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TRANSFORMER LAMINATIONS, DESIGN CONSIDERATIONS

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Engineers and designers of transformers and inductors will find the information presented in the following helpful in the selection of magnetic materials and core shapes for specific applications.

Why Magnetic Materials

Magnetic materials are useful for the generation and distribution of electrical power because these materials allow to transmit large power densities at low losses. In addition, voltage and impedance can be easily changed from one level to another, since changes in the flux density of materials induce voltages in copper coils surrounding the magnetic cores (Faraday's law).

The energy density in a magnetic material is

$$E = \tfrac{1}{2} HB \left(\frac{A}{cm} \ \frac{V}{cm^2} \right) \text{ or } \left(\frac{VAs}{cm^3} \right) \quad (1)$$

H is the magnetic field, B the magnetic induction ($1\ Vs/cm^2 = 10^8$ Gauss $= 10^4$ Tesla). In a field of 500 A turns/cm and an induction of 2 Tesla, an energy density of $5 \cdot 10^{-2}\ W/cm^3$ can be stored, which is as high as in the best capacitors. By multiplying equation (1) with core volume $V_c = A_c \cdot lm$, where A_c is the core cross section and lm the mean path length and assuming a sinusoidal change of B at the frequency f, it can be rewritten as follows. The power handling capacity in VA is

$$VA = 4.44\ lm\ A_c\ f\ B\ H\ 10^{-8} \quad (2)$$

Since $H = ni/lm$, n number of turns, i current in the turns and $ni = S\ Aw\ K$, S current density in the copper wire, Aw core window, 2K copper fill factor (.35% for primary and secondary turns), the power handling capacity of a transformer as derived from the energy storage equation is

$$VA = 4.55\ S\ B\ f\ Ac\ Aw \cdot 10^{-4} \quad (3)$$

in which Ac and Aw are in in^2, B in Tesla, S in A/in^2 and f is the frequency.

The same result is, of course, obtained if we multiply Faraday's law for induction with the current i. $E_i = -n\ Ac\ dB/dt$, where E_i is a voltage induced in n turns by a flux change dB/dt. Solving this equation for sinusoidal flux, we find

$$E_i = 4.44\ nfB\ Ac \cdot 10^{-4} \text{ volts,}$$

in which Ac is in square cm multiplying with i, we find for the power VA

$$VA = 4.44\ n\ f\ B\ Ac\ i \cdot 10^{-4} \quad (4),$$

since $ni = S \cdot Aw \cdot K$, we can substitute in equation 4 and transform into in^2, so that $VA = 4.55\ S\ B \cdot f\ Ac\ Aw \cdot 10^{-4}, (5) = (3)$ in volt amperes.

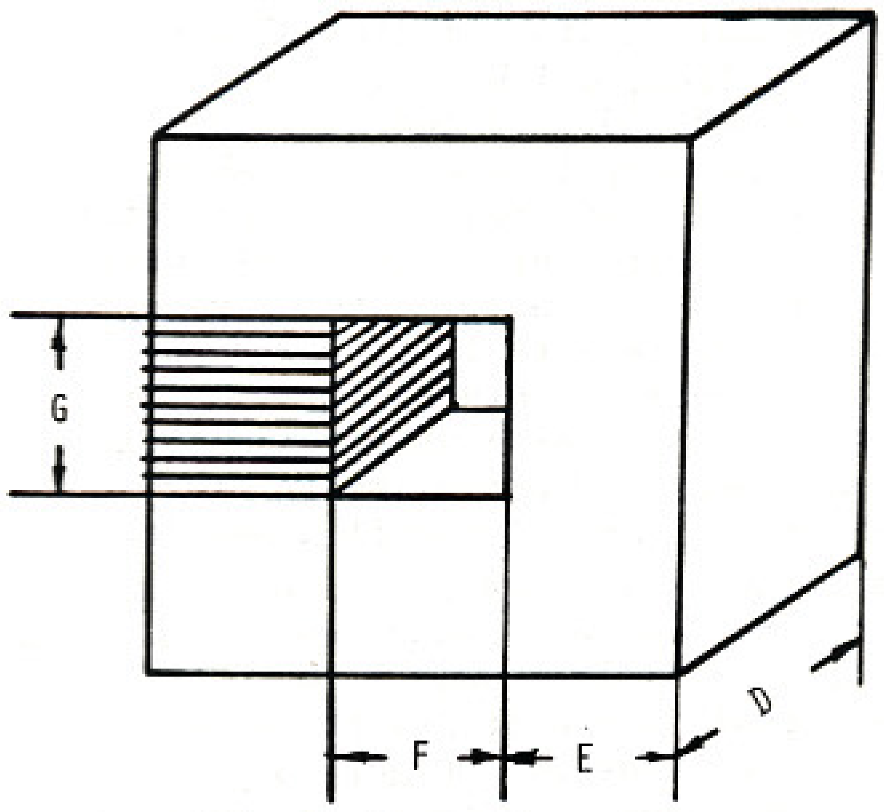

Fig. 1 Transformer Core

Ac = ED = cross section of core
Aw = Gf = window area

Metallic magnetic materials can be used from low frequencies of a few Hz to high frequencies of few hundred kHz, ferrites and iron powder cores can be used up into the MHz range. With above equations, the designer can select suitable dimensions for the copper coil and the magnetic core cross section at the given frequency which meets the loss requirement. Most manufacturers of core components list in their catalogs the Aw Ac products for available shapes of core structures. Transformers and inductors can be reduced in weight and volume by operating at higher frequency or by selecting materials which can work at a higher flux density.