TECH TIP 1B: WHICH TYPE OF POWDER CORE?

Almag

INTRODUCTION

Because powder cores have properties that are at the same time both similar to and different from ferrite, we can take advantage of the differences to make 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 TECH TIP, I shall give a first example of the sort of size reductions that can be achieved, and then explain the different families of powder core that are available to prepare for further explanation in later issues.

USING THE "SOFT" SATURATION OF POWDER CORES

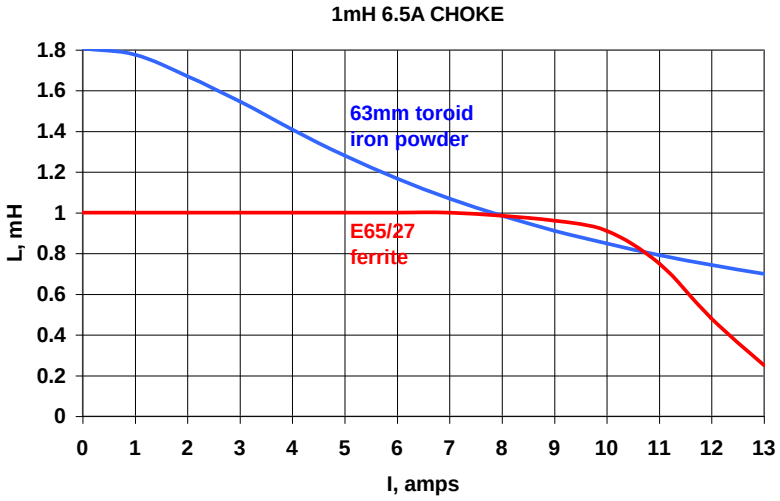
TECH TIP 1A "How Are Powder Cores Different", described the "soft" saturation of powder cores and compared it to the "hard" saturation of gapped ferrite cores, and explained that taking advantage of this effect can give storage chokes that are both smaller and less costly than their ferrite equivalent.

To see how, consider a 1mH PFC choke for a 500W SMPSU with universal input.
This would have an rms current of 6.5A, and a peak current including ripple of 10.7A.

On a ferrite core, we have to design the choke so that it does not saturate at the 10.7A current and would need to use an E65/27 core. The curve of inductance vs bias current, calculated and confirmed by measurement, is shown in red below.

Using a powder toroid, we do not have to worry about any abrupt saturation, as the inductance will roll-off quite slowly with current. The main concern is now ensuring that the choke has enough inductance in the critical area and that the required turns can be practically wound in a wire gauge that is thick enough to prevent excessive self heating.

Designing to match the inductance of 0.8mH at the 10.7A peak current, this can comfortably be achieved on a 63mm diameter toroidal core in the inexpensive 72 perm grade of iron powder, with a winding of 85 turns. This could be machine wound in up to 1.7mm copper, to give a coil resistance of 0.063ohms and a resistive temperature rise of less than 20 degrees C.
The off-load inductance would be 1.8mH, reducing to 0.8mH at 10.7A peak, but still holding-up an inductance of 0.7mH at 13A, by which time the E65 ferrite has fallen to 0.25mH.
The curve for this core is shown in blue below.



The size of the E65/27 choke would be 65mm x 65mm x 53mm height, a volume of 224cm^3.
The wound size of the choke on the 63mm toroidal core would be 71mm diameter x 36mm height, a volume of 143cm^3 , a reduction of 36%.

But the 63mm core is comfortably capable of doing the job. The choke size, still using economical iron powder cores, could be further reduced to 58mm diameter x 35mm height, a volume of 93cm^3 , a reduction of 58%, provided that a resistance of 0.13ohms and a resistive temperature rise of about 45 degrees C could be accepted.

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THE FAMILIES OF POWDER CORE MATERIALS

The families of powder cores are made from different magnetic alloys, with different levels of performance and pricing. In order of decreasing core loss these are:-

Material	*Core loss*	*Ripple frequency*	*On-load inductance*	*Cost*
Iron powder	Highest	lower	Medium	Low
Hi-Flux	Medium	lower	Highest	Higher
Super-MSS	Low	high	Medium	Medium
MPP	Lowest	highest	Medium	Highest

For each material family, a number of carefully controlled permeability grades are offered, each one most suitable for different current bias level and operating frequency range.
Within a given family of cores there are rules of thumb that can be used to aid selection:-

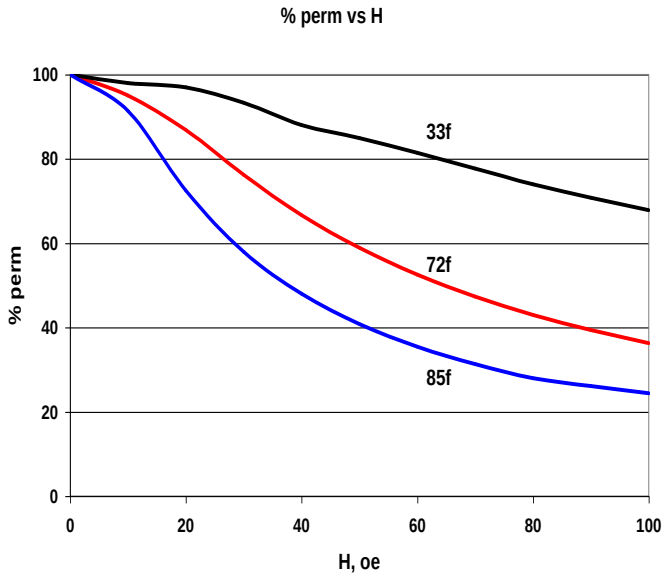
Higher permeability
Higher core loss
Higher off-load inductance
Higher inductance swing with dc current
Lower overload margin

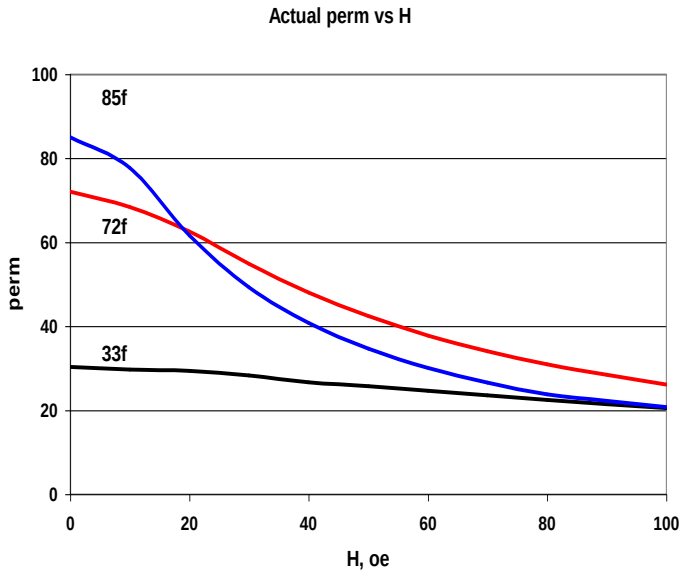
Lower permeability
Lower core loss
Lower off-load inductance
Lower inductance swing with dc current
Higher overload margin

IRON POWDER CORES low cost Almag WE & WP lo-cost ranges

Iron powder cores have a particularly good ratio of performance to price.
They are readily available in both toroidal and E-core format.
They are also available in a very wide range of permeabilities.
The very low permeability grades are mainly used at rf frequencies well into the MHz region.
For storage and differential emc chokes the 33, 72 and 85 permeability grades are most suitable.

Curves of permeability under bias conditions for these grades are shown below:-





As can be seen, the 85 perm grade has the highest off-load permeability, but this falls quite rapidly with bias, so that by 20oe the 72 perm has higher on-load permeability. The main use of this grade is for dimmer suppression/rise-time chokes, and for small chokes where the bias is restricted by windability. This grade is used within the Almag Type WD Light Dimmer rise-time & emc choke standard range.

The 33 perm grade has a lower on-load permeability up to about 80oe of bias.
It is still a very useful grade, as bias levels of 80oe+ are common in medium power storage chokes, and high power chokes on larger core sizes (75-135mm diameter) can be driven up to 150oe or more.
It is also useful where a choke with a low inductance "swing" is required for control circuit stability.
This grade is used within the Almag Type WP Low-Cost storage choke standard range.

The 72 perm grade is the lowest cost of these grades, and is widely used for low-medium power chokes where some inductance "swing" is allowable, or in fact can even be preferred for the reduced ripple-current at low loads resulting from the higher off-load inductance.
This grade is used within the Almag Type WE and WS Low-Cost storage choke standard ranges.

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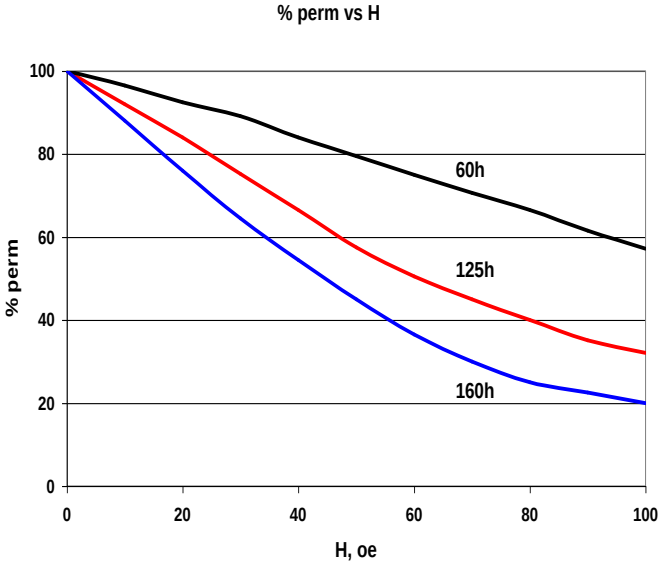
IRON POWDER CORES (contd.)

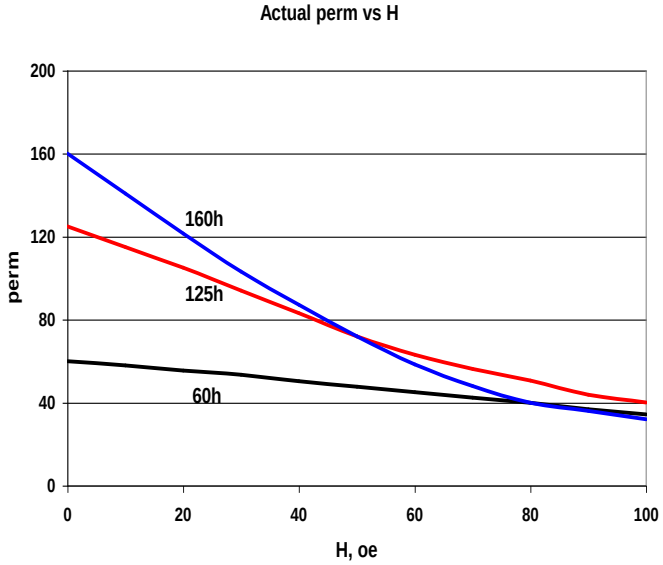
Iron powder cores have a relatively high core loss, and this generally governs the frequency range over which they can be used, rather than the fall-off of permeability with frequency or the self-capacitance of the winding.
The upper frequency is determined by permissible temperature rise due to these core losses, and this depends on the ratio of surface area (for cooling) to core volume (which generates the losses).
This ratio is highest for smaller core sizes, and these can be used at frequencies as high as 500kHz in, for instance, switching regulator chokes.
Medium to large sized cores need good magnetic design to minimise ac ripple flux densities, to allow operation in the 25-100kHz range.

HI-FLUX CORES higher cost Almag WH hi-storage range

Hi-flux cores have the highest energy storage capability, nearly twice that of iron powder.
As a 50-50 nickel-iron alloy the cores are considerably more expensive, but chokes wound on Hi-Flux cores still give a good performance/price ratio.
Core losses are about 20-25% of those of iron powder.
Hi-flux cores are readily available in toroidal format, in a range of permeabilities.
For storage and differential emc chokes the 60, 125 and 160 permeability grades are most suitable.

Curves of permeability under bias conditions for these grades are shown below:-





For all of these grades, the increased energy storage capability can be used to make storage and emc chokes that are smaller and more efficient, as in the Almag Type WH High-Performance range.

As can be seen, the 160 perm grade has the highest off-load permeability, but this falls with bias, so that by 45oe the 125 perm has higher on-load permeability. The main use of this grade is for small chokes where the bias level is restricted by the turns and the wire diameter that can be practically wound.
This grade is used for smaller chokes within the Almag Type WH High-Performance storage choke range.

The 60 perm grade has a lower on load permeability up to about 100oe of bias. It is still very useful where a choke with a low inductance "swing" is required for control circuit stability and for medium-high power chokes where bias levels can easily exceed 100oe.

The 125 perm grade is the lowest cost of these grades, and is used for low-medium power chokes where some inductance "swing" is allowable, or in fact can even be preferred for the reduced ripple-current at low loads resulting from the higher off-load inductance.
This grade is used for larger chokes within the Almag Type WH High-Performance storage choke range.

Hi-flux powder cores have a core loss of about 20-25% of that of iron powder. but where the higher energy storage capability is used to reduce the choke size this lower loss is needed to cope with the increased ripple flux density that results.
Hi-flux cores can therefore be used over approximately the same frequency range as iron powder cores.

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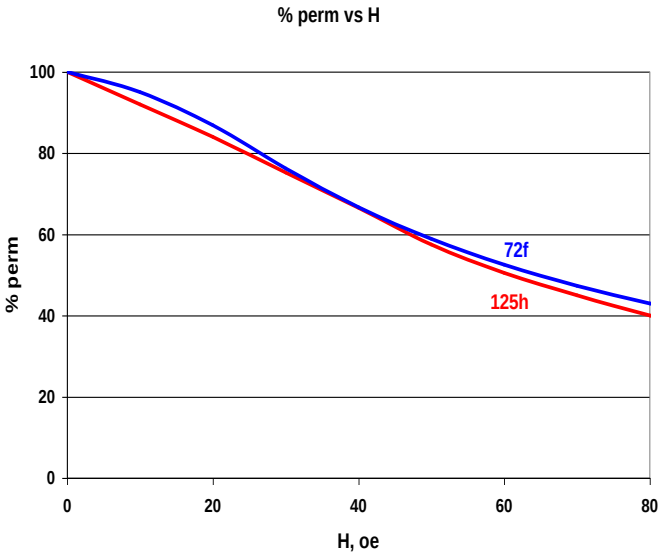
HI-FLUX CORES (contd.)

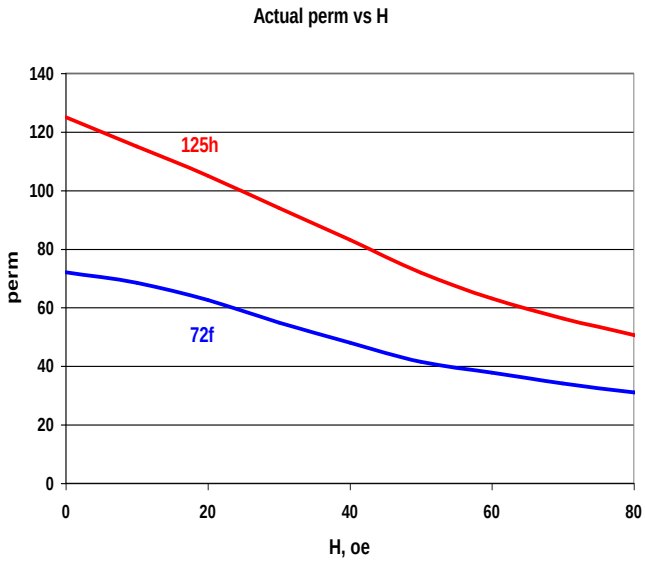
But where does this increased energy storage capability come from?
Quite simply, the cores have a far better percentage hold-up of permeability with bias, so that:-

125 perm Hi-flux has a similar percentage hold-up to 72 perm iron powder
60 perm Hi-flux has a similar percentage hold-up to 33 perm iron powder

But the off-load permeabilities are much higher, so the actual on-load permeabilities are about 70-80% higher. So are the on-load inductances and therefore energy storage capablities.

The curves for 125 perm high flux and 72 perm iron powder demonstrate this:-





SENDUST CORES medium cost Almag WK hi-frequency range

Sendust cores are the latest addition to the powder core families, tailored to the move towards higher power conversion switching frequencies. They can be considered as a higher frequency version of iron powder or as a lower cost alternative to MPP cores for many applications.

As a complex aluminium-iron alloy, with no nickel content, Sendust core prices are between those of iron powder and the Hi-Flux and MPP nickel-iron cores.

They have an energy storage capability similar to that of iron powder cores, but have the advantage that they have only about 10-15% of the high frequency core losses, allowing them to be used at 2 to 3 times higher switching frequencies. If advantage is taken of the 2 to 3 times reduction of inductance for the same pk-pk ripple currents at these higher frequencies, then the lower energy storage requirement means that a smaller core size can be used.

Sendust cores are readily available in toroidal format, in tightly grouped grades of 60, 75, 90 & 125perm, under the trade names Super-MSS from Arnold and Kool-Mu from the Magnetics divison of Spang.
A premium 26 perm grade is also available for very linear filters, such as Class D audio amplifier output chokes.

Even with a relatively low core loss, it is these losses that determine the frequency range over which Sendust cores may be used, rather than the fall-off of permeability with frequency.

The upper frequency is determined by permissible temperature rise due to these core losses, and this depends on the ratio of surface area (for cooling) to core volume (which generates the losses).
This ratio is highest for smaller core sizes, and these can be used at frequencies as high as 1MHz in, for instance, switching regulator chokes.
Medium to large sized cores need good magnetic design to minimise ac ripple flux densities, to allow operation in the 50-200kHz range.

In these frequency ranges, it becomes important to minimise winding self-capacitance to maximise choke resonant frequencies. One approach is to use single-layer windings.

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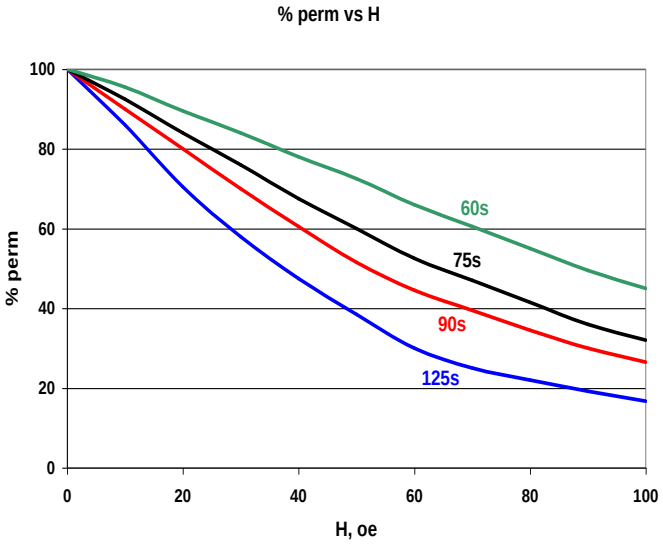
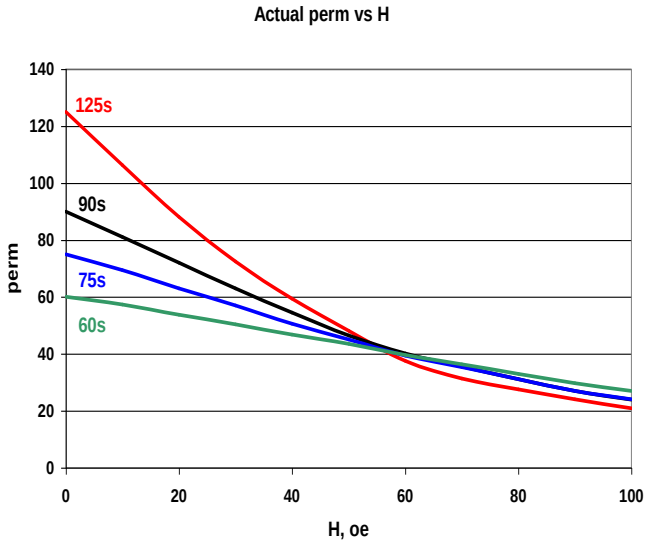
SENDUST CORES (contd.)

Curves of permeability under bias conditions are shown below:-





The 60 perm grade has a lower on-load permeability up to about 60oe of bias, but is very useful for low "swing" inductors and for medium-large sized storage chokes where bias levels of 60oe+ are easily achieved.

The 125 perm grade is particularly suitable for smaller chokes, such as switching regular chokes, as it has a high on-load permeability up to about 50oe of bias.

The 75 and 90 perm grades have similar on-load inductances, and would be used for medium size chokes, the actual grade being selected dependant on the amount of inductance "swing" that can be accepted.

All of these grades are used within the Almag Type WS High-Frequency storage choke standard range.

MPP CORES highest cost Almag custom designs

MPP cores have the lowest high frequency core loss of any of the powder core families, and a permeability that is very stable with both ac flux density and with frequency, making them suitable for high Q emc filters as well as high frequency storage chokes.

As an approximately 80-20% nickel-iron alloy they also have the highest cost. The 125 perm grade has the lowest price of the available grades, with higher costs for the 60 perm and 160 perm grades.

MPP cores are readily available in toroidal format, with a wide range of grades from 14 to 350perm. Very high permeability grades, from 200 to 350 perm, are widely used for small differential emc filters. For storage and differential emc chokes the 60, 125 and 160 permeability grades are most suitable.

Even with a very low core loss, it is these losses that determine the frequency range over which MPP cores may be used, rather than the fall-off of permeability with frequency.

The upper frequency is determined by permissible temperature rise due to these core losses, and this depends on the ratio of surface area (for cooling) to core volume (which generates the losses).
This ratio is highest for smaller core sizes, and these can be used at frequencies as high as 1MHz in, for instance, switching regulator chokes.
Medium to large sized cores need good magnetic design to minimise ac ripple flux densities, to allow operation in the 50-200kHz range.

In these frequency ranges, it becomes important to minimise winding self-capacitance to maximise choke resonant frequencies. One approach is to use single-layer windings.

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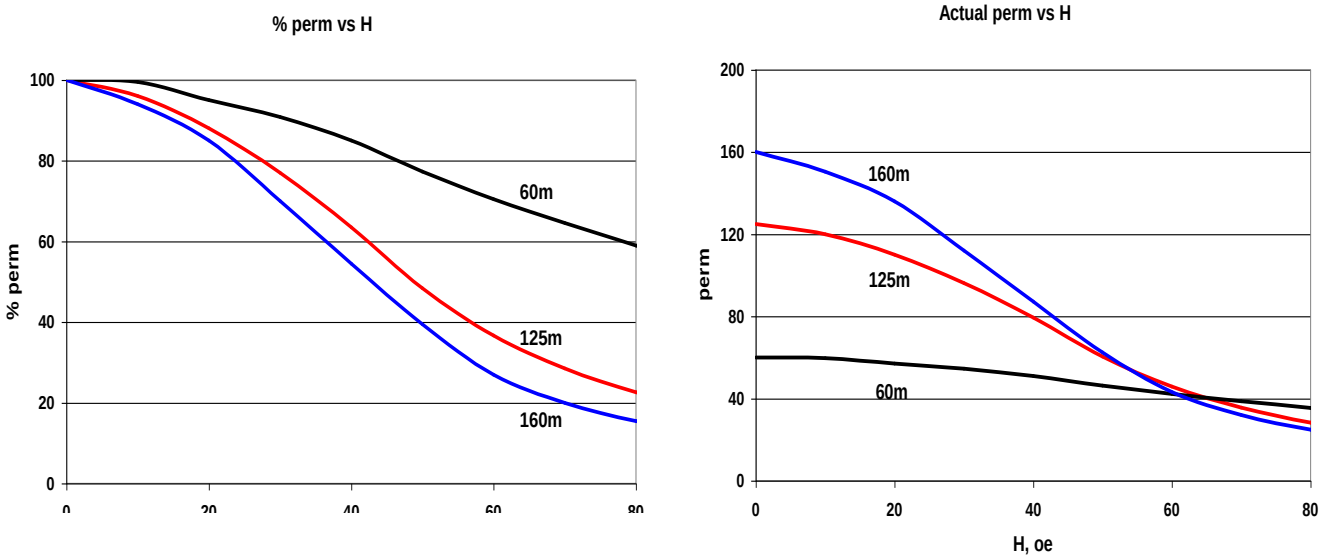
MPP CORES (contd)

Curves of permeability under bias conditions for the storage choke grades are shown below:-



As can be seen, the 160 perm grade has the highest off-load permeability, but this falls with bias, so that by 50oe the 125 perm has higher on-load permeability. The main use of this grade, and the higher permeability grades, is for small chokes where the bias level is restricted by the turns and the wire diameter that can be practically wound.
This is particularly the case for small feedthrough differential emc filter chokes using cores of only about 6mm diameter, where the limited number of turns that can be applied gives bias levels of typically 10-20oe.

The 60 perm grade has a lower on load permeability up to about 80oe of bias. It is still very useful where a choke with a low inductance "swing" is required for control circuit stability and for medium-high power chokes where bias levels can easily exceed 80oe.

The 125 perm grade is the lowest cost of these grades, and is used for low-medium power chokes where some inductance "swing" is allowable, or in fact can even be preferred for the reduced ripple-current at low loads resulting from the higher off-load inductance.

SUMMARY

So there we have it, four distinct families of powder core materials, each offering a different mix of properties, performance and price for the designer to choose from.

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