Magnetic Circuits

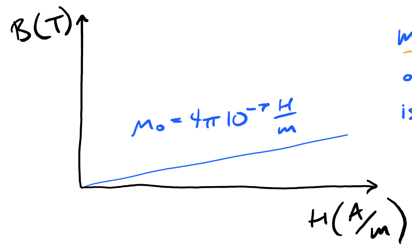
Thursday, January 21, 2016 11:37 AM

$\boxed{B=\mu H}$ $\mu_0 = 4\pi 10^{-7}\frac{F}{m}$

FLUX DENSITY

MAGNETIC FIELD

for materials with low permeability, assume μ is constant

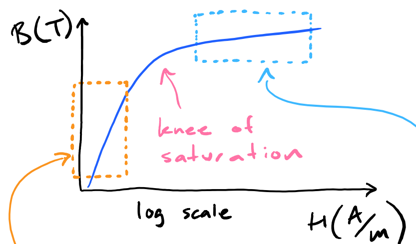


magnetization characteristic of the material (B-H curve) is a straight line

(true for air, plastic, wood fabrics, vacuum, etc.)

↳ pretty much always equals $4\pi 10^{-7}\frac{H}{m}$

for materials with a higher permeability



Iron, cobalt, nickel and their alloys

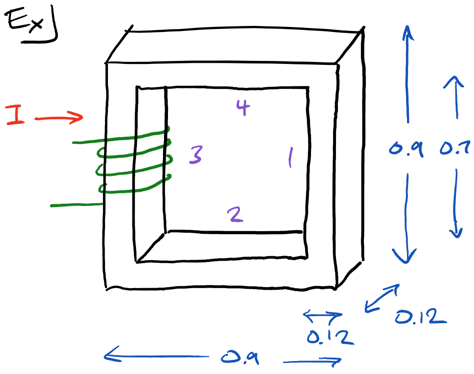
magnetization characteristic is <u>not</u> linear or constant

linear region (very steep part of magnetization characteristic)

saturation region (slope is close to that of air/vacuum, $4\pi 10^{-7}\frac{H}{m}$)

"all electrical machines operate with a flux density that lands them in the saturation region"

Ex)



LENGTHS GIVEN IN m
COIL HAS 1200 TURNS
FLUX NEEDED IS 1.2 MMx
NO MAGNETIC LEAKAGE

↳ assume all flux is in the iron and is constant throughout

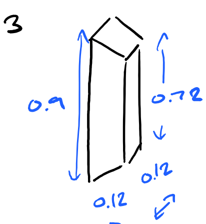
AMPS NEEDED?

WHAT IS THE INDUCTANCE OF THE COIL?

Simplified solution: assume constant permeability of air, 5500

1. Identify legs with uniform B, compute magnetic potential drop of each leg seperately

LEG 3

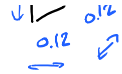


$A_3 = 0.12 \cdot 0.12 = 0.0144\,m^2$ (cross-section area crossed by flux)

$\phi_3 = 1.2\,MM_x \cdot \frac{1\,wb}{10^8\,M_x} = 0.012\,wb$ (flux)

$B_3 = \frac{\phi_3}{A_3} = 0.833\,T$ (flux density in leg)

$H_3 = \frac{B_3}{\mu} = \frac{0.833T}{5500\mu_0} = 120.6\,\frac{A}{m}$ (magnetic field in leg)



A_3

$H_3 = \frac{B_3}{\mu} = \frac{0.833T}{5500\mu_0} = 120.6\ \frac{A}{m}$ (magnetic field in leg)

$\ell_3 = \frac{0.9 + 0.72}{2} = 0.81m$ (equivalent length, average by convention)

can only use this formula because we're assuming constant μ

(not normally true)

$U_3 = H_3 \ell_3 = 120.6 \frac{A}{m} \cdot 0.81m = \boxed{97.7A}$ (magnetic potential drop)

if you repeat for legs 1, 2, and 4, you get $U_1 = 167.4$, $U_2 = 110.7$, $U_4 = 138.4$

2. use ampere's law

$$\sum N_k I_k = \underbrace{H_1 \ell_1}_{U_1} + \underbrace{H_2 \ell_2}_{U_2} + \underbrace{H_3 \ell_3}_{U_3} + \underbrace{H_4 \ell_4}_{U_4} = 514.128\ A$$ (total magnetic potential drop)

↳ must be equal to total magnetomotive force

(by ampere's law)

$NI = 514.128\ A$

1200 turns

$I = \frac{514.128A}{1200} = \boxed{0.428A}$

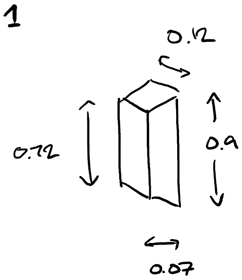
3. find flux linkages of the coil created by current

$\lambda = N\phi = 1200 \cdot 0.012Wb = 14.4Wb$

$L = \frac{\lambda}{I} = \frac{14.4\ Wb}{0.428A} = \boxed{33.6H}$

Ex) cont'd REPEAT ABOVE WITHOUT ASSUMING μ IS CONSTANT

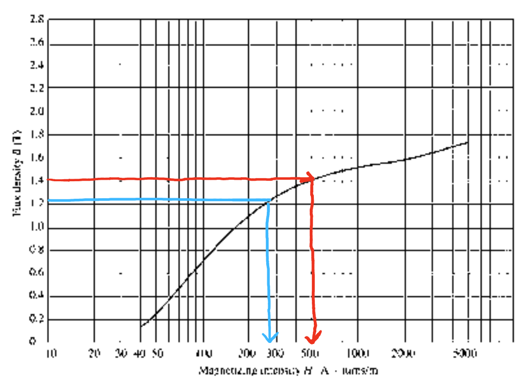
LEG 1



$A_1 = 0.12m \cdot 0.07m = 0.0084\ m^2$

$\phi_1 = 1.2\ MMx \cdot 10^{-8} = 0.012\ Wb$

$B_1 = \frac{\phi_1}{A_1} = 1.43T$

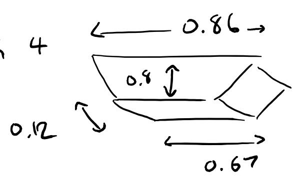


$H_1 \simeq 500\ \frac{A}{m}$

$\ell_1 = \frac{0.9 + 0.72}{2} = 0.81m$

$U_1 = H_1 \ell_1 = 500 \cdot 0.81m = \boxed{405A}$

LEG 4



$A_4 = 0.08 \cdot 0.12 = 0.0096\ m^2$

$\phi = 0.012\ Wb$

$B_4 = \frac{\phi_4}{A_4} = 1.25T$

$H_4 \simeq 270\ \frac{A}{m}$

$\ell_4 = \frac{0.86 + 0.67}{2} = 0.765m$

$U_4 = H_4 \ell_4 = \boxed{207A}$

$$U_4 = H_4 l_4 = \boxed{207A}$$

LEG 2 same process $\longrightarrow$ $B_2 = 1T$, $H_2 = 157 \frac{A}{m}$, $\boxed{U_2 = 122A}$

LEG 3 $B_3 = 0.83T$, $H_3 = 120 \frac{A}{m}$, $\boxed{U_3 = 97A}$

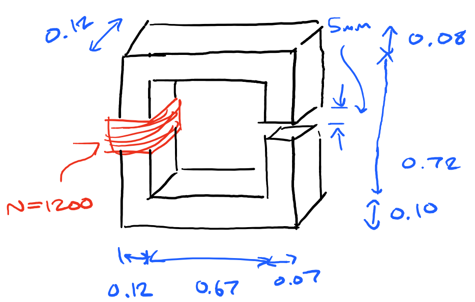
$$NI = U_{TOT} = U_1 + U_2 + U_3 + U_4 = 831 A$$

magnetomotive force

$$I = \frac{831A}{1200} = \boxed{0.69A}$$

inductance, $L = \frac{\lambda}{I} = \frac{N\phi}{I} = \frac{1200 \cdot 0.012 Wb}{0.69A} = \boxed{20H}$

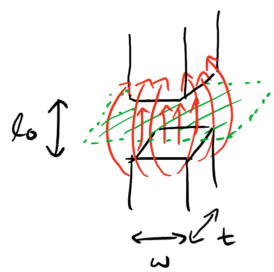
AIR GAP $\rightarrow$ magnetic potential drop in air gap must be accounted for



$\phi = 1.2 MMx = 0.012 Wb$

Process is the same as before, but must treat air gap as another leg.

↳ has same flux (assuming no leakage) but larger cross-section



approximate air gap cross-section as

$$\boxed{A_g = (w + l_0)(t + l_0)}$$

$$B_0 = \frac{\phi}{(w+l_0)(t+l_0)}$$

In air gap, μ is constant and known: $4\pi 10^{-7}$

$$H_0 = \frac{B_0}{\mu_0}, \quad U_0 = H_0 l_0$$

IDEAL IRON (approximation)

infinite permeability

↳ $H = \frac{B}{\mu} = \emptyset$

regardless of flux density, magnetic field and magnetic potential drop is $\emptyset$

this means the U of each of the legs of the iron core could be assumed as $\emptyset$

only left with air gap

↳ all MMF is applied to the gap directly

(amps)

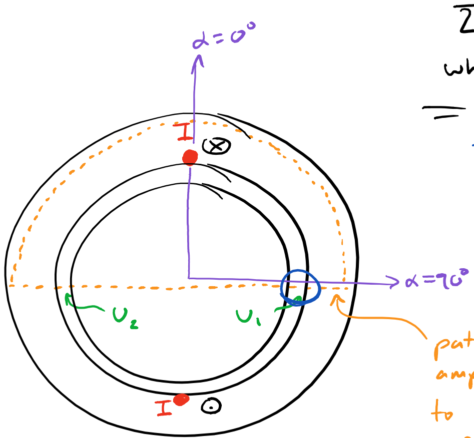
CYLINDRICAL MAGNETIC CIRCUIT (like motors/generators)

Still assuming ideal iron

44:40 - 45:15

$$\sum N_k I_k = H_0 l_0$$

what is value of magnetic field, H, at every point along the air-gap



path for ampere's law to solve @ 90°

=

total magneto motive force applied in that path is equal to current through it

we know there is no magnetic potential drop in the iron, but there is potential drop across the two gaps, $U_1 = U_2 = H_0 l_0$

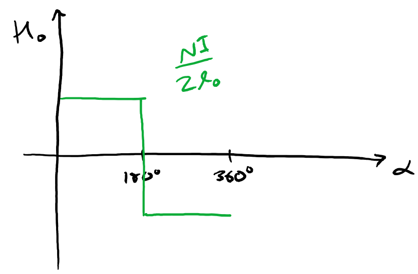
$$NI = U_1 + U_2 = 2H_0 l_0 \rightarrow H_0 = \frac{NI}{2l_0}$$

FROM ϕ to 180° $I > \phi$ (x)

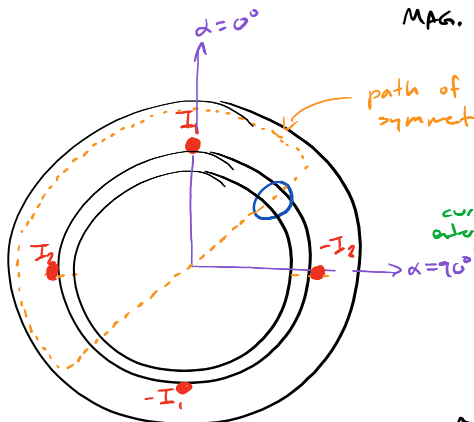
$$\therefore H_0 = +\frac{NI}{2l_0}$$

FROM 180 to 360° $I < \phi$ ($\cdot$)

$$\therefore H_0 = -\frac{NI}{2l_0}$$



MAG. FIELD IN AIR GAP FOR EVERY α ALONG AIR GAP?



path of integration chosen to be symmetrical

total magnetic potential drop (only occurs in the air gap)

from 0° to 90°

current entering surface

$$N_1 I_1 + N_2 I_2 = 2H_0 l_0$$

$$H_0 = \frac{N_1 I_1 + N_2 I_2}{2l_0}$$

from 90° to 180°

$$N_1 I_1 - N_2 I_2 = 2H_0 l_0$$

$$H_0 = \frac{N_1 I_1 - N_2 I_2}{2l_0}$$

(assuming $I_1 = I_2$)