TECH TIP 1A: HOW ARE POWDER CORES DIFFERENT?

Almag

INTRODUCTION

Powder cores are a small but important family of materials that bridge the gap between low frequency strip cores and high frequency ferrite cores. Their unique combination of high saturation flux, relatively low core loss and distributed airgap makes powder cores an ideal solution for chokes and inductors used in many power conversion applications.

Why are powder cores better? That really should have been why are powder cores sometimes better: sometimes they are better, and sometimes they are not. It depends what you try to do with them.
For storage chokes of all types, yes, they can be better. Sometimes much better.
For transformers, resonant inductors and common-mode chokes then no, they are not better.

What do I mean by "better", and why are they better?
Because they have properties that are at the same time both similar to and different from ferrite, we can take advantage of the differences to make storage chokes that take up less space and cost less.
That applies to many choke types, including pfc chokes, output chokes and differential emc chokes.
The difference is that they not only have a higher saturation, but it is also a "soft" saturation.

In this first series of Tech Tips that I shall be sending out over the next few weeks, I shall be going through from the basic properties of powder cores, the different material types and grades available, and how to take full advantage of their properties in actual choke designs.

First, we need to go back to first principles.

THE CRITICAL MAGNETIC PARAMETERS

Many parameters are specified for magnetic materials, in a mixture of units that makes direct comparison difficult. For storage, pfc and emc chokes the important parameters are:-

Saturation flux density

Determines the maximum volts per turn in a transformer, and the saturation current of a choke.

Core losses

Limit the upper useable frequency of each particular material type, from temperature rise effects or by rolling-off the permeability at high frequency.

Permeability

Determines the magnetising current in a transformer and, more importantly, is the parameter that provides an inductor with inductance.

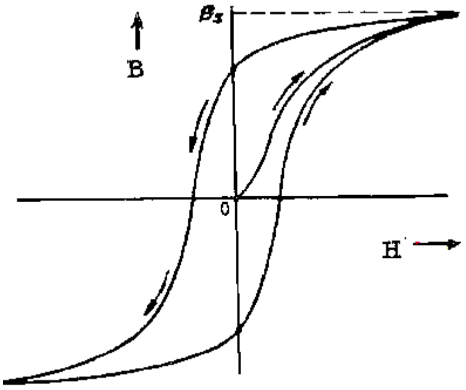


Fig.1

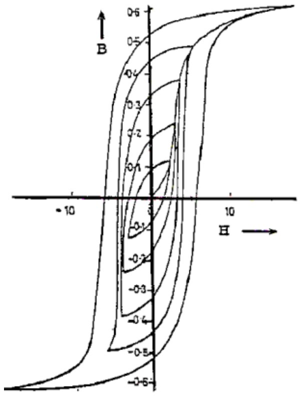


Fig.2

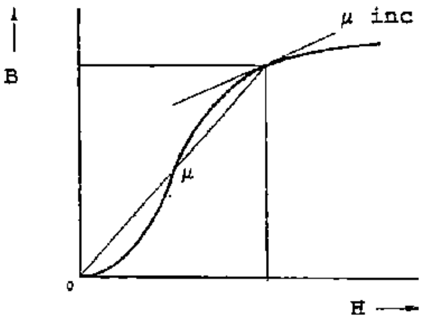


Fig.3

Fig.1 shows the hysteresis loop of a material driven to saturation. The saturation flux density, Bs, can be clearly seen as the value of flux density B that cannot be increased, no matter how much the value of the magnetising force H is increased.

Fig.2 shows the family of hysteresis loops for a core driven to a range of flux densities below saturation. This is unwieldy to use.

Fig.3 shows the magnetisation curve that we use instead. This is formed by plotting the tips of the B-H hysteresis loops.

THE CRITICAL MAGNETIC PARAMETERS (contd)

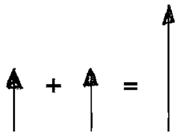
The permeability (u) of the core is the ratio of B/H at any point on the magnetisation curve, and reflects how easily the material can be magnetised. Most magnetic materials are inherently non-linear, and the permeability will vary at different drive levels on this curve.

The slope of the curve at any point is known as the incremental permeabilty (u inc), and is a very important parameter when designing a choke that has to work with a level of standing dc or 50/60Hz ac current which biasses the core to a point part way along its magnetisation curve.
This slope, as dB/dH, represents the coil voltage that results from a change of coil current, and so determines the effective inductance that the coil presents to a high frequency ac signal.

FERROMAGNETICS vs FERRIMAGNETICS

All of the commonly used magnetic materials fall into one of two basic groups, and are either ferromagnetic or ferrimagnetic. The physical properties of the two groups are so widely different that each would naturally lay claim to opposite ends of the power electronics frequency spectrum.

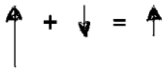
Ferromagnetic



Bsat = 0.8T - 2.0T

The individual magnetic dipoles will align with the magnetic field and reinforce to give a high Bsat of 0.8T to 2.2T (Teslas).
Ferromagnetic materials include iron, nickel and cobalt, and a variety of alloys of these materials.
As metallic materials they have limited resistivity, giving higher eddy-current losses and are naturally suited to low frequency operation.

Ferrimagnetic



Bsat = 0.35T - 0.55T

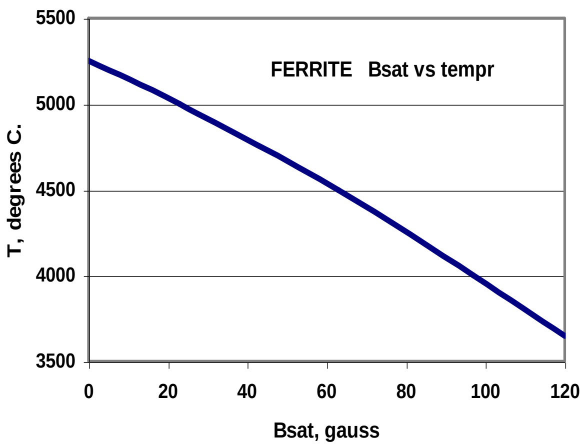
The individual dipoles are of two types.
The larger diploes align with the field, whilst the second, smaller dipole aligns against the field. This interference effect gives a low Bsat of 0.3T to 0.5T.

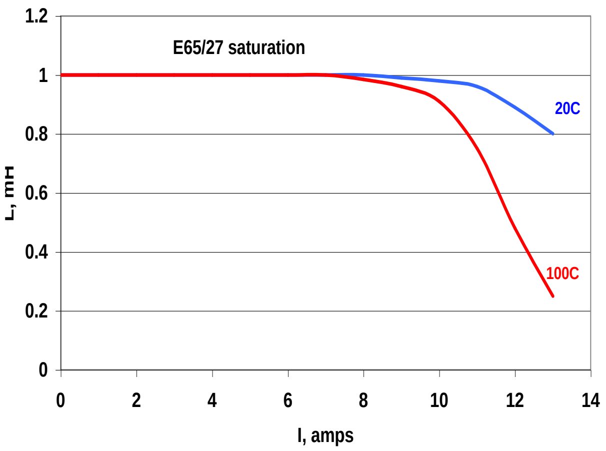
Ferrites are sintered alloys of iron oxide, and are ceramics with high resistivity and low eddy current losses, naturally suited to high frequency operation.

FERRITE CORES

The ferrites used in power conversion are normally MnZn (manganese-zinc) grades.
These have a Bsat of around 0.5T at 25°C, but this falls continuously with increasing temperature, and by 100°C will have reduced by about 20%.

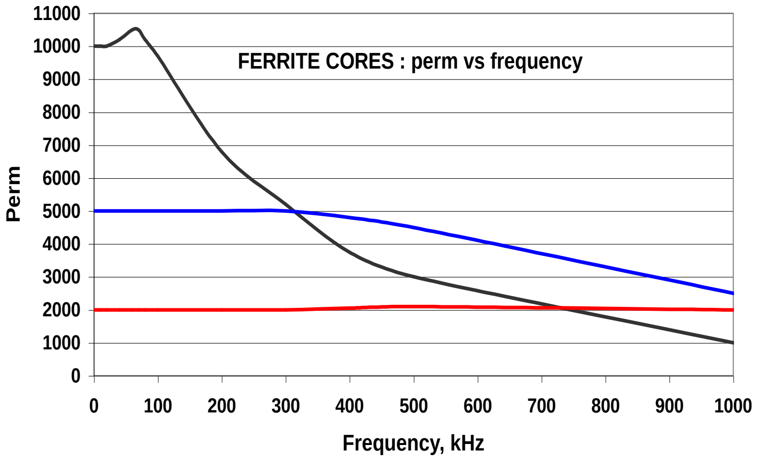
The volts/turn from a transformer will drop correspondingly, as will an inductor saturation current.
This effect can be demonstrated from actual testing of a 6.5A rms E65/27 cored boost power factor correction choke, which had a saturation current of 13A at 20°C, and as expected this fell to 10.7A at 100°C.





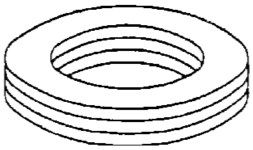
FERRITE CORES (contd.)

An advantage of ferrite cores is that the high resistivity of the ceramic material gives low core loss at high frequency, and a core permeability that holds-up to well over 1MHz for the 2,000u power grades.

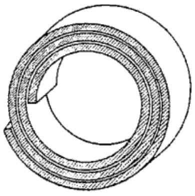


FERROMAGNETIC TAPE CORES

Ferromagnetic materials have the big advantage of a high saturation flux density, Bsat.
But as metallic materials they have the disadvantage of low resistivity.
It is possible to reduce the resulting eddy current losses by reducing the material thickness to limit their circulation path. Laminations may be stamped from thin strip, or a spiral of insulated strip can be wound into a toroidal tape core.



Lamination stack



Tape core

Additionally, the resistivity of iron can be increased by alloying with silicon.
Nickel iron alloys have significantly lower losses, and strip thicknesses down to 0.025mm have been used for high power inverter transformers to around 20kHz.

FERROMAGNETIC POWDER CORES

An alternative method of reducing eddy current losses is to use a powder core, where individual small metallic particles are seperated by an insulating coating.

For inductors this has the added advantage of adding a distributed airgap into the magnetic circuit.
By carefully controlling the particle size and the insulating coating various standard core permeabilites can be produced, offering well defined permeability and saturation characteristics.

To simplify the calculation of inductance the core manufacturer quotes a closely toleranced A_L value for each core type, and inductance is then given by $L = N^2 / 1000^2 \times A_L$.

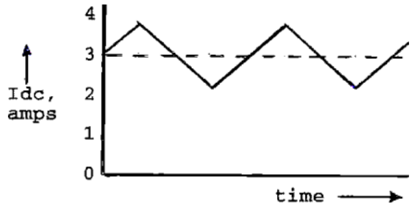
With a distributed gap core, the saturation characteristic becomes much "softer" than the abrupt "hard" saturation of a discrete airgap, important where the core has to cope with the high peak/rms ratio of ac chokes, peaky transients or short term overload conditions.

The actual incremental permeability will depend on the powder core material and on the permeability grade, and curves are published by the manufacturers for each family of powder cores.
Examples of these are shown in Tech Tip 1B "Which Type of Powder Core".

The dramatic reduction in eddy currents not only reduces core loss but also allows the core permeability to hold up to 0.3Mz or more, making powder cores suitable for high frequency power inductors and differential interference suppression emc chokes.

CORES FOR STORAGE CHOKES

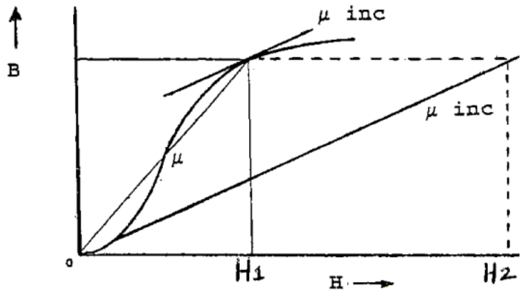
Many applications need a choke that can maintain a high frequency inductance when passing a dc or 50/60Hz ac bias current. An important example is a SMPSU output storage choke, where the ripple current can vary from 20kHz for a high power unit, to over 500kHz for a switching regulator.



It would be possible to use an ungapped core and rely on the incremental permeability of the core, but this would need a very large core. It is better to use a gapped magnetic circuit to reduce the effective permeability and to increase the saturation magnetising force to give a higher energy storage capability.

In the example shown, the upper curve is for an ungapped core, and the lower curve is for a gapped core. At points H1 and H2 respectively they have the same incremental permeabilty.

For the gapped core:-
H2 = 3 x H1
Turns, N = x3 (proportional to H)
Inductance = x9 (proportional to N^2)

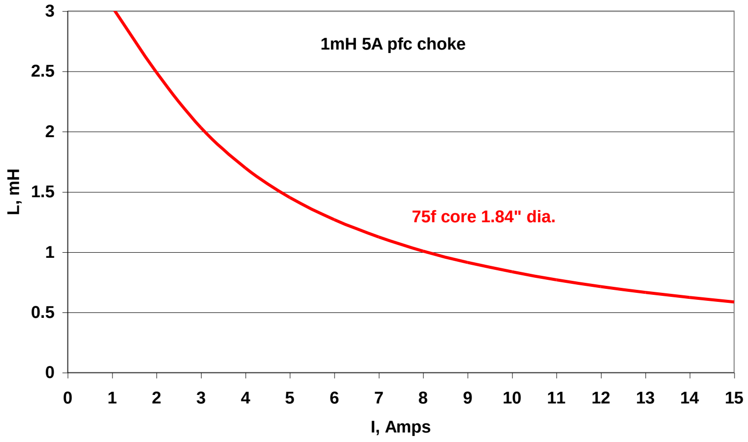


SOFT SATURATION

In a powder core the gap is distributed around the core as a series of very small gaps between the powder particles. This gives a low flux leakage, which is important for radiated emc and when the cores are positioned close to a CRT display.

An important further advantage is that powder cores have a "soft saturation" characteristic, where the permeability gradually rolls-off with increasing current bias, so that a useful inductance is maintained at three or four times the thermal current rating.
Compare this with the quite abrupt saturation characteristic of the E65/27 ferrite core shown earlier.

The fall-off for a 5Arms 1mH pfc choke on an inexpensive iron powder core is shown below.



This has an inductance of 1.45mH at 5A, 1.0mH at the 8A operating peak, and still holds-up 0.6mH at 15A ie 3 times the thermal current rating.
That is what is meant by a "soft-saturation" characteristic.

In the Tech Tip 1B, we will show how to take advantage of this characteristic to design smaller and lower cost chokes, and give a summary of the four different families of power cores that are readily available.