A user guide to soft magnetic materials (part 4 of 4)

Powder cores

Powder cores consist of soft-magnetic metallic powder, mostly iron and its alloys (mixed with nickel, molybdenum, silicon and others), embedded in a binder material. The powder mix is pressed into desired shapes, but as it is not sintered, grains stay isolated. As a result, all these cores contain a so-called distributed air gap resulting in low permeability and soft saturation behaviour. The different compositions of powder, grain size and densities of the particles within the core allow for a wide range of permeability (10 to 550) and other material properties.

Most materials are derived from known tape materials like Fe-Si or different NiFe alloys. The five most popular types of powder cores are Iron powder, Molypermalloy Powder (MPP), High Flux, Sendust (Kool Mµ) and XFlux.

Production, resulting morphology and properties

The first step in the production of the powder cores is the preparation of the raw materials. Iron or iron alloys are melted and merged together to get a material with a specific composition and purity.

These metallic blocks are physically reduced in size by different procedures (rolling, cutting, milling) until the desired level of powdered grains is achieved. Different size grains are separated by sieving processes. The final powder is then composed by those grains which are insulated from each other by a binder material within a chemical process.

The powder is inserted into a mould, which determines the form of the powder core, and then compressed in one direction. After pressing, cores are annealed and cooled down with a specific temperature-time profile. After this process the bare cores are finished.

They undergo etching and grinding processes to give them their final shape. Finally, cores are coated and painted. These secondary operations influence mechanical properties (eg toroid cores can be more easily wound with bevelled edges) as well as the magnetic properties (eg smoothing the surface of E-cores to avoid additional parasitic air-gaps).

The most interesting property of the majority of powder cores is that they have low permeability due to distributed gaps. Eddy currents are small due to small grain size and effective insulation of the grains. Both features result in flat µ(f) behaviour and high saturation fields, so large currents can be applied without saturating the core.

Materials

Molypermalloy Powder (MPP)

MPP powder is an alloy of around 80% nickel, 17% iron and 3% molybdenum. The high amount of nickel influences the electrical and magnetic behavior and also the price, which is high compared with other materials.

The maximum available permeability of MPP cores is μ=550, significantly higher than other powder cores. The cores have the lowest losses of all powder cores and a very good inductance stability under DC-bias and also higher temperatures.

High Flux

High Flux powder contains approximately 50% iron and 50% nickel. Cores made from this powder reach an overall permeability of 14-160. The mixture enables a very high flux level (double compared with MPP) through the core before reaching saturation, which gives the core its name. This characteristic makes High Flux cores an ideal solution for high DC-bias chokes. Often, it enables the designer to reduce the core size, if it is used instead of MPP or Sendust material. The material has more losses compared with MPP and Sendust but less than XFlux under the same excitation conditions.

Sendust (KoolMμ)

Sendust powder is based on an alloy of roughly 85% iron, 9% silicon and 6% aluminium. The material is relatively low cost as it doesn't contain nickel. The permeability range is between 26 and 125. The soft saturation of Kool Mμ cores starts at relatively low current. The losses in the material are low, which makes them the preferred choice for the usage in storage chokes in relatively high-frequency SMPS.

Recently, improved variants of Sendust, such as Mag Inc's Kool Mμ MAX, have been released with lower losses and more stable L(I) behaviour.

Silicon-iron (XFlux, Fluxsan)

The iron-silicon alloy, with approximately 6.5 % silicon, leads to a very stable inductance over DC bias in the range of high-flux cores. As they contain no nickel, they are the cheaper alternative if losses are not critical.

Due to the relatively large loss generation in the XFlux cores, they are mostly used when frequency doesn't exceed 30 kHz or if the amplitude of the high-frequency part of the current through the component is limited.

Iron powder

Iron-powder cores offer a permeability of between 4 and 100. Most iron-powder cores use an organic binder, which is susceptible on thermal ageing under high temperatures. Iron powder cores are cheaper compared with other powder cores, but lead to more core losses compared with Sendust, High Flux and MPP cores.

The pressure during the pressing process is moderate, which makes iron powder cores available in many different shapes, such as E-cores, pot-cores and rods. Large iron powder E-cores or pot cores, which can be gapped in their middle leg in addition to the distributed air-gap within the material, offer the possibility to decrease effective permeability further and enable the cores to be stable at even higher currents.

The following table compares the technical characteristics of the different powder core types.

Table 1: Comparison of powder-core materials (Origin: Magnetics Inc.)

	MPP	High Flux	Kool Mµ	Si-Fe	Iron powder
Permeability	14-550	14-160	26-125	26-60	10-100
Saturation (B_sat)	0,7 T	1,5 T	1,0 T	1,6 T	1,2-1,4 T
Max temperature (°C)	200	200	200	200	Variable
AC core loss	Lowest	Moderate	Low	High	Highest (and variable)
Core shapes	Toroid	Toroid	Toroid, E-core, other shapes	Toroid	Toroid, E-core, other shapes
DC bias	Better	Best	Good	Best	Good
Alloy composition	Fe Ni Mo	Fe Ni	Fe Si Al	Fe Si	Fe

Comparison with gapped ferrites

The manufacture of ferrite and metal powder cores sounds very similar, but there are big differences between both classes, not only due to different composition leading to, for example, different saturation induction. Different annealing conditions (temperature is much higher for ferrites) lead to a shrinking of the green body of ferrites, which is a challenge for achieving defined shapes or a dense body with small grain-grain distances. Ferrites reach higher permeabilities and are mechanically more stable.

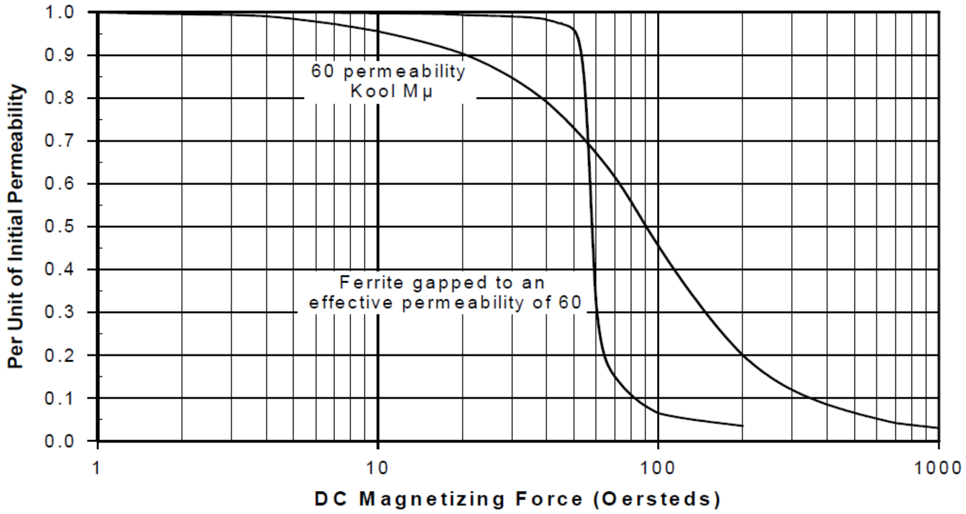
Powder cores, as well as gapped ferrites, are able to store energy as their inductance is stable up to specific current.

$$E_{mag} = \frac{1}{2} \cdot L(I) \cdot I^2$$

Thanks to this property, both can be used as storage, differential mode filter chokes or for damping reasons under a DC-bias. Also the effective (overall) permeability of a gapped ferrite core is often in the same range as the permeability of the powdered cores (µ=4-500). Both core types can be used under relatively high frequencies of several 10ths of a kHz, as the cores have a high resistivity. At higher frequencies, ferrites or Sendust powder cores are the preferred solution.

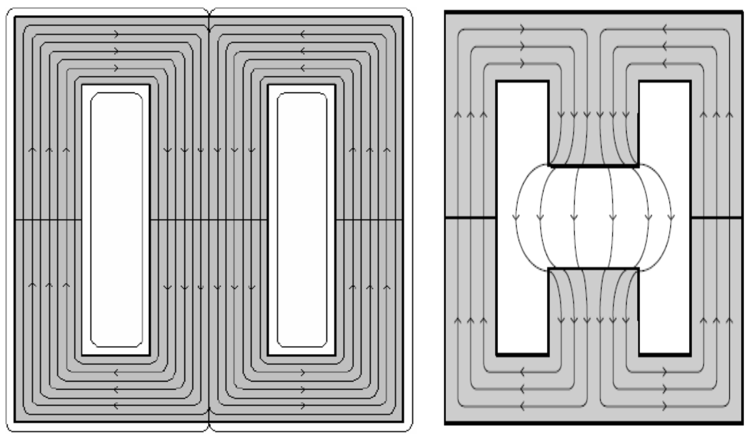
A very important difference between gapped ferrites and powder cores is the saturation behaviour. The saturation of a ferrite core is reached with a flux density of 0.3 to 0.5 T, depending on material and temperature. Powder cores lose their permeability at much higher flux levels of 0.7 to 1.5 T. Not only is the maximum flux different, but also the current-inductance characteristic of the chokes made by those cores, due to the particle structure of the powder cores. The reason is distributed gaps in the direction of the flux and in any other direction; therefore the saturation of the powder cores is soft in comparison with a gapped ferrite (Figure 1, origin: Magnetics Inc.). This is because some particles in the powder will saturate earlier, due to their position and so lose their permeability. In a gapped ferrite structure, the biggest part of the ferrite material will saturate at the same excitation, as the material is relatively equally fluted by the magnetic flux.

Figure 1: Comparison of saturation behaviour of a powdered core (distributed gap) and a gapped ferrite (Origin: Magnetics Inc.)



A further advantage of the distributed gap within the material compared with a gapped core is the avoidance of fringing flux around the gap, which is shown in the figure below. The AC-part of the fringing flux entering the high-conductive copper winding of the choke could lead to losses due to high-induced eddy currents. Powdered cores can reduce fringing flux, enabling the designer to place the winding closer to the core and save space.

Figure 2: Comparison of fringing flux of a powder core (left) and a gapped structure (Origin: Magnetics Inc.)



Conclusion

Powder cores are available with a broad variance of materials offering several characteristics. This makes them usable for different operational conditions and hence the preferred choice for a lot of power applications, such as storage chokes, input and output filter or for damping purposes. They also offer different advantages (soft saturation, reduced fringing, high B_{sat}) compared with gapped ferrites.