Magnetic components

Magnetic core material.
Dc – 10 kHz

- Alloys of iron and silicon, chrome or cobalt
- High electric conductivity
- Laminated plates to avoid eddy current losses
- High flux densitity 1.8 T

Magnetic core material.
1 kHz – 100 kHz

- Cores are made of powder of iron and silicon, chrome or cobalt
(same material as above)

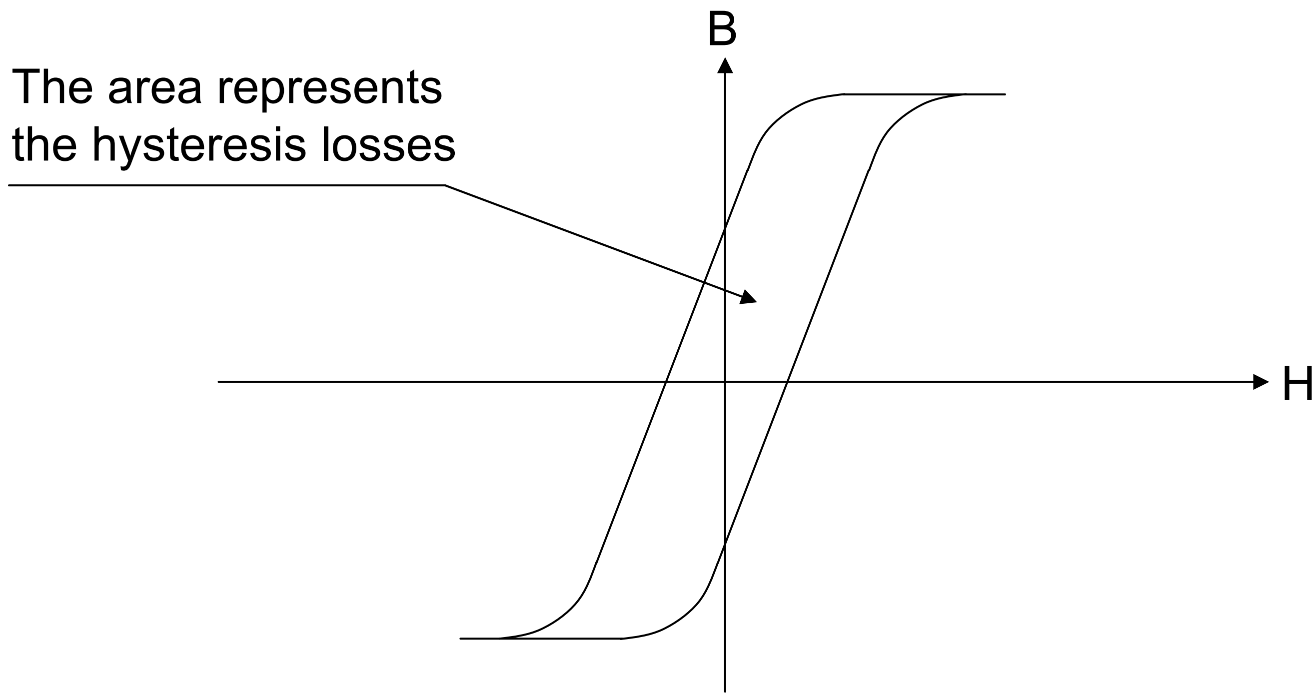
- The grains are covered with an insulating layer which reduces eddy current losses

- However, hysteresis losses increase

Magnetic core material.
30 kHz – 10 MHz

- Ceramic compound of soft ferrite, mixed with zinc or nickel
- Crystal dimension typical 10 – 20 µm, which reduces eddy current losses
- However, hysteresis losses increase

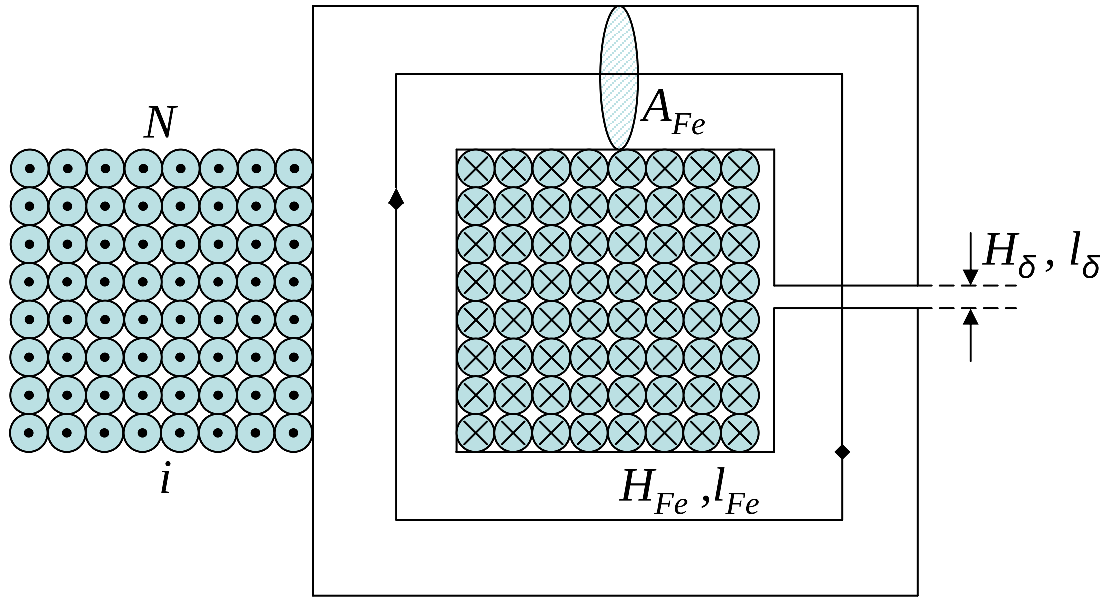
Hysteresis



Hysteresis is caused by internal friction in the material. The magnetic domain wall movement, causing the magnetic flux density to lag the magnetic field

Inductors

Basic gapped inductor with core



The incductance $$L = \frac{d\psi}{di} = \{no\ saturation,\ no\ hysteresis\} = \frac{\psi}{i}$$

Ampère’s circutial law $$N \cdot i = \oint \vec{H} \cdot d\vec{s} = H_{Fe} \cdot l_{Fe} + H_{\delta} \cdot l_{\delta}$$

Flux density $$\begin{cases} B_{Fe} = \mu_{Fe}\mu_0 H_{Fe} \\ B_{\delta} = \mu_0 H_{\delta} \end{cases}$$

Inductance with air gap

$$N \cdot i = H_{Fe} \cdot l_{Fe} + H_\delta \cdot l_\delta = \frac{B_{Fe}}{\mu_0 \mu_{Fe}} \cdot l_{Fe} + \frac{B_\delta}{\mu_0} \cdot l_\delta =$$

$$= \{\psi = N \cdot \phi = N \cdot B_{Fe} \cdot A_{Fe} = N \cdot B_\delta \cdot A_\delta\} =$$

$$= \frac{\psi \cdot l_{Fe}}{N \cdot A_{Fe} \cdot \mu_0 \cdot \mu_{Fe}} + \frac{\psi \cdot l_\delta}{N \cdot A_\delta \cdot \mu_0} =$$

$$= \{A_\delta \approx A_{Fe}\} \approx \frac{\psi}{N \cdot A_{Fe} \cdot \mu_0} \cdot \left(\frac{l_{Fe}}{\mu_{Fe}} + l_\delta \right)$$

$$L = \frac{\psi}{i} = \frac{N^2 \cdot A_{Fe} \cdot \mu_0}{\left(\frac{l_{Fe}}{\mu_{Fe}} + l_\delta \right)} = \left\{ l_\delta >> \frac{l_{Fe}}{\mu_{Fe}} \right\} \approx \frac{\mu_0 \cdot A_{Fe} \cdot N^2}{l_\delta}$$

Inductance without air gap

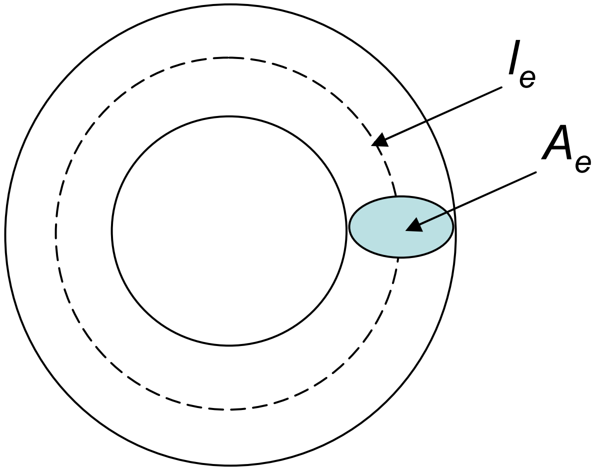
$$N \cdot i = H_{Fe} \cdot l_{Fe} = \frac{B_{Fe}}{\mu_0 \mu_{Fe}} \cdot l_{Fe} =$$

$$= \left\{ \psi = N \cdot B_{Fe} \cdot A_{Fe} \right\} =$$

$$= \frac{\psi \cdot l_{Fe}}{N \cdot A_{Fe} \cdot \mu_0 \cdot \mu_{Fe}}$$

$$L = \frac{\psi}{i} = \frac{N^2 \cdot A_{Fe} \cdot \mu_{Fe} \mu_0}{l_{Fe}}$$

Iron powder toroid core



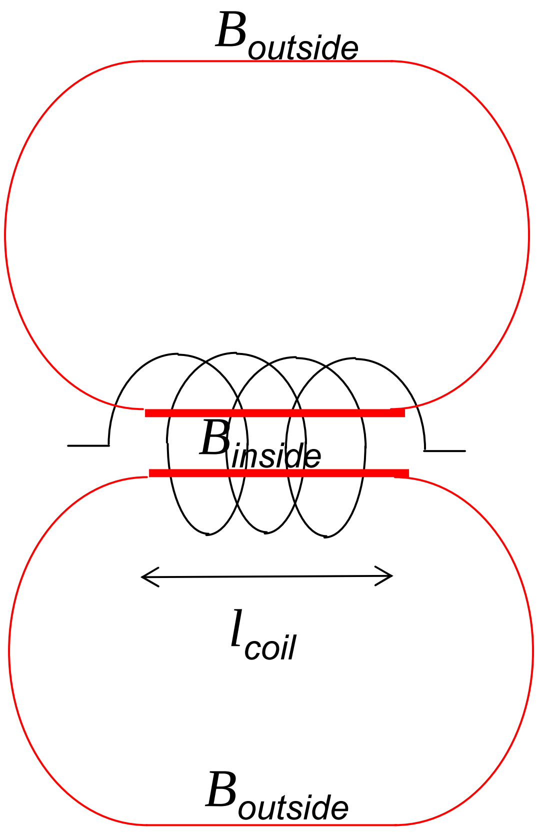
$$L = \frac{\mu_0 \mu_e \cdot A_e \cdot N^2}{l_e}$$

Inductance with air coil (without iron)

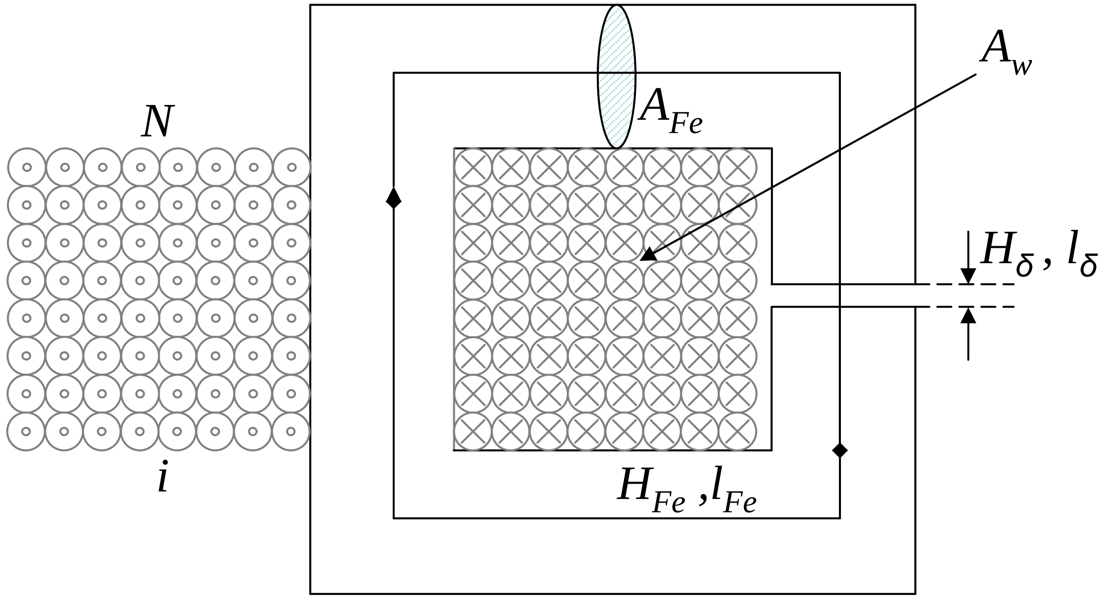
$$N \cdot i = H_{inside} \cdot l_{coil} = \frac{B_{inside}}{\mu_0} \cdot l_{coil} + \frac{B_{outside}}{\mu_0} \cdot L =$$

$$= \left\{ \begin{matrix} B_{outside} \Rightarrow 0 \\ B_{inside} = \dfrac{\psi_{inside}}{N \cdot A} \end{matrix} \right\} = \frac{\psi_{inside}}{N \cdot A \cdot \mu_0} \cdot l_{coil}$$

$$L = \{no\,saturation\} = \frac{\psi_{inside}}{i} = \frac{N^2 \cdot A \cdot \mu_0}{l_{coil}}$$



AP product



AP product $$AP = A_w \cdot A_{Fe}$$

AP-product for an inductor

The flux

$$\hat{\psi} = L \cdot \hat{i}_m = N \cdot A_{Fe} \cdot \hat{B}_m, \;\Rightarrow\; N = \frac{L \cdot \hat{i}_m}{A_{Fe} \cdot \hat{B}_m}$$

The available copper area of the core

$$A_w = \frac{N \cdot A_{Cu}}{k_{Cu}} = \left\{ A_{Cu} = \frac{I_{Cu}}{J_{Cu}} \right\} = \frac{N \cdot I_{Cu}}{k_{Cu} \cdot J_{Cu}} =$$

$$= \frac{L \cdot \hat{i}_m \cdot I_{Cu}}{A_{Fe} \cdot \hat{B}_m \cdot k_{Cu} \cdot J_{Cu}}$$

$$L \cdot \hat{i}_m = k_{Cu} \cdot \frac{J_{Cu}}{I_{Cu}} \cdot \hat{B}_m \cdot A_w \cdot A_{Fe} = \left\{ AP = A_w \cdot A_{Fe} \right\} \Rightarrow$$

The AP product with a single winding on the core

$$AP = \frac{L \cdot \hat{i}_m \cdot I_{Cu}}{k_{Cu} \cdot \hat{B}_m \cdot J_{Cu}} = \left\{ i_m(t) = i_{Cu}(t) \right\} = \frac{L \cdot \hat{i}_{Cu} \cdot I_{Cu}}{k_{Cu} \cdot \hat{B} \cdot J_{Cu}}$$

$$A_{wl} = \frac{A_w}{N_w} = \frac{N \cdot A_{Cu}}{N_w \cdot k_{Cu}}$$

The AP product with several windings on the core

$$AP = \frac{L_k \cdot \hat{i}_{Cu,k} \cdot I_{Cu,k}}{k_{Cu} \cdot \hat{B} \cdot J_{Cu}}$$

Transformer expression

$$U_1 \approx \frac{e_{\max}}{\sqrt{2}} = \frac{N \cdot \omega \cdot \phi_{\max}}{\sqrt{2}} = \frac{N \cdot 2 \cdot \pi \cdot f \cdot \phi_{\max}}{\sqrt{2}} =$$

$$= N \cdot \sqrt{2} \cdot \pi \cdot f \cdot A \cdot B_{\max} = 4.44 \cdot f \cdot N \cdot A \cdot B_{\max}$$

$$B_{\max} = \frac{U_1}{4.44 \cdot f \cdot N \cdot A}$$

AP-product for a transformer

The apparant power

$$S = V \cdot I$$

$$\frac{d\psi}{dt} = N \cdot A_{Fe} \cdot \frac{dB}{dt} = e = V - R_{Cu} \cdot i \approx V$$

$$V = N \cdot A_{Fe} \cdot \omega \cdot \frac{\hat{B}}{\sqrt{2}}$$

$$I = I_{RMS} = A_{Cu} \cdot J_{RMS}$$

$$A_w = N_w \cdot \frac{N \cdot A_{Cu}}{k_{Cu}}$$

$$A_{Cu} = \frac{k_{Cu} \cdot A_w}{N_w \cdot N}$$

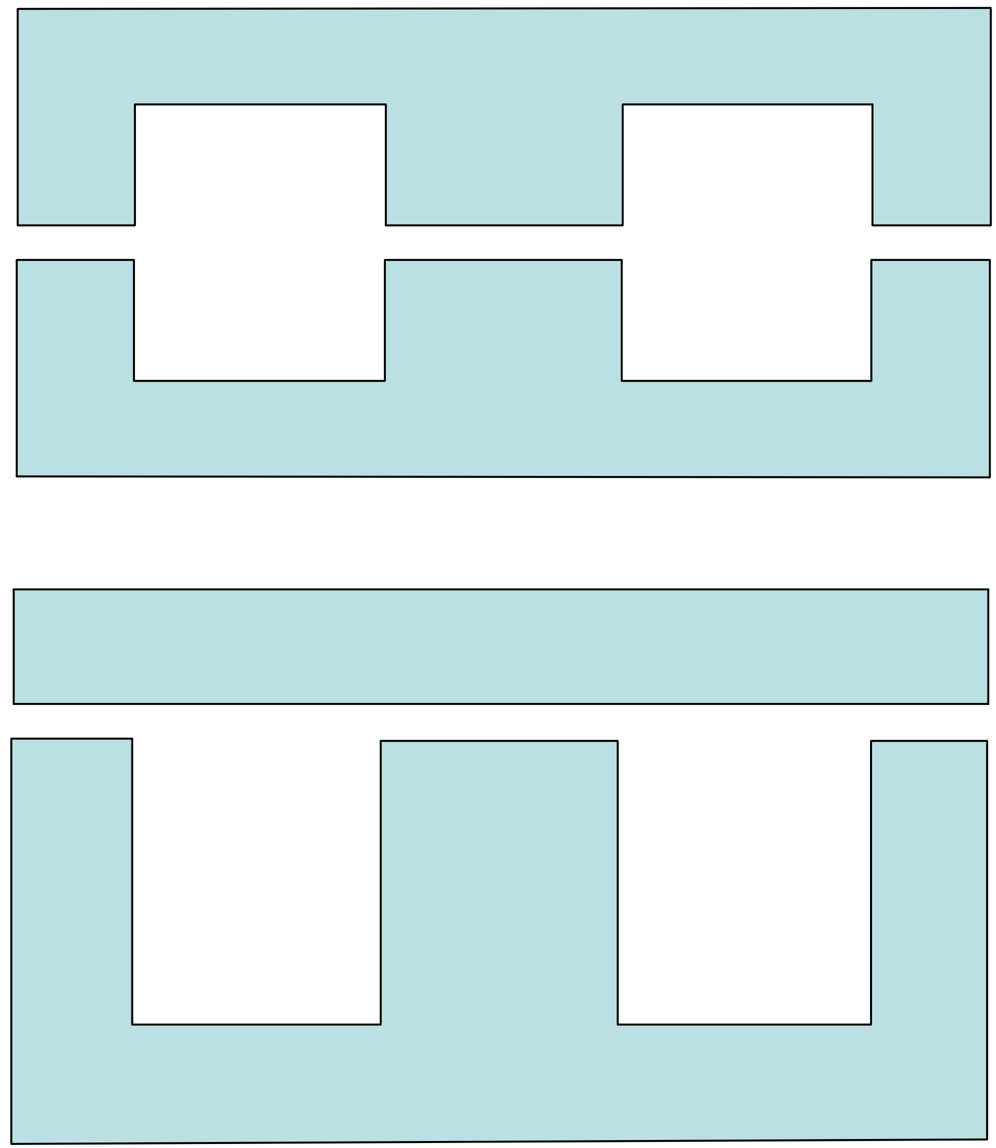
$$I = \frac{k_{Cu} \cdot A_w}{N_w \cdot N} \cdot J_{RMS}$$

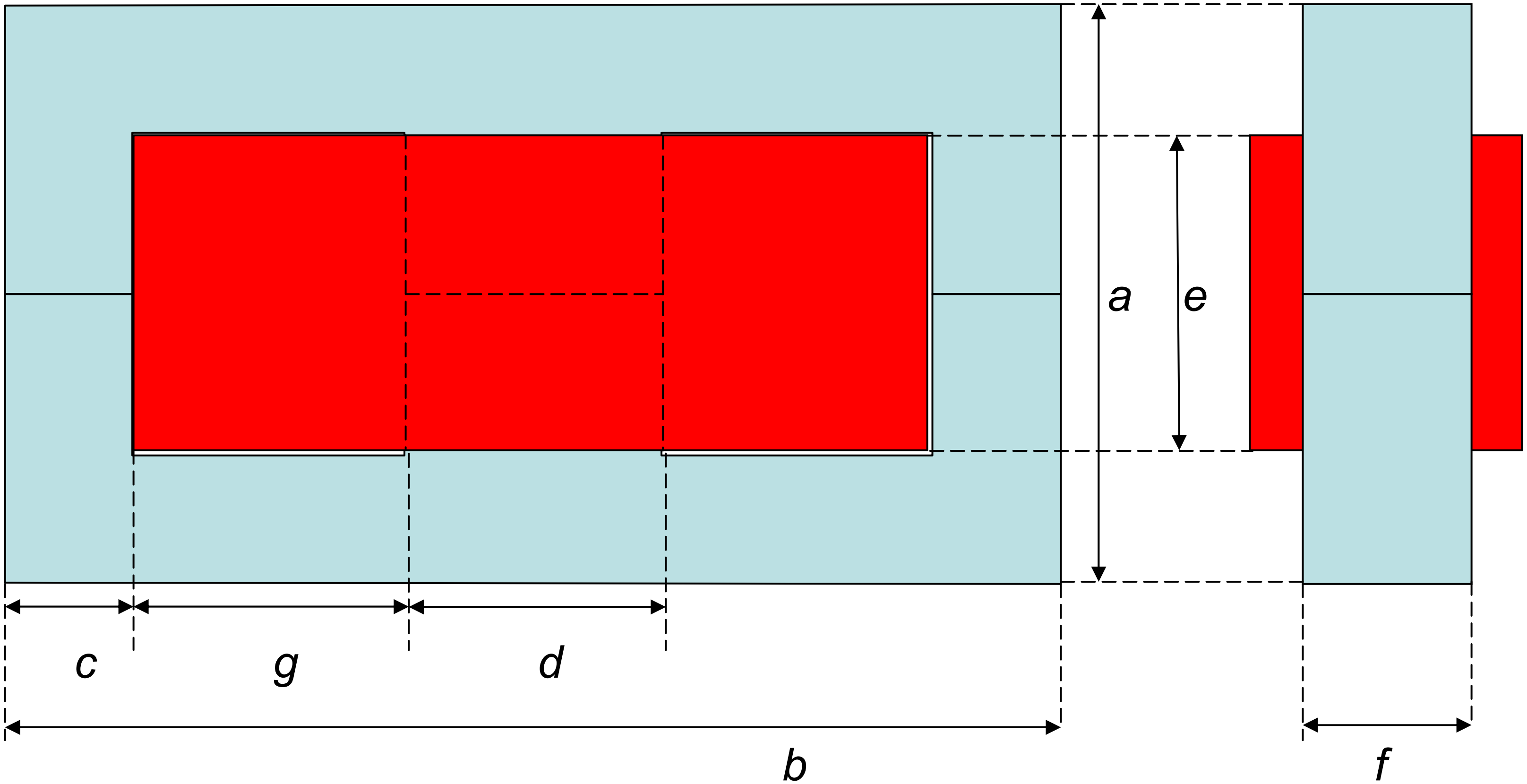
$$S = \frac{N \cdot k_{Cu} \cdot J_{RMS} \cdot A_{Fe} \cdot A_w \cdot \omega \cdot \hat{B}}{N_w \cdot N \cdot \sqrt{2}} = \frac{k_{Cu} \cdot J_{RMS} \cdot AP \cdot \omega \cdot \hat{B}}{N_w \cdot \sqrt{2}}$$

The AP product with several windings on the core

$$AP = \frac{\sqrt{2} \cdot S \cdot N_w}{k_{Cu} \cdot J_{RMS} \cdot \omega \cdot \hat{B}}$$

EE and EI laminated cores





<u>*Optimum values*</u>

$AP(=A_{fe}A_{Bobbin})$	$3.75d$	$A_{fe}=k_{fe}df, A_{bobbin}=k_{bobbbin}eg$
a	$3.5d$	$k_{fe}<1$ $k_{bobbin}<1$
b	$4d$	
c	$0.5d$	
e	$2.5d$	
f	$1.5d$	
g	d	