Electrical Machines

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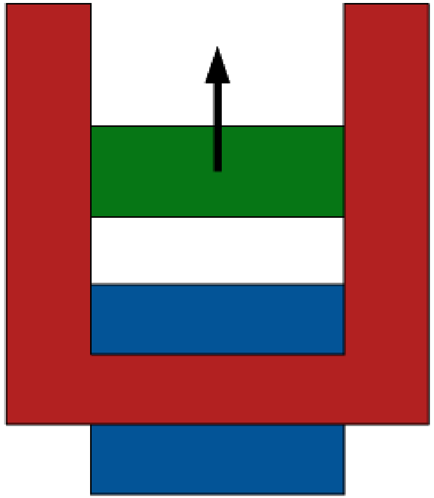
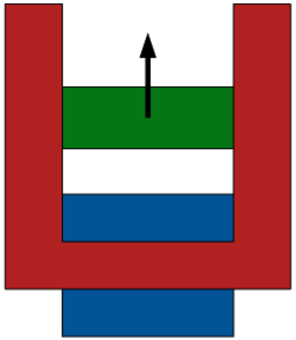


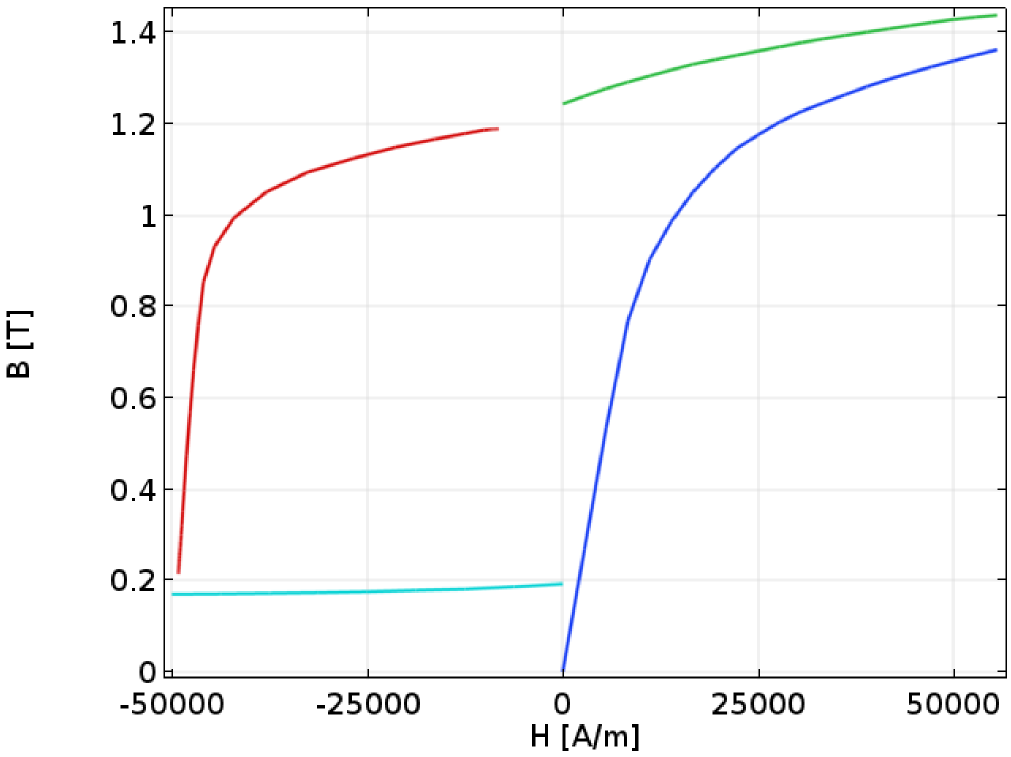
1.5[T] at 5400[A/m]

Geometry of the magnetic circuit, featuring soft iron (red); a coil (blue); and an AlNiCo-like material (green). The AlNiCo bar is initially nonmagnetic, then magnetized because of an applied current to the coil and demagnetized because of the extraction from the magnetic circuit (arrow).

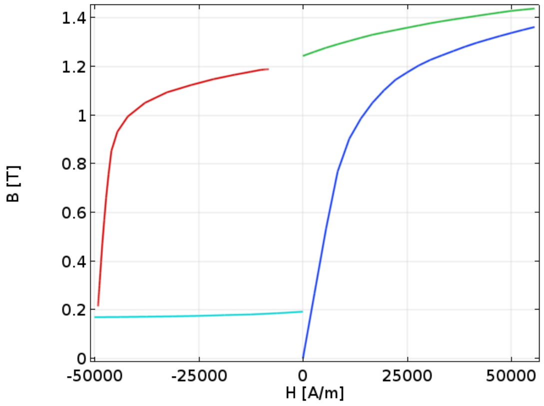


- ✓ The AlNiCo component starts from a nonmagnetized state and magnetizes because of an applied current to the coil
- ✓ The AlNiCo component is magnetized because of the current of Step 1 and keeps most of its magnetization, even when the coil current is removed
- ✓ The magnetized AlNiCo component gets partially demagnetized when extracted from the core
- ✓ The demagnetized AlNiCo component is brought back in the magnetic circuit, essentially keeping the low magnetic remanent flux from when it was out of the magnetic circuit

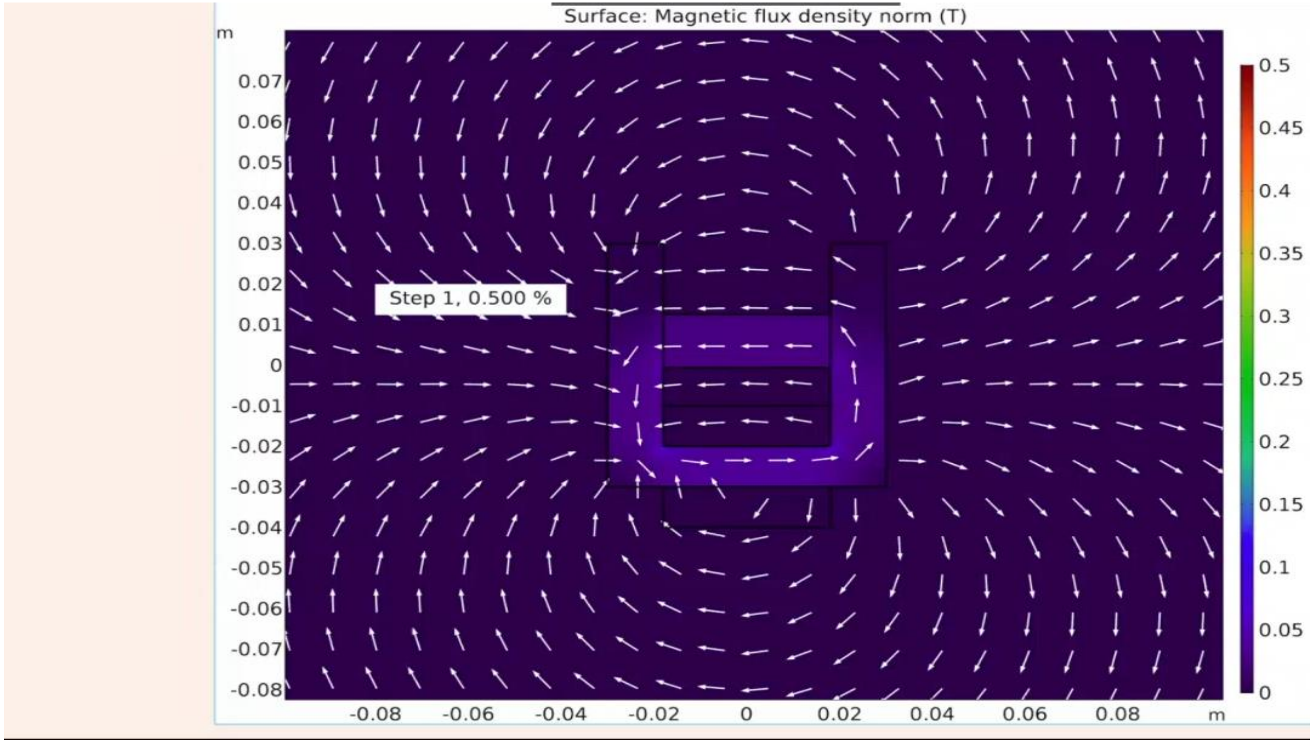
H [kA/m]	B [T]
-50 (coercive magnetic field, Hc)	0
-48	0.5
-47	0.7
-46	0.85
-44	0.96
-40	1.03
-35	1.08
-30	1.11
-20	1.155
-10	1.187
0	1.2 (Remanent flux, Br)



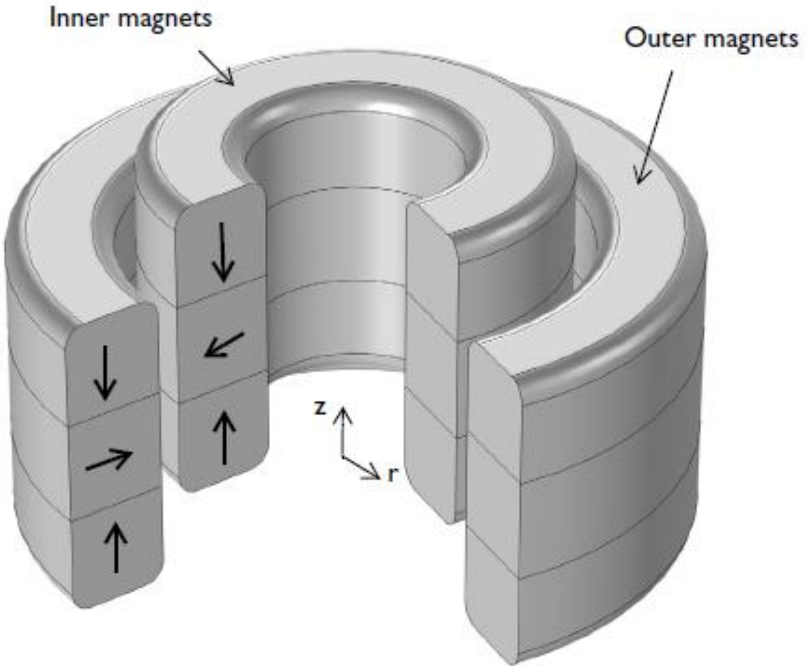
Horizontal component of magnetic flux density in the center of the AlNiCo during the four-step process

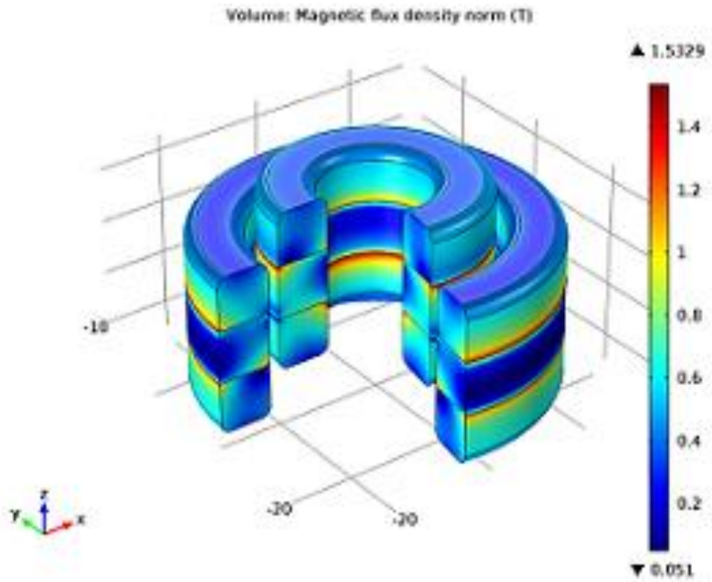


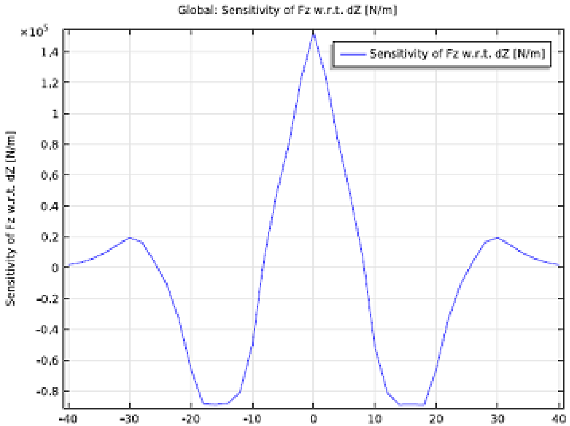
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-50000
-25000
0
25000
50000
B [T]
H [A/m]



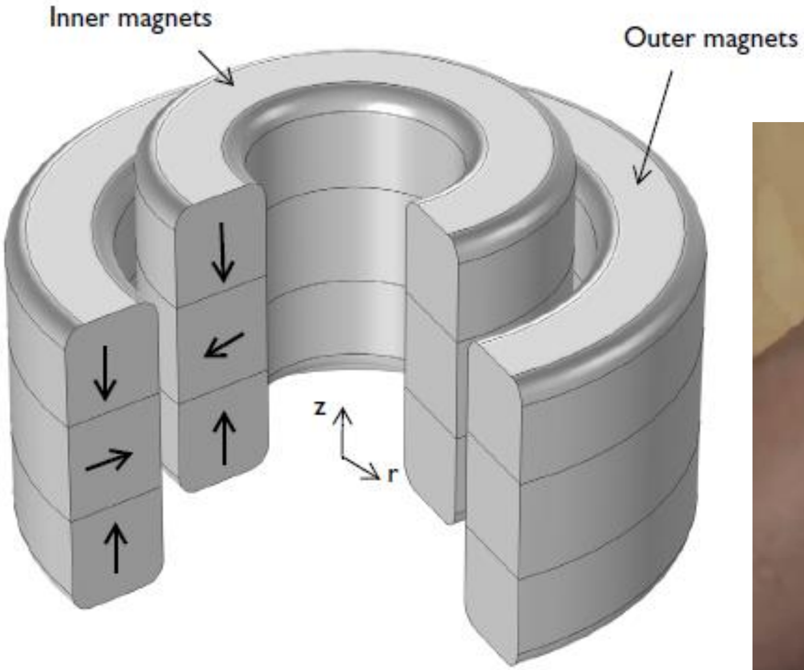
Surface: Magnetic flux density norm (T)
Step 1, 0.500 %
m
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
m
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0



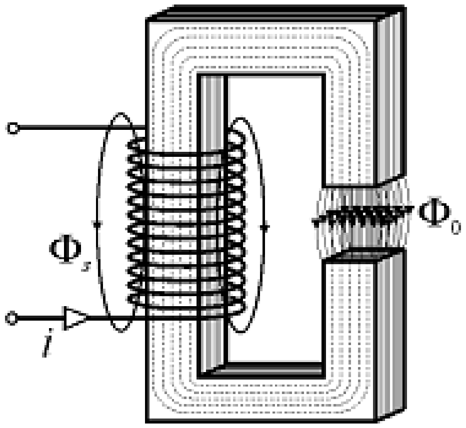




The axial and radial direction are represented by z and r-axes respectively. The magnetization direction of the permanent magnets is shown as black arrows.


Inner magnets
Outer magnets
z
r

Hysteresis loss



$$u_0(t) = U_{0m}\cos\omega t$$

the magnetic flux in core

$$u_0(t) = -e_0(t) = \frac{d\Psi(t)}{dt} = w\frac{d\mathbf{\Phi_0}(t)}{dt} = U_{0m}\cos\omega t$$

$$\Downarrow$$

$$\mathbf{\Phi_0}(t) = \frac{1}{w}\int u_0(t)\,dt = \frac{U_{0m}}{w}\int \cos\omega t\,dt = \frac{U_{0m}}{w\omega}\sin\omega t = \mathbf{\Phi}_{0m}\sin\omega t$$

crest value emf

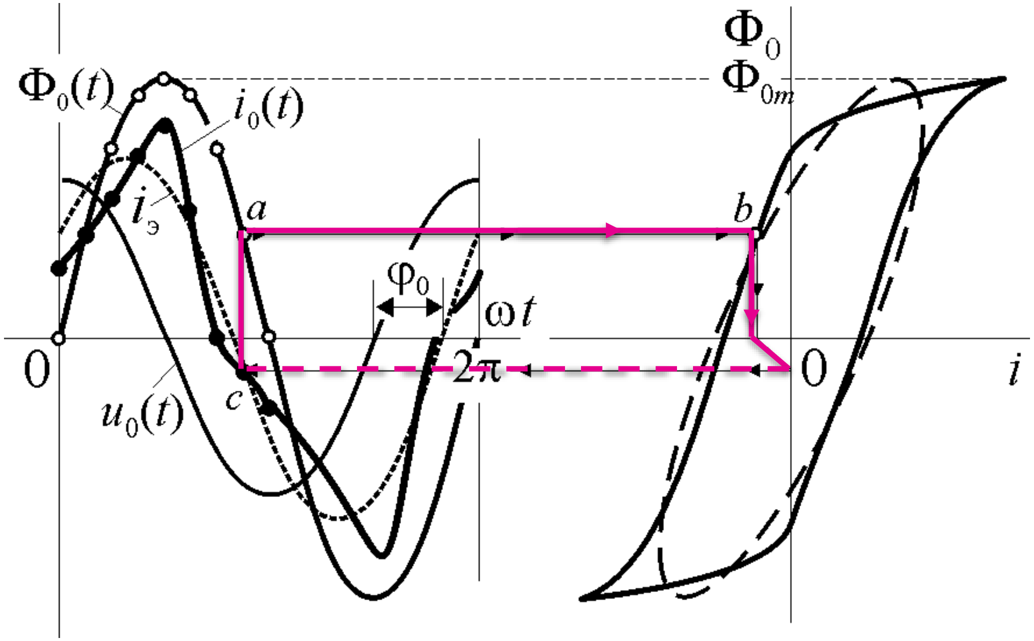
$$E_{0m} = U_{0m} = w\omega\Phi_{0m} = w2\pi f\Phi_{0m}$$

root-mean-square value emf

$$E_0 = U_0 = E_{0m} / \sqrt{2} = 4,44wf\Phi_{0m}$$

For the ideal solenoid

$$\Phi_{0m} = \frac{U_0}{4,44wf}$$



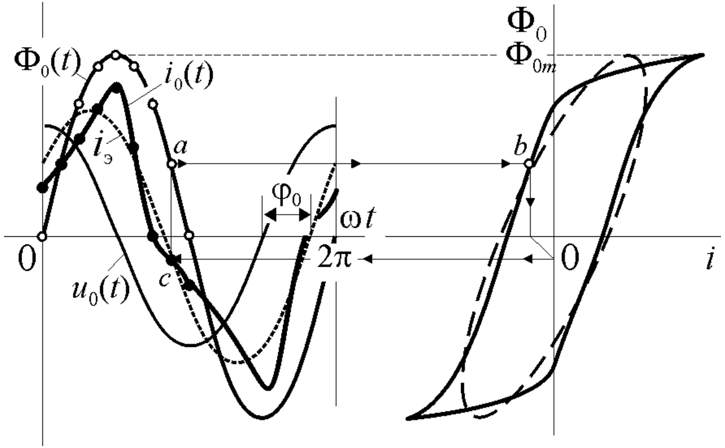
Voltage and magnetic flux

The magnetic flux in core

$$\varphi_0 = \arccos\left(\frac{P_0}{U_0 I_{0э}}\right) < \pi/2$$

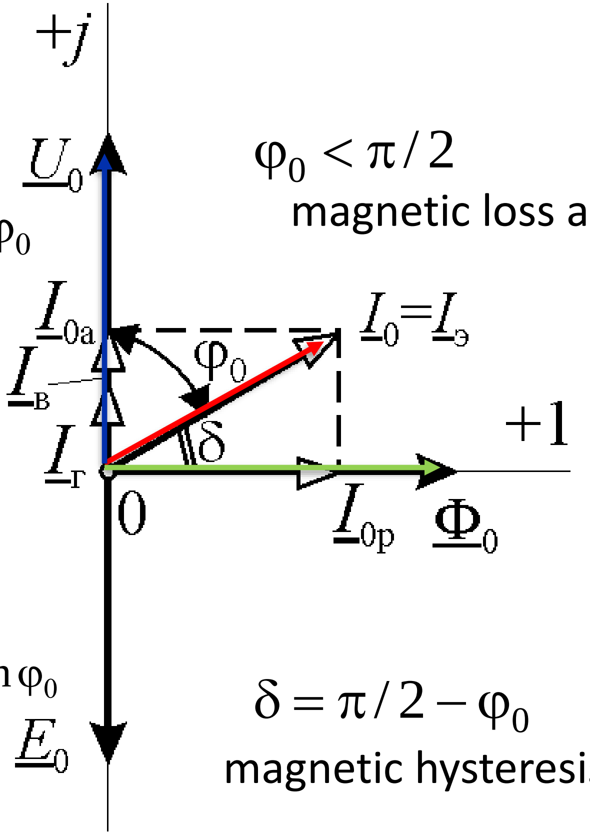
$$P_0 = U_0 I_{0\text{a}}$$

$$I_{0\text{a}} = I_0 \sin\delta = I_0 \cos\varphi_0$$



$$I_{0\text{p}} = I_0 \cos\delta = I_0 \sin\varphi_0$$

$$Q_0 = U_0 I_{0\text{p}}$$



$\varphi_0 < \pi / 2$

magnetic loss angle

$\delta = \pi / 2 - \varphi_0$

magnetic hysteresis angle

Hysteresis loss

$$P_{\Gamma} = \eta f B_m^n V$$

η – the core coefficient (depending on material);

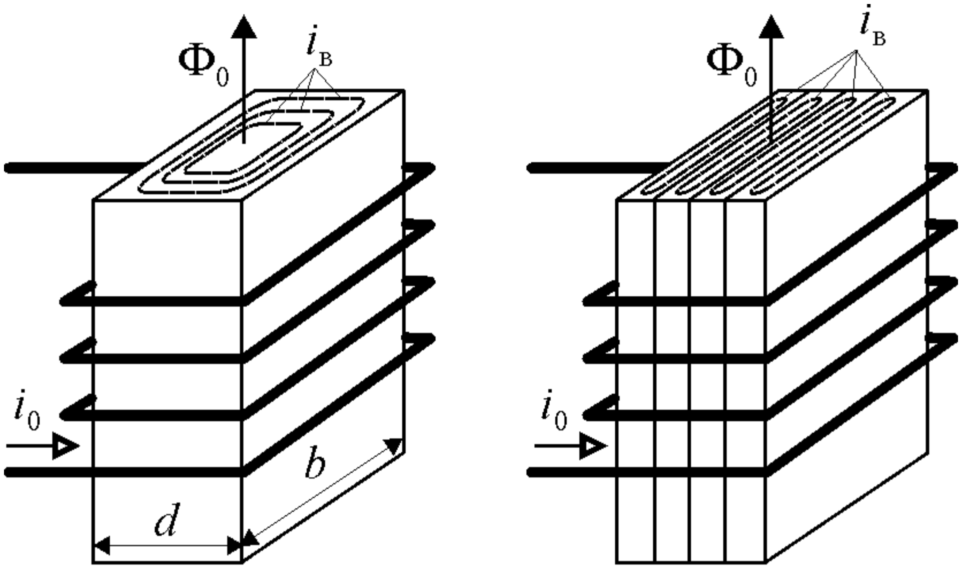
f – frequency;

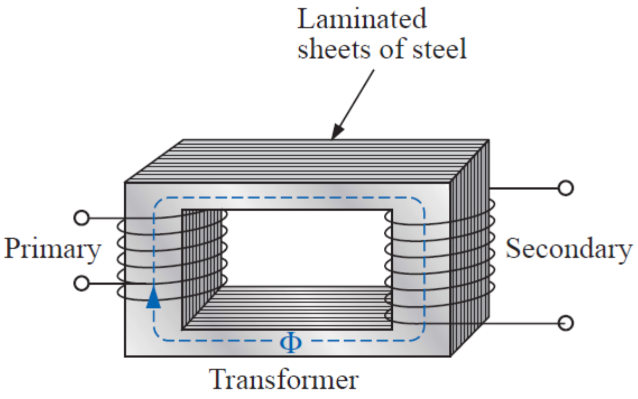
V – core dimension;

B_m – maximum flux density ;

$1{,}0 < n < 2{,}0$ – coefficient depending on material and flux density

Eddy current losses





Whirling currents loses

$$P_e = \xi d^2 f^2 B_m^2 V$$

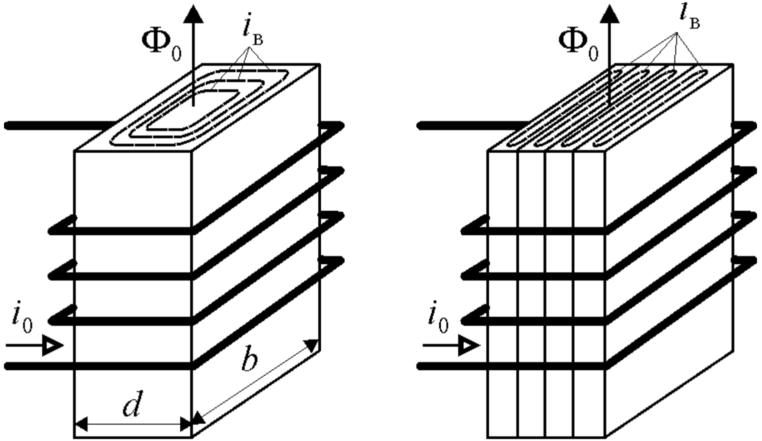
ζ– coefficient depending on conductivity core;

$d \ll b$– plate core thickness;

f – frequency of magnetic reversals per second (Hz);

V – core dimension;

B_m – maximum flux density



$$P_1 = I^2 R_1 > P_2 = (I/n)^2 R_2 \;\Rightarrow\; P_1 / P_2 \approx n^2 \Big|_{R_1 \approx R_2}$$

Thank you!

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