Energy conversion I

Lecture 3:

Topic 1: Magnetic materials and Circuits (S. Chapman, ch. 1)

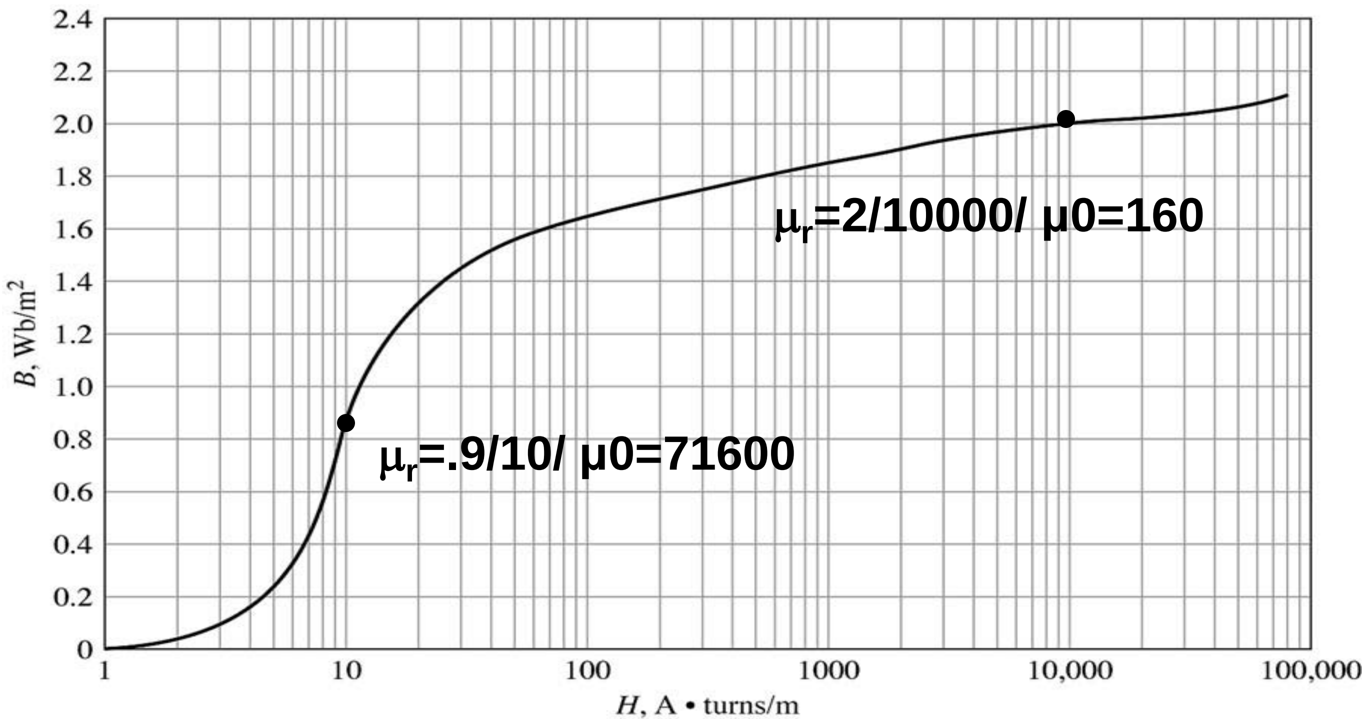
- Magnetic Field production and Mag. Circuits modeling
- **Ferromagnetic Materials behavior**
- **Faraday's law**
- Electrical Equivalent Cct. For magnetic Ccts
- Permanent Magnet Materials
- Force applied on a wire by external magnetic field
- Voltage induced in on moving conductor in magnetic field

Ferromagnetic Materials behavior

For **non-magnetic** materials there is a **linear** relationship between the flux density **B** and coil current **I** (or the magnetic field intensity **H**). That is the permeability is constant and usually very close to μ_0.

For **magnetic** materials, the **permeability** is much **higher** than μ_0. However, the permeability **depends on the current** over a wide range.

Dc **magnetization curve (/Saturation curve)** for M-5 **grain-oriented** electrical steel 0.012 in thick. *(Armco Inc.)*



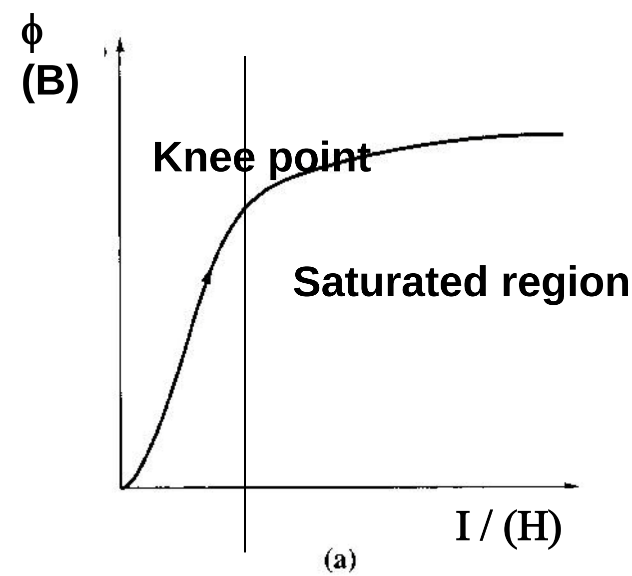
Ferromagnetic Materials behavior

Magnetic materials are used in **Electric Machines** to generate required **flux** with **less effort** (**Magnetizing current**).

To have a **linear behaviour**, Magnetic **saturation** should be **avoided**.

Since: **$H = Ni/l_c = F/l_c$ Horizental** axis can be **I**, **F** or **H**

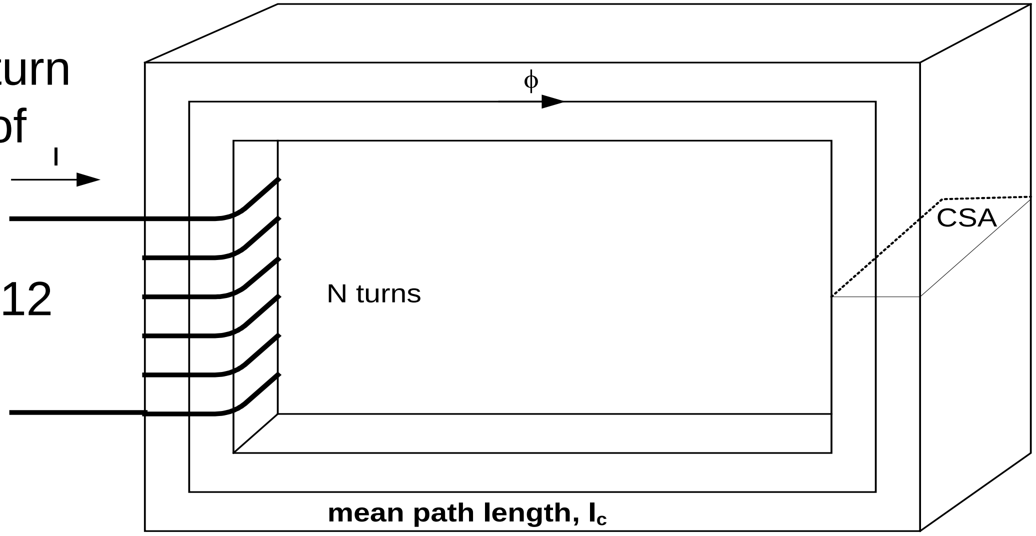
Since **$\phi = BA$**, **Vertical** axis can be ϕ or **B.**



Ferromagnetic Materials behavior

Example:

A square magnetic core, mean path length : 55cm, csa: 150cm^2. 200 turn coil of wire. Magnetization curve of the core as shown. Find:



a) How much current to produce 0.012 Wb in the core?

b) What is the core's relative permeability at that current level?

C)What is its reluctance?

Ferromagnetic Materials behavior

Solution:

A square magnetic core, mean path length : 55cm, csa: 150cm^2. 200 turn coil of wire. Magnetization curve of the core as shown. Find:

a) $B = \phi / A = 0.012 / 0.015 = 0.8$ T

from magnetizing curve: **H = 115 Atr/m**

$H.L_c = NI \rightarrow I = H\,L_c / N = 115 \times 0.55/200$

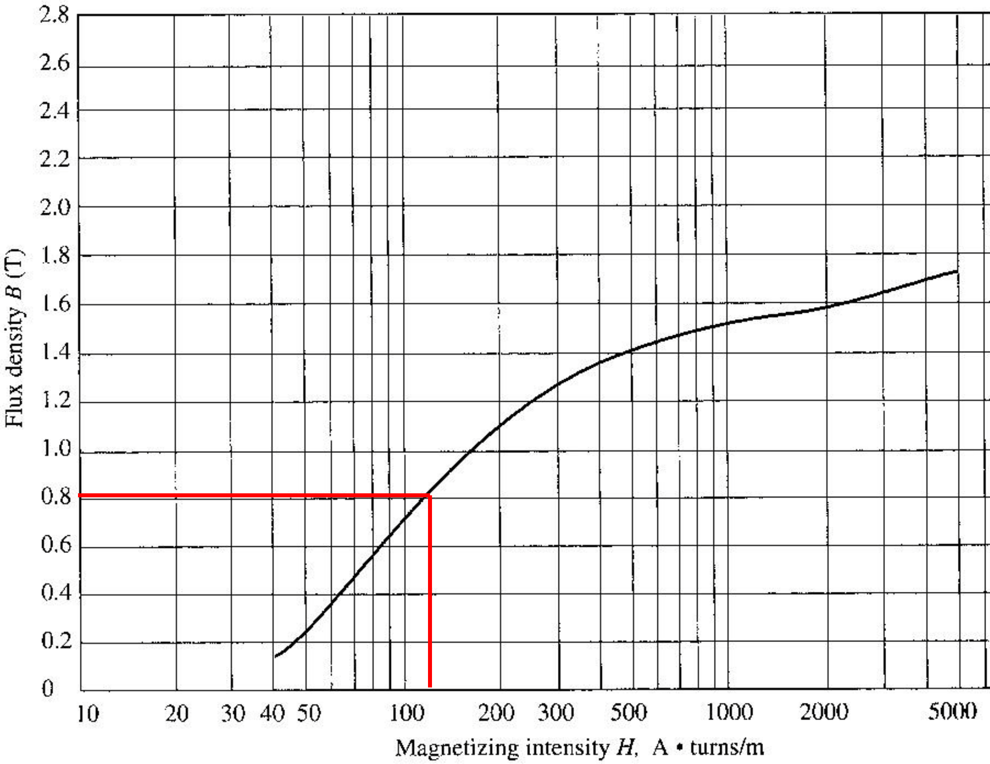
I = 0.316 A

b) $B = \mu_r \mu_0 H \rightarrow \mu_r = B / (\mu_0 H) = 0.8/(115 \times 4\pi \times 10^{-7})$

μr = 5540

c) $F = \phi R \rightarrow R = F / \phi = 115 \times 0.55/0.012$

R = 5270 Atr/Wb

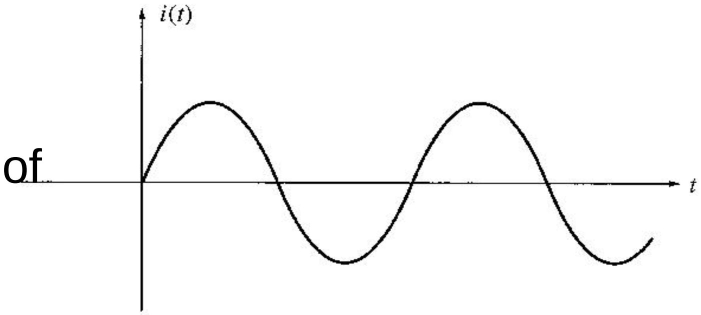


(c)

Think about other ways to solve.

Ferromagnetic Materials behavior

Hysteresis Magnetizing



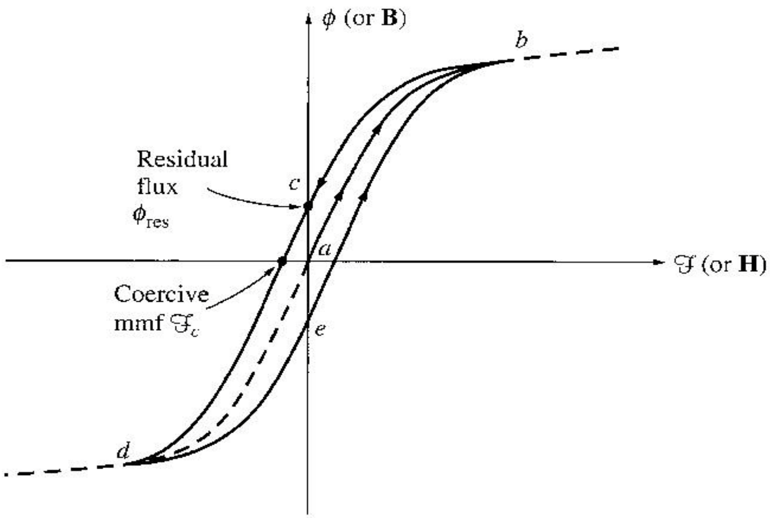
(a)

Hysteresis Magnetizing behavior: another source of nonlinearity
NOTE: **flux** depends on the **amount of current** applied **and** on the **previous value of the flux.**

When **mmf** is **removed**, the **flux** goes to **residual flux**. Like **permanent magnets**

Coercive mmf must be applied in the **opposite direction** To force the flux to zero

Area enclosed in the **hysteresis loop** is directly **proportional** to the **energy lost** in **an ac cycle**.



(b)

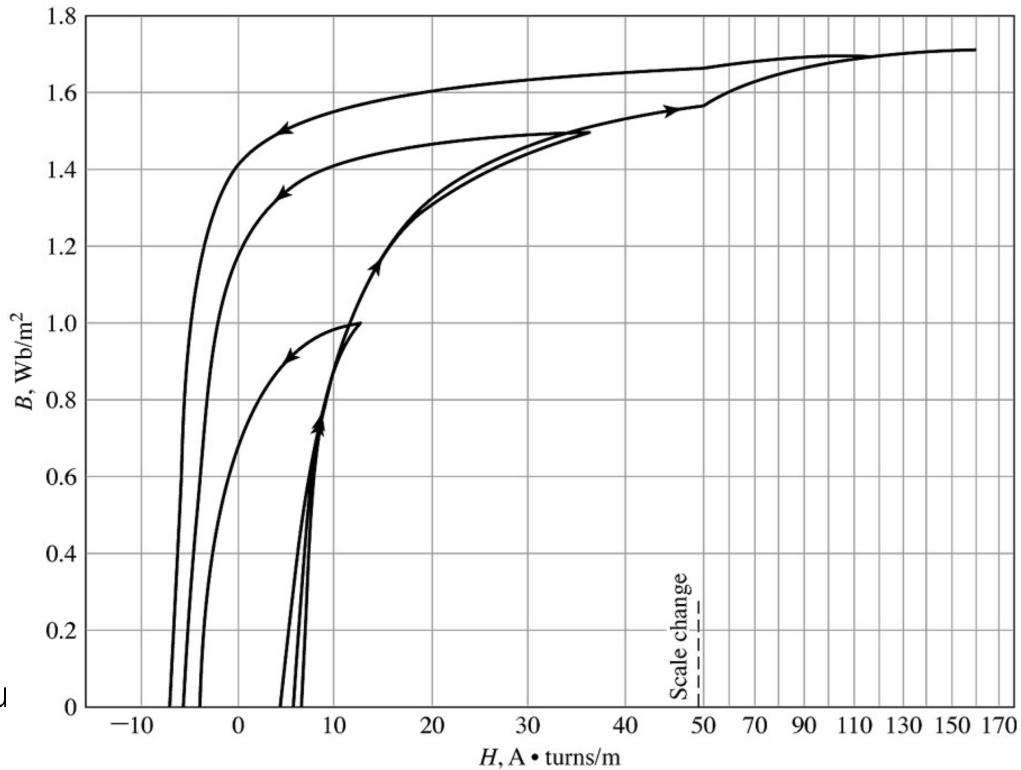
Ferromagnetic Materials behavior

Energy Losses in a Ferromagnetic Core

<u>**Area** enclosed in the **hysteresis loop** is directly **proportional** to the **energy lost** in **an ac cycle**.</u>

Area enlarges if amplitude of **AC current (or B_{max}) increases**

$$P_h = K_h V f B_{\max}^n$$ V: Volume, f: frequency, 1.5<n<2.5



B-H* loops for M-5 grain-oriented electrical steel 0.012 in thick. Only the top halves of the loops are shown here. *(Armco Inc.)

Faraday's Law

Effect of Time varying magnetic field on its surrounding:

Basis of **Transformer** operation

'If a flux passes through a turn of a coil of wire, voltage will be induced in the turn of the wire that is directly proportional to the rate of change in the flux with respect of time'

$$e_{ind} = -\frac{d\phi}{dt}$$

For a coil of **N** turns:

$$e_{ind} = -N\frac{d\phi}{dt}$$

Minus sign comes from **Lenz's** Law:

'The direction of the build-up voltage in the coil is such that if the coils were short circuited, it would produce current that would cause a flux opposing the original flux <u>change</u>.'

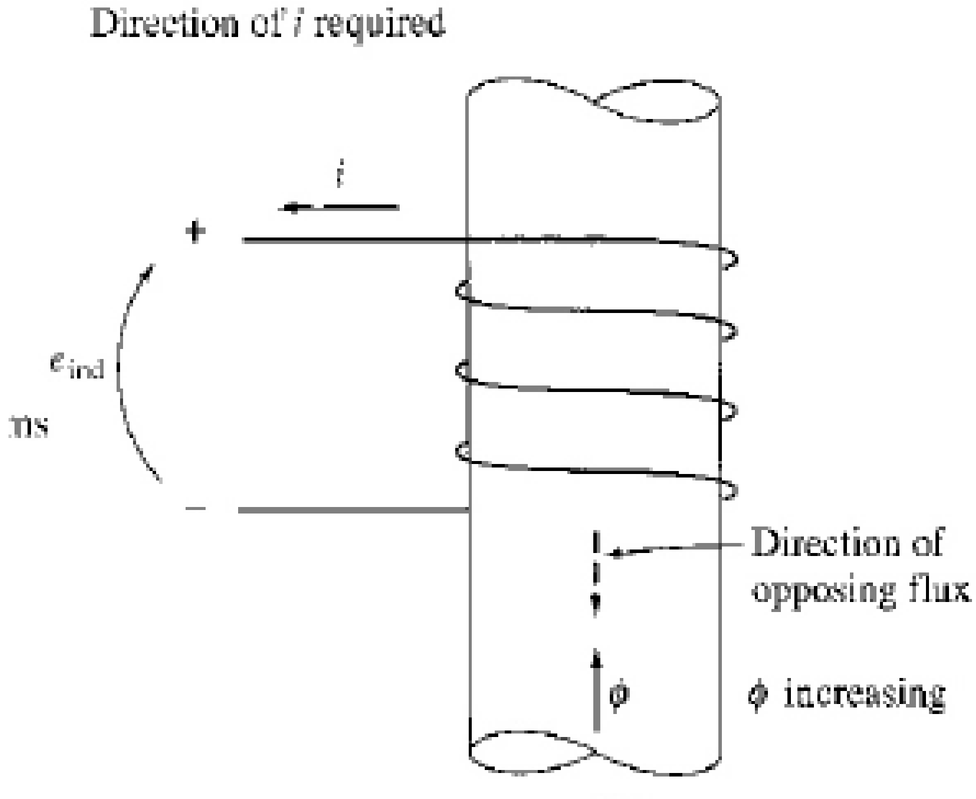
Flux Linkage

NOTE: the minus sign is often left out and the polarity of the resulting voltage can be determined from physical considerations.
For an N turn Winding, more precisely:

$$e_i = \frac{d\phi_i}{dt}$$

$$e_{ind} = \sum_{i=1}^{N} e_i = \sum_{i=1}^{N} \frac{d\phi_i}{dt}$$

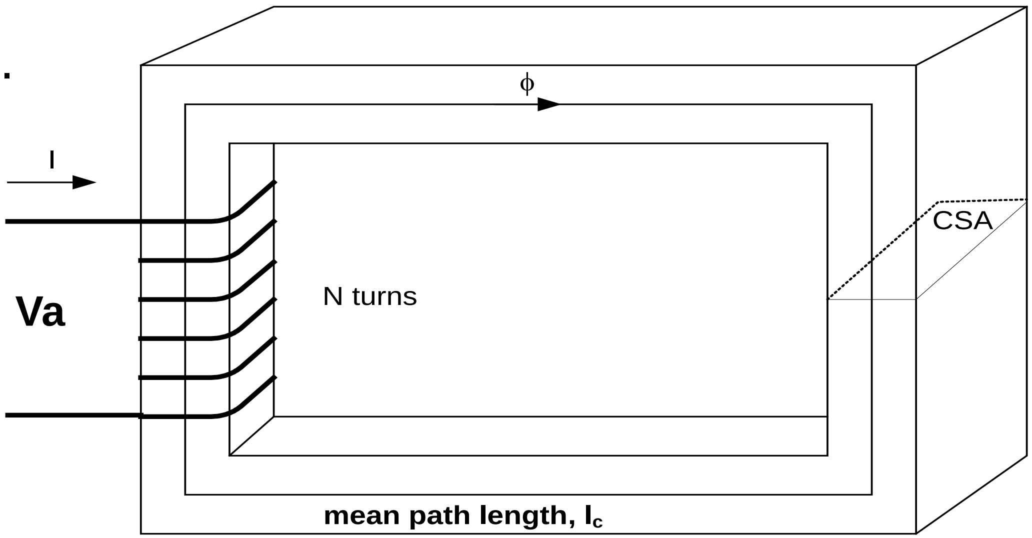
$$= \frac{d\sum_{i=1}^{N}\phi_i}{dt} = \frac{d\lambda}{dt}$$



λ: Flux Linkage (Wb)

Example:

Following figure shows a coil of wire wrapped around an iron core.
mean path length : 55cm, csa: 150cm^2.
200 turn coil of wire.
Neglecting wire resistance what is B if applied voltage is: 300sin(100πt)



Solution:

$$v = e_i = \frac{d\lambda}{dt} = N\frac{d\phi}{dt} = NA\frac{dB}{dt}$$

$$B = -B_m \cos(100\pi t)$$

$$B_m = \frac{V_m}{100\pi NA} = \frac{300}{100\times\pi\times 200\times 0.015}$$

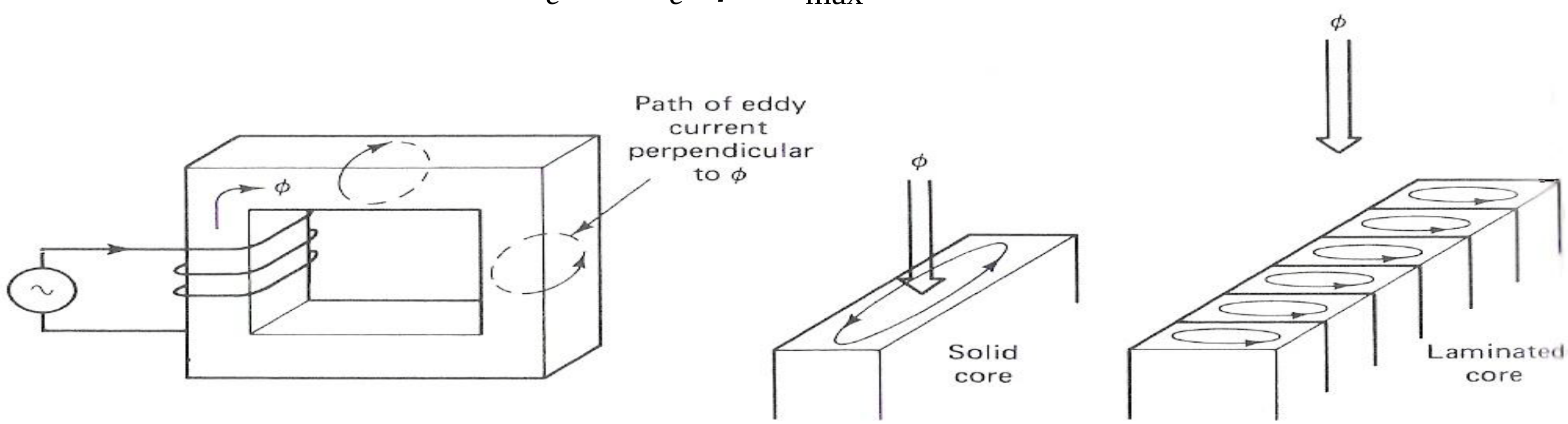
$$B_m = 0.32T$$

Sinusoidal V $\longrightarrow$ Sinusoidal B

Think about the effect of μ!

Eddy Current

Faradays Law: **time-varying flux induces voltage within a ferromagnetic core.**
Induced voltages + **Low resistance** of core cause **swirls of current** (Eddy currents).
Energy dissipation (in the form of **heat**) due to **eddy currents** are in **resistive material** (**iron**) core $P_e = K_e V f^2 B_{\max}^2$



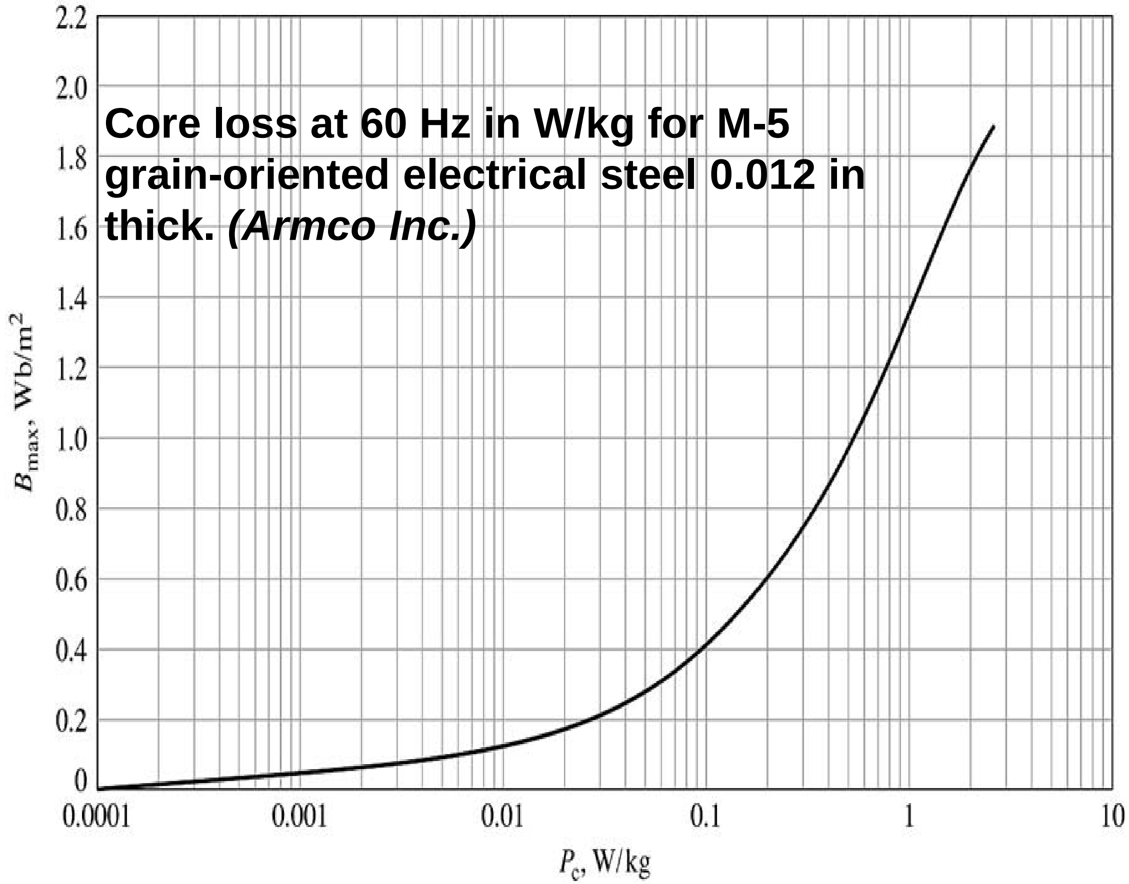
Using **insulated laminated cores** To **reduce** energy loss.

Magnetic Core Loss

Core Loss Due to Hysteresis: $$P_h = K_h V f B_{\max}^n$$ 1.5<n<2.5

Core Loss Due to Eddy Current $$P_e = K_e V f^2 B_{\max}^2$$

Both in AC excitation



Core loss at 60 Hz in W/kg for M-5 grain-oriented electrical steel 0.012 in thick. ***(Armco Inc.)***