.001	1.0
TSF-7070-25-10-06	4.899	0.394	1.928	0.850	0.001	1.0

Part #	LIdc/Ve	H	N	NIdc	AL	Lair	Perm	B
TSF-7070-25-10-13	2.59E-4	12	47	47	457	2.02	226	2716
TSF-7070-25-16-06	3.39E-4	15	88	88	128	0.68	189	2834
TSF-7070-25-10-06	5.19E-4	21	82	82	149	1.01	148	3100

Part #	Gap Factor	Gap
TSF-7070-25-10-13	4E-3	0.0077
TSF-7070-25-16-06	5E-3	0.0146
TSF-7070-25-10-06	7E-3	0.0135

Fig 6 show measurements made on samples per the Hanna curve designs fit the effective permeability vs. dc magnetizing plot for the new Boost material.

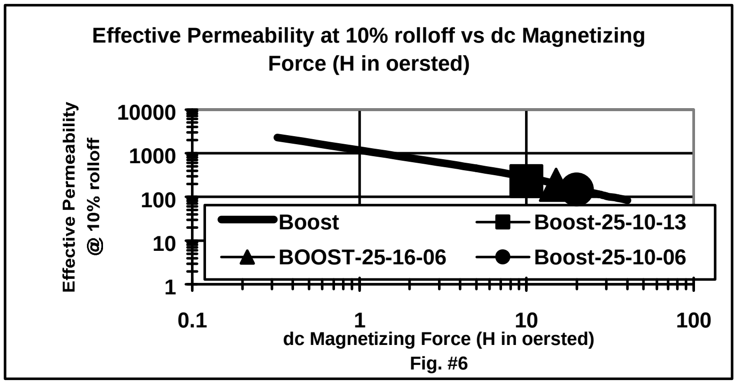


Fig. #6