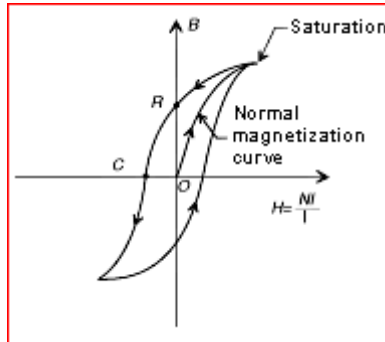# Magnetic and Transformers Design Consulting

How Transformers, Chokes and Inductors Work, and Properties of Magnetics

The magnetic properties are characterized by its hysterisis loop, which is a graph of flux density versus magnetization force as shown below:

Hysterisis Loop

When a electric current flows through a conductor (copper wire), it generate a magnetic field. The magnetic field is strongest at the conductor surface and weakens as its distance from the conductor surface is increased. The magnetic field is perpendicular to the direction of current flow and its direction is given by the right hand rule shown below.
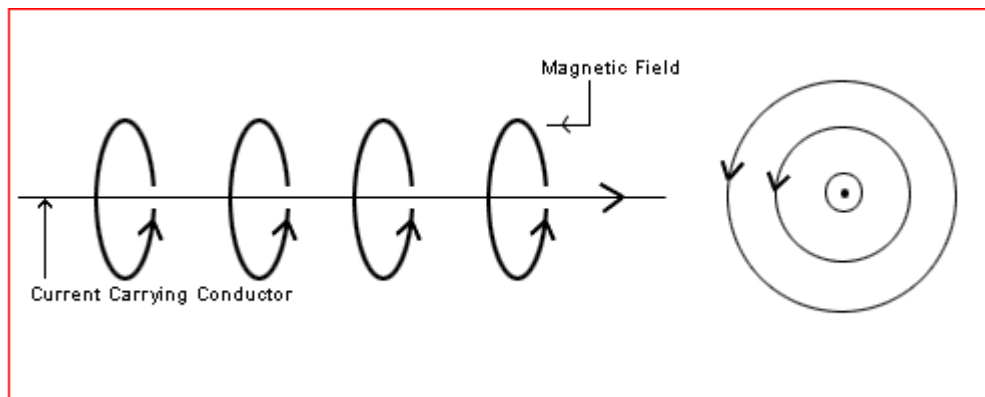
When the conductor or wire is wound around a magnetic materials (ferrite, nanocrystalline, amorphous, iron, nickel steel, grain oriented steel, MPP, sendust, high flux, etc), and current flows through the conductor, a flux is induced on the magnetic materials. This flux is induced by the magnetic field generated by the current carrying conductor. The magnetic material's atomic parts got influenced by the magnetic field and causes them to align in a certain direction.

The application of this magnetic field on the magnetic materials is called magnetization force. Magnetization force is called Oersted or A/m (amperes per meter)or A/cm.

The units for Magnetization force is "H"

The results of applying these magnetic field from the current carrying conductor causes the magnetic materials to have magnetic flux being formed inside the magnetic materials. The intensity of these flux is called flux density. Therefore flux density is defined as the flux per square area.

Flux density is called gauss or Tesla. I Tesla is10,000 gauss, or 1mT is 10 gauss.

The unit for Flux is "B"

Thus, the hysterisis loop is often called the BH curve. Understanding of the BH curve is extremely important in the designs of transformers, chokes, coils and inductors.

For a square wave application as in SMPS (square wave), the Flux density or B in Gauss is given as:

$$B = \frac{E \times 10^8}{4ANf} \quad ;$$

E = Input or Output Voltage, in volt (rms)

A = Cross Sectional Area, in cm^2

f = Switching frequency, in Hz

N = Number of Tums

Note that B is a function of voltage (input voltage if calculated from primary windings, and output voltage if calculated from secondary side). For square wave, the constant in the above formula is 4.0, and for sinewave, it is 4.44. Flux will reduce if you increase the number of turns, increase the switching frequency or increasing the size of the cores (increasing the area)

The magnetization force or H in Oersted is given as:

$$H = \frac{0.4\pi NI}{l} \quad ; \quad \begin{array}{l} N = \text{No. of turns} \\ I = \text{Current in Amps} \\ l = \text{Magnetic Path Length in cm} \end{array}$$

Note that H is a function of input current. The unit for H in the above formula is in Oersted. The conversion from Oersted to A/m or A/cm is one Oersted = 1.2566 A/cm. As the current swings from positive to negative the flux changes as well, tracing the curve.

The permeability of a magnetic material is the ability of the material to increase the flux intensity or flux density within the material when an electric current flows through a conductor wrapped around the magnetic materials providing the magnetization force.

The higher the permeability, the higher the flux density from a given magnetization force.

If you look at the BH loop again, you will note that the permeability is actually the slope of the BH curve. The steeper the curve, the higher the permeability as shown below.
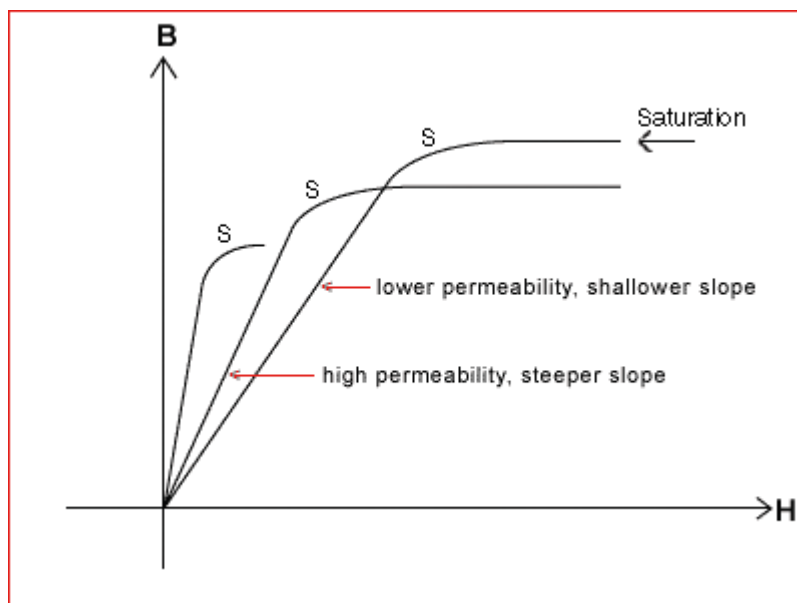
As the magnetization force increases (or the current over the conductor is increased), a point is reached where the magnetic material or core will saturate. See point "S" above on the curves. When that happens, any further increase in H, will not increase the flux. More importantly, the permeability goes to zero as the slope now is flat. In this situation the magnetic material or core will fail to work as a transformer, chokes, or inductors.

So, it is very important in a choke or inductor design, not to drive the core into saturation by increasing the current (AC or DC). Usually it is the DC current that saturate the cores since it is a constant current, and puts the cores to a certain

flux level.

In a transformer design, you must make sure that the maximum AC current swings from positive to negative is well below the saturation point.

Another way to get saturation is by increasing the flux density which is normally achieved by increasing the voltage (see equation above).

$$B = \frac{\text{Voltage x } 10^8}{4ANf}$$

From the BH curve, you can see that when the permeability is high (slope is steep), the cores will go into saturation faster. Conversely, when the permeability is low, the cores saturate at a much higher flux density.

Power ferrite cores normally have a permeability of about 2000, and they saturate faster than iron powder or MPP cores where the permeability of Iron Powder or MPP core is 125 or so.

The typical saturation flux density of Power Ferrite material is under 4000 gauss (400mT). Whereas the saturation flux density of MPP material is 7000 gauss. High Flux is 15,000 gauss and Iron Powder is 10,000 gauss.

A transformer is an energy transfer device, so you want to have minimum losses when you transfer energy from primary side to secondary side. This is why a ferrite cores is used.

In a choke or inductor design, the application is for energy storage, and there is always a DC current flowing through, so you want to use a iron powder, MPP, sendust or high flux cores. Also, the saturation flux is a lot higher, so a higher DC current can flow through.

Core Losses

There are always energy losses in transformers and chokes. These energy losses will generate heat and cause thermal problems. The losses in a transformer, chokes or inductors are from the following sources:

1. Hysterisis loss from the sweeping of flux from positive to negative and the area enclosed by the loop is the loss. Hysterisis loss is due to the materials intrinsic properties due to the energy used to align and re-align the magnetic domains. You can lower this loss by using a more expansive materials such as TDK PC 44, for example.
2. Eddy current loss from the circulating currents within the magnetic materials due to differential in flux voltage inside the cores itself. This loss is high dependent upon the thickness of the walls of the cores. The higher the switching frequency, the higher will be this eddy current loss.
3. Copper or winding loss. This is also dependent on the wire size, switching frequency, etc. Skin effect and

proximity effect will contribute to this loss.

Our engineers are experts at selecting the right types of materials, designs and analysis for your particular application.