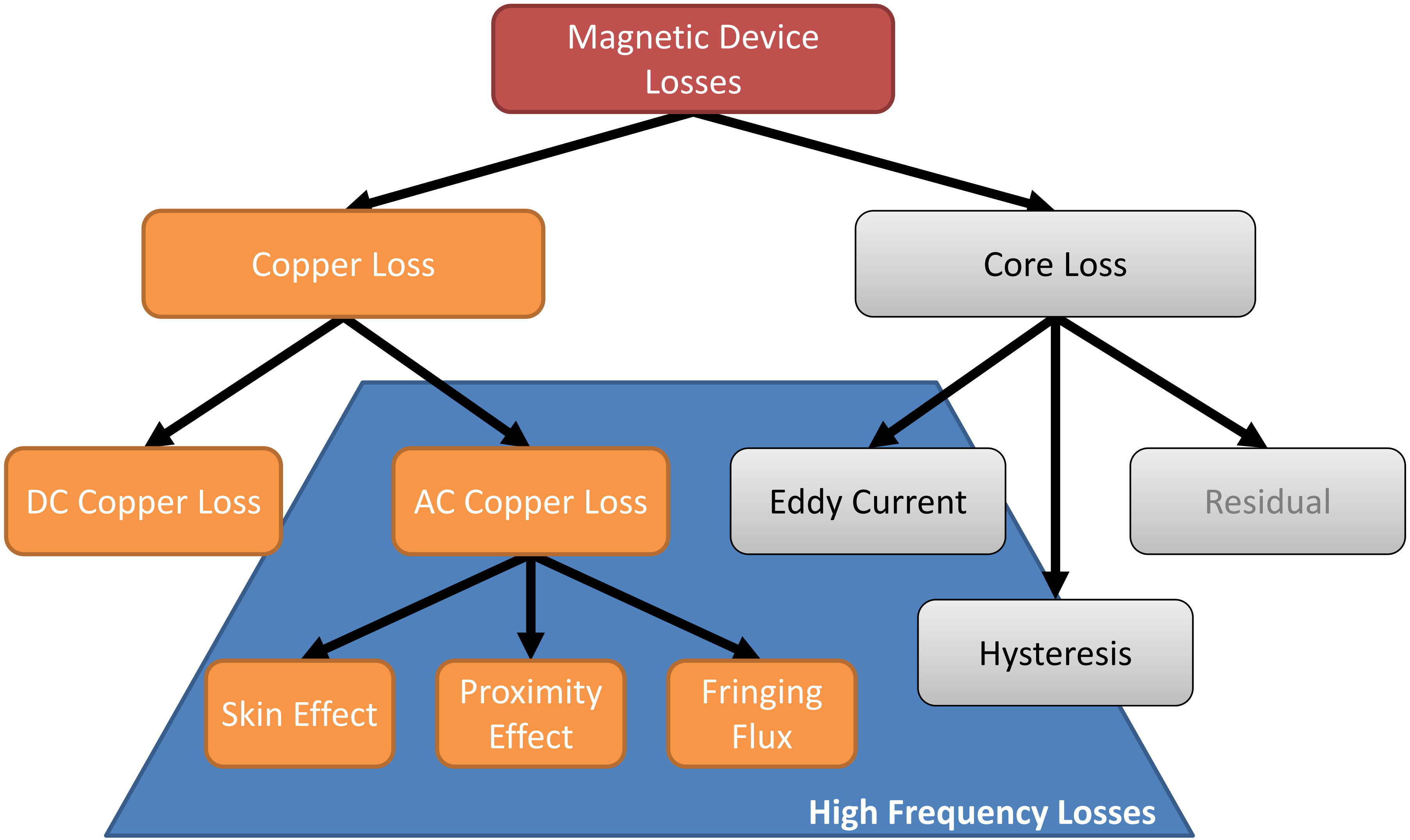
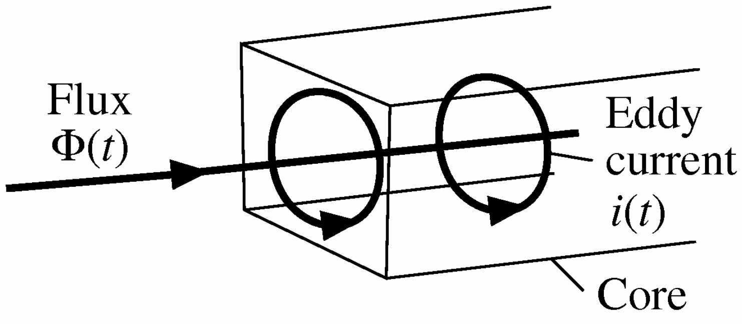
13.3 Magnetics Losses

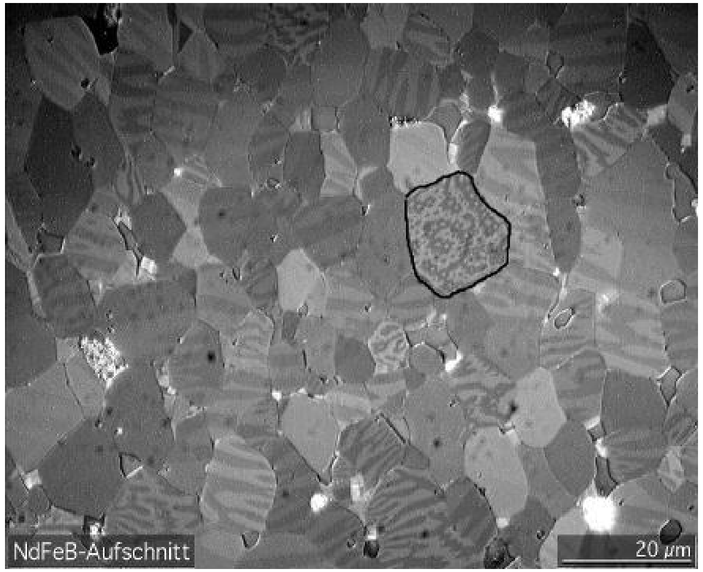


Eddy Currents in Magnetic Materials

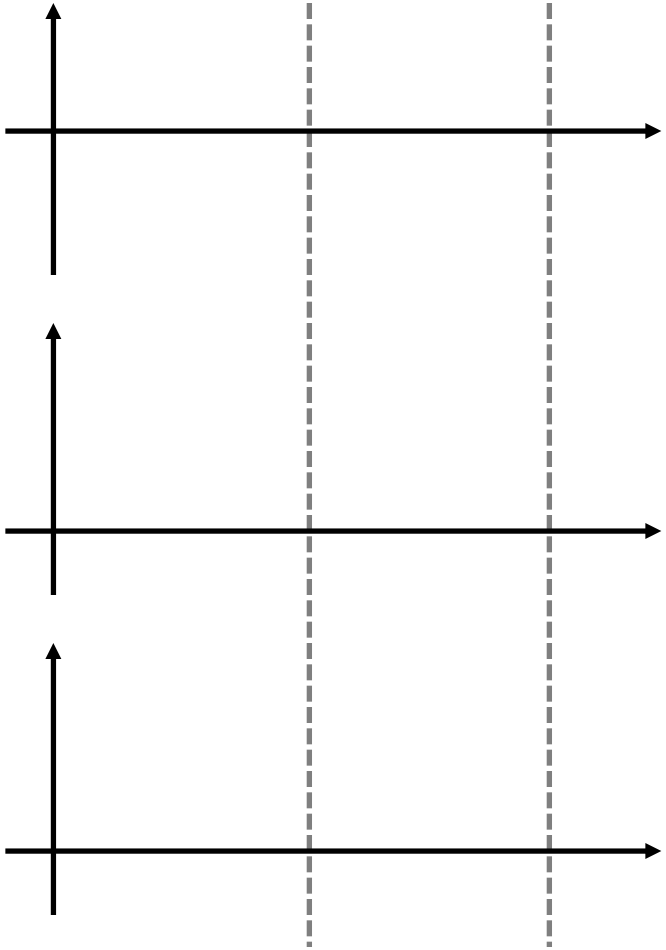


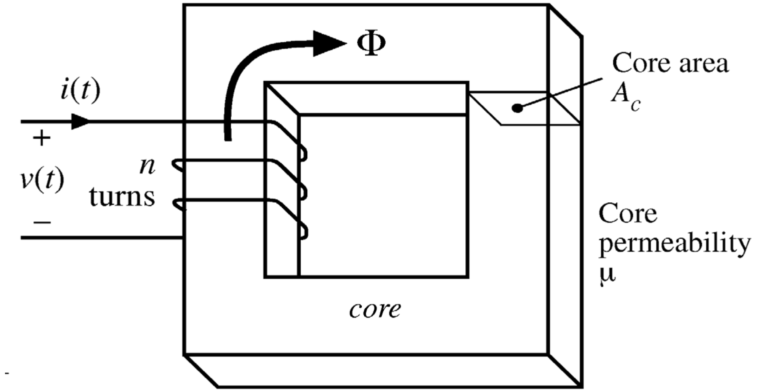
Core Loss

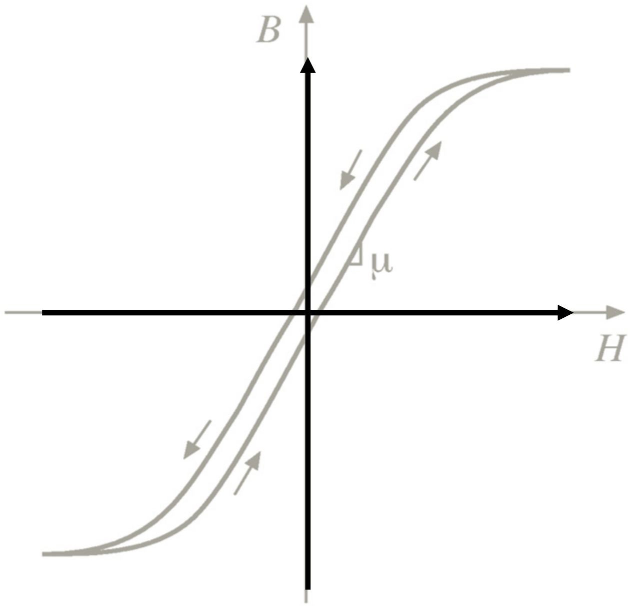
- Physical origin due to magnetic domains
- Modeling Approaches
  - Empirical (curve fit) models of materials
  - Direct measurement-based models
  - Physics-based models



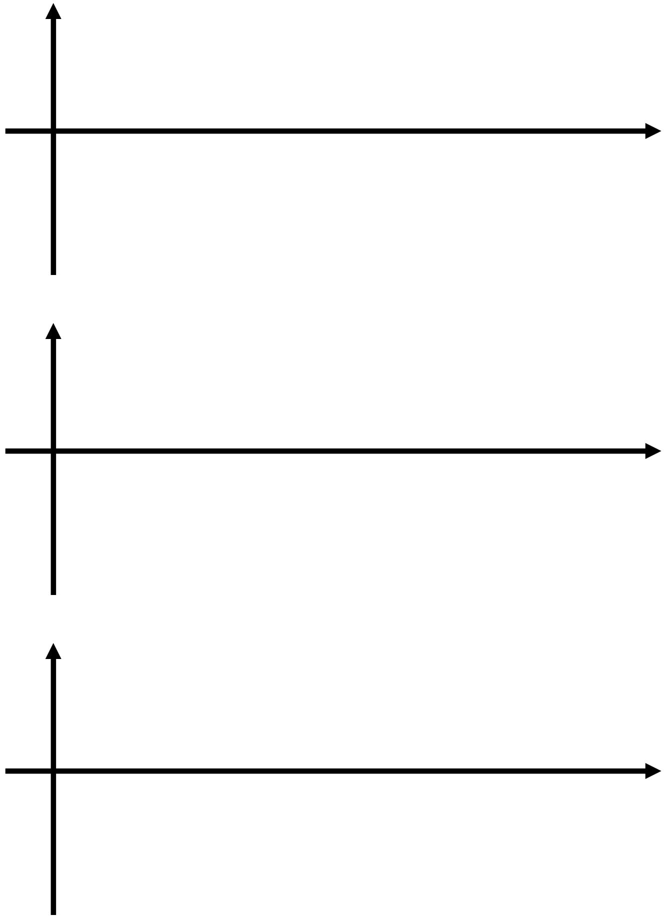
B-H Curve: Filter Inductor

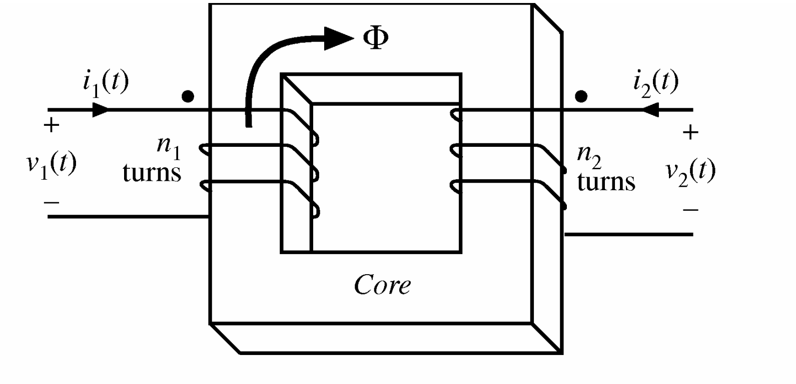


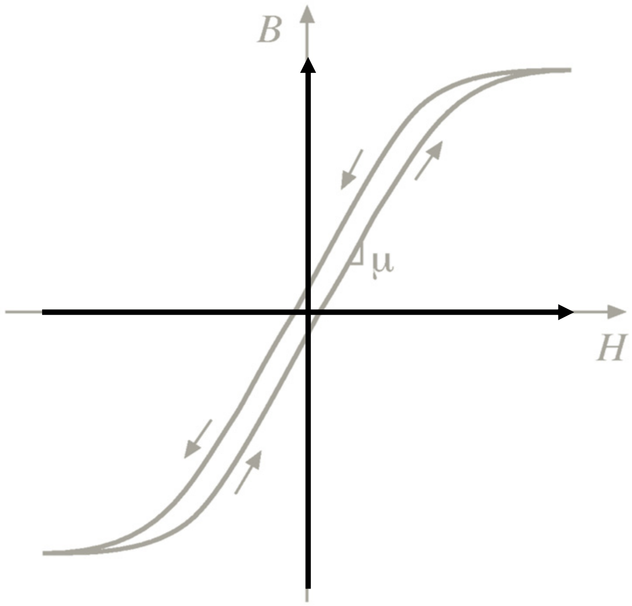




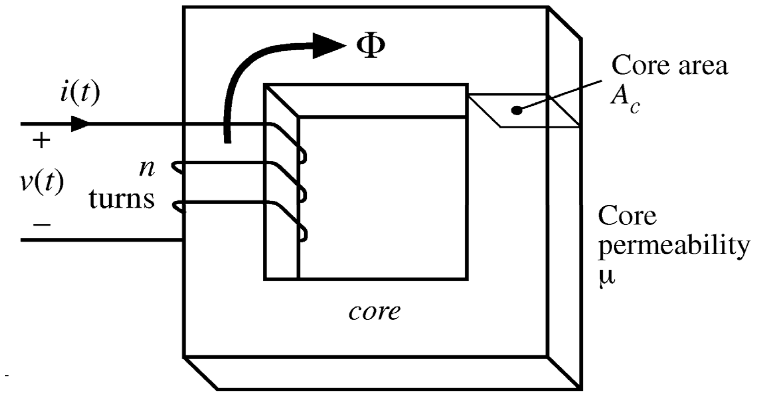
B-H Curve: Transformer

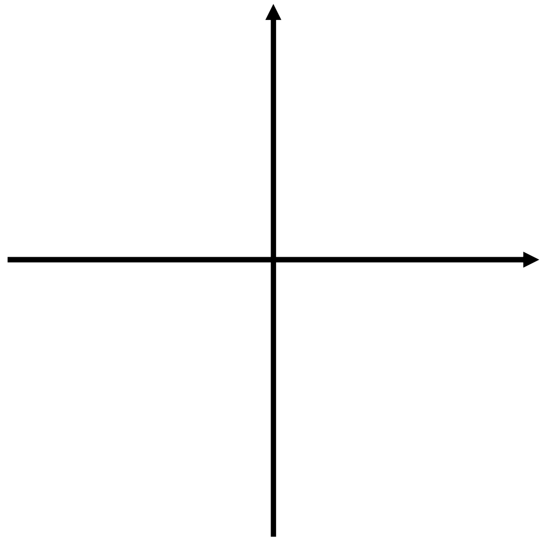






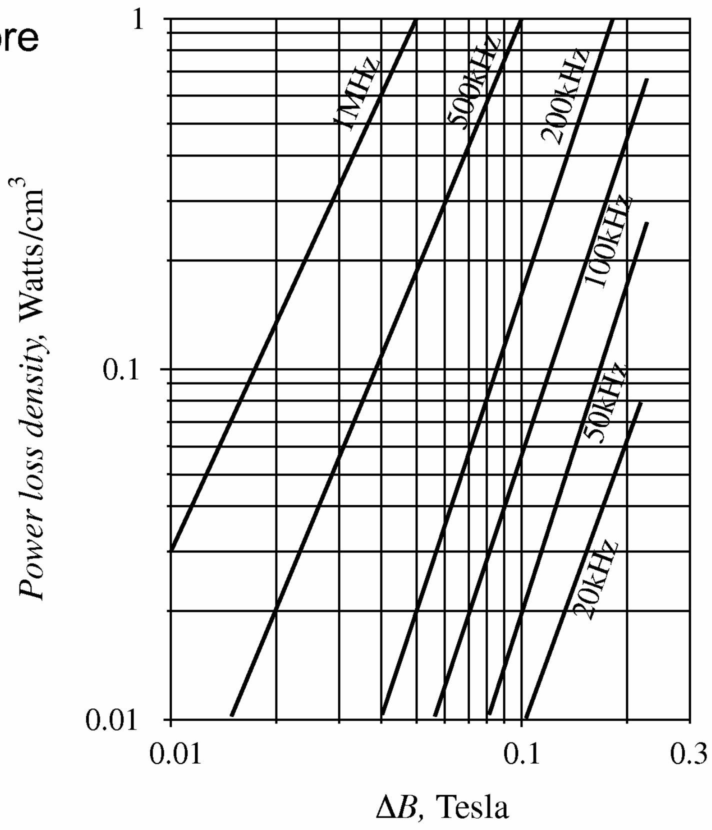
Hysteresis Loss





The Steinmetz Equation

Ferrite core material



Empirical equation, at a fixed frequency:

$$P_{fe} = K_{fe} (\Delta B)^{\beta} A_c \ell_m$$

Alternately:

$$P_v = K_m f^{\alpha} (\Delta B)^{\beta}$$

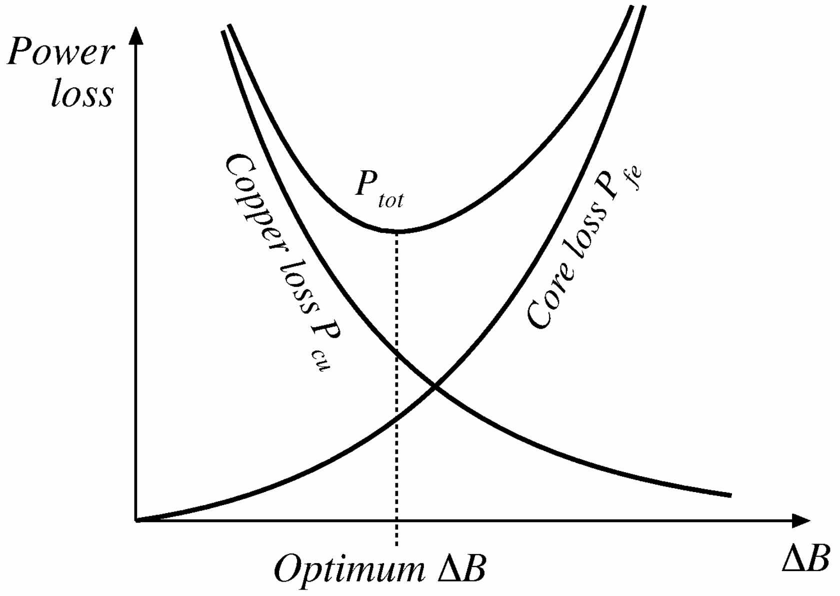
Steinmetz Equation: Notes

- Purely empirical; not physics-based
- Parameters α, β, K vary with frequency
- Correct only for sinusoidal excitation
  - Nonlinear; Fourier expansion of waveforms cannot be used
- Modified empirical equations perform better with nonsinusoidal waveforms
  - MSE
  - GSE
  - iGSE
  - i^2GSE

Transformer Design Constraints

Minimizing Total Loss

There is a value of ΔB that minimizes the total power loss



$$P_{tot} = P_{fe} + P_{cu}$$

$$P_{fe} = K_{fe}(\Delta B)^{\beta} A_c \ell_m$$

$$P_{cu} = \left(\frac{\rho \lambda_1^2 I_{tot}^2}{4 K_u} \right) \left(\frac{(MLT)}{W_A A_c^2} \right) \left(\frac{1}{\Delta B} \right)^2$$

Calculation of Total Loss

Substitute optimum ΔB into expressions for P_{cu} and P_{fe}. The total loss is:

$$P_{tot} = \left[A_c \ell_m K_{fe}\right]^{\left(\frac{2}{\beta+2}\right)} \left[\frac{\rho \lambda_1^2 I_{tot}^2}{4K_u} \frac{(MLT)}{W_A A_c^2}\right]^{\left(\frac{\beta}{\beta+2}\right)} \left[\left(\frac{\beta}{2}\right)^{-\left(\frac{\beta}{\beta+2}\right)} + \left(\frac{\beta}{2}\right)^{\left(\frac{2}{\beta+2}\right)}\right]$$

Rearrange as follows:

$$\frac{W_A \left(A_c\right)^{\left(2(\beta-1)/\beta\right)}}{(MLT)\ell_m^{(2/\beta)}} \left[\left(\frac{\beta}{2}\right)^{-\left(\frac{\beta}{\beta+2}\right)} + \left(\frac{\beta}{2}\right)^{\left(\frac{2}{\beta+2}\right)}\right]^{-\left(\frac{\beta+2}{\beta}\right)} = \frac{\rho \lambda_1^2 I_{tot}^2 K_{fe}^{(2/\beta)}}{4K_u \left(P_{tot}\right)^{\left((\beta+2)/\beta\right)}}$$

Left side: terms depend on core geometry

Right side: terms depend on specifications of the application

The K_{gfe} Method

Define $$K_{gfe} = \frac{W_A \left(A_c\right)^{\left(2(\beta - 1)/\beta\right)}}{(MLT)\ell_m^{\left(2/\beta\right)}} \left[\left(\frac{\beta}{2}\right)^{-\left(\frac{\beta}{\beta+2}\right)} + \left(\frac{\beta}{2}\right)^{\left(\frac{2}{\beta+2}\right)} \right]^{-\left(\frac{\beta+2}{\beta}\right)}$$

Design procedure: select a core that satisfies

$$K_{gfe} \geq \frac{\rho \lambda_1^2 I_{tot}^2 K_{fe}^{\left(2/\beta\right)}}{4K_u \left(P_{tot}\right)^{\left(\left(\beta+2\right)/\beta\right)}}$$

Appendix D lists the values of K_{gfe} for common ferrite cores

K_{gfe} is similar to the K_g geometrical constant used in Chapter 14:

- K_g is used when B_{max} is specified
- K_{gfe} is used when ΔB is to be chosen to minimize total loss

The K_{gfe} Method

$$K_{gfe} \geq \frac{\rho \lambda_1^2 I_{tot}^2 K_{fe}^{(2/\beta)}}{4K_u \left(P_{tot}\right)^{\left((\beta+2)/\beta\right)}} 10^8$$

$$\Delta B = \left[10^8 \frac{\rho \lambda_1^2 I_{tot}^2}{2K_u} \frac{(MLT)}{W_A A_c^3 \ell_m} \frac{1}{\beta K_{fe}} \right]^{\left(\frac{1}{\beta+2}\right)}$$

$$n_1 = \frac{\lambda_1}{2\Delta B A_c} 10^4 \qquad n_k = n_1 \frac{n_k}{n_1}$$

$$\alpha_k = \frac{n_k I_k}{n_1 I_{tot}} \qquad A_{wk} \leq \frac{\alpha_2 K_u W_A}{n_2}$$

Verify $B_{max} < B_{sat}$