"Boost" Material Improves Inductor Characteristics Under DC Bias Conditions

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> A new soft ferrite material named "Boost" handles more dc magnetizing force (than previous core materials) before its associated output inductance value rolls off due to saturation effects.

Certain applications require a component to provide a minimum inductance to filter out unwanted pulse waveforms while passing direct current. For example, 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 pulses can be calculated from the voltage and current waveforms (*Figure 1*):

Inductance = Epk Dp / (Ipk – Ic) (1)

An understanding of 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) shown in *Figure 2*. 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.

The left side of *Figure 2* 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 small operational loops in *Figure 2* with no dc bias operate well below saturation near the major material loop's origin. The effective permeability (the slope of

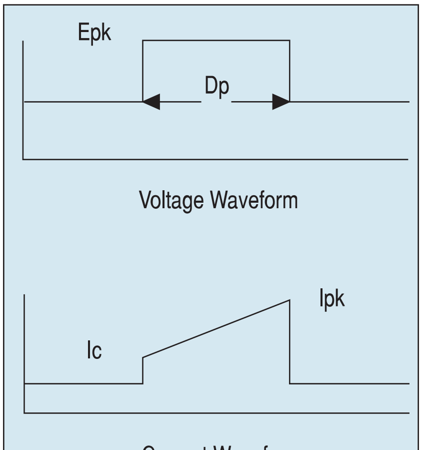

Figure 1. *Pulse voltage and current waveforms.*

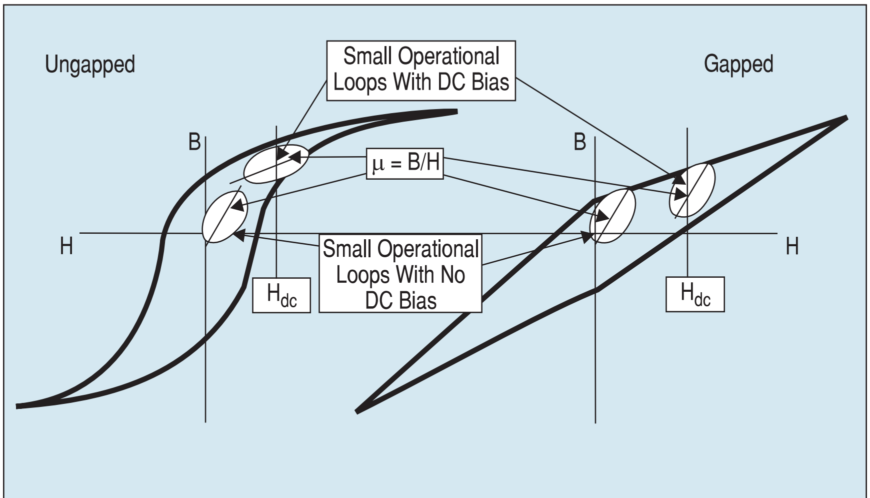

Figure 2. *Hysteresis loop for gapped and ungapped core material.*

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.

"Boost" is a new material grade designed to handle more dc magnetizing force before the inductance rolls off. Inductance Index AL is an industry term that describes a core's ability to provide inductance in nH/turn squared. NI_{dc} is the required ampere-turns that are needed. *Figure 3* shows the Inductance Indexes for several different gap depths on an E21 (41-16-12) size core of Boost material. 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 given ampere turns (NI_{dc}) if gapped to any specific Inductance Index (A_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.

By converting the vertical axis from the Inductance Index (A_L value) to effective permeability (μ_e), the data collected on this core size can be used to predict the capability of any core size and shape. Equation (2) calculates the effective permeability.

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

Using Equation (2), and the horizontal axis from ampere turns (NI_{dc}) provides the magnetizing force (H). *Figure 4* shows the effective permeability vs. the dc magnetizing force for the Boost material.

$$H = 0.4\pi NI_{dc}/L_e \qquad (3)$$

A_L = Inductance Index (nH/N^2)
N = Number of turns
H = Magnetizing force in oersteds
L_e = Magnetic path length in cm

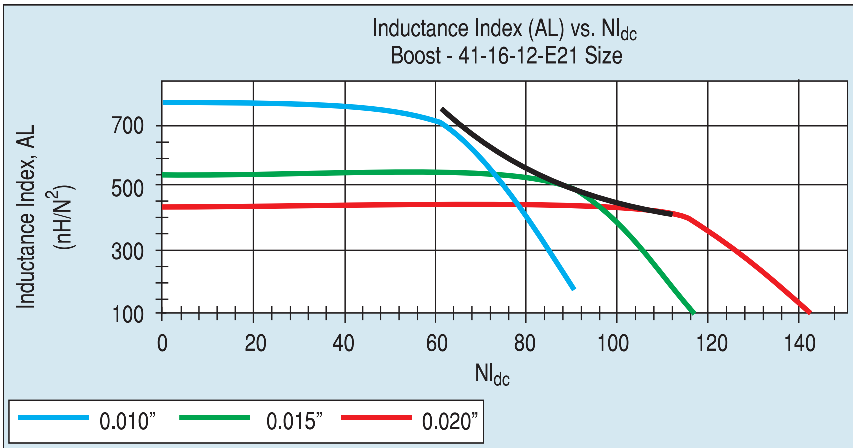

Figure 3. *Inductance index Vs NI_{dc}.*

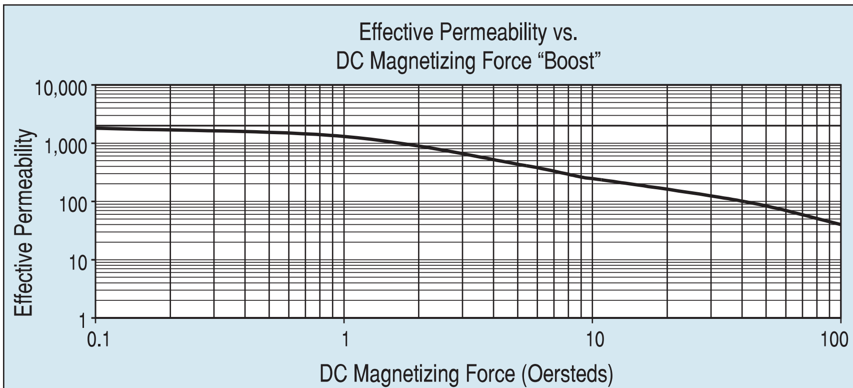

Figure 4. *Effective permeability Vs dc magnetizing force (H_{dc}).*

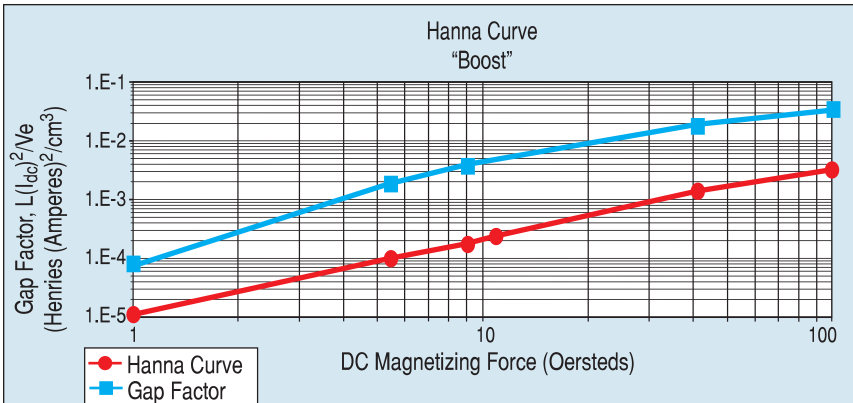

Figure 5. *Gap factor and Hanna curve.*

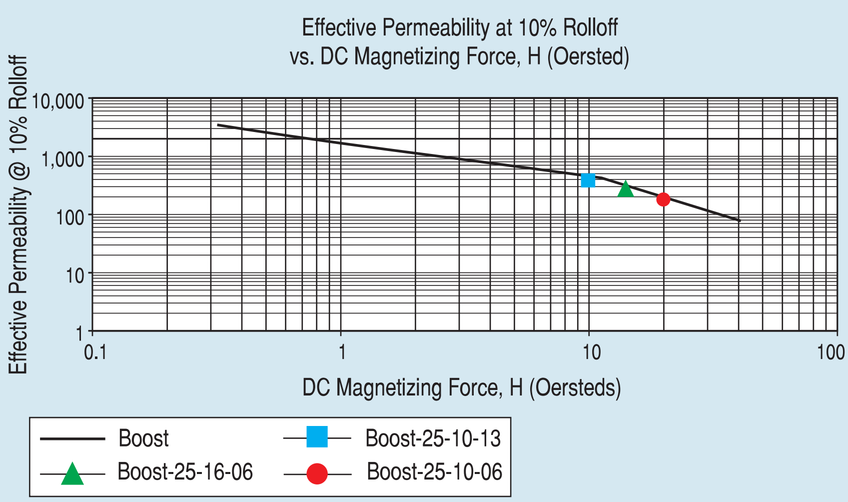

Figure 6. *Effective permeability Vs H_{dc}.*

	Magnetic Path Length	Core Area	Core Volume	Core Window Area	Inductance	Direct Current
Part #	L_e (cm)	A_e(cm^2)	V_e (cm^3)	W_a (cm^2)	L (H)	I_{dc} (A)
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

Table 1. *Core set arameters and design requirements.*

Part #	LI_{dc}/V_e	Magnetizing Force (H) Oersteds	Turns (N)	Ampere Turns (NI_{dc})	Induct-ance Index (A_L)	Effective Permeability (μ_e)	Flux Density (B) Gauss
7070-25-10-13	2.59E-4	12	47	47	457	226	2716
7070-25-16-06	3.39E-4	15	88	88	128	189	2834
7070-25-10-06	5.19E-4	21	82	82	149	148	3100

Table 2. *Calculated design results including turns.*

I_{dc} = dc current in amps

The data can also be used to create a design tool known as a "Hanna curve" by plotting $\frac{L \times I_{dc}^2}{V_e}$ vs. dc magnetizing force, Hdc, where the inductance value rolls off.

Where:

L = Inductance (in Henrys)

I_{dc} = dc current (in amperes)

V_e = Core volume (in cm^3)

A gap factor curve, which is the core gap divided by the core's magnetic path length (L_e) vs. the dc magnetizing force (H_{dc}) where the inductance value rolls off is also useful (*Figure 5*). Together these two curves are used to select a core size, calculate the coil turns and determine the core's gap depth as follows:

1. Calculate $L(I_{dc})^2/V_e$ in Henrys-Amperes^2/cm^2
2. Read dc magnetizing force (H_{dc}) at the value where $L(I_{dc})^2/V_e$ intersects the Hanna curve
3. Calculate turns: $N = \frac{HL_e}{0.4\pi I_{dc}}$
4. Calculate gap: $\frac{GapFactor \times L_e}{2.54}$

L = Desired inductance in Henrys

I_{dc} = DC bias current in amps

V_e = Effective core volume in cm^3

N = Turns on coil

H = Magnetizing force in oersteds from Hanna curve

L_e = Magnetic path length in cm

Part #	Gap Factor	Gap (in.)
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

Table 3. *Calculated design results for gap depths.*

Gap = Core gap in inches

Gap Factor = Value from gap factor curve at same dc magnetizing force as Hanna curve

Tables 1, *2* and *3* show examples of a 1 millihenry inductor with 1.0 dc A 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.

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

References

1. E. C. Snelling, Soft Ferrite Properties and Applications, Butterworth & Co., Ltd., 1988
2. Soft Ferrite Guidelines, Magnetic Materials Producers Association, 1998.

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