

Friday, November 20, 2015      12-2:30pm      Min Kao Room 121

## CURENT Open House

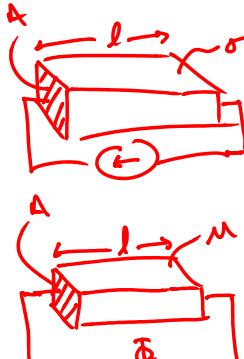
<b>Learn About</b>	<b>Come Visit Our Labs</b>	<b>Refreshments</b>
Research Opportunities	Visualization Room	Pizza and Drinks
Graduate School Funding	Power Electronics Lab	Provided Starting at
Benefits of CURENT	High Power Electronics Lab	Noon
	Hardware Testbed	
	FNET	

Discover the Exciting Applications of Power and Power Electronics  
In Grid, IT, EV, Renewables, and more!

RSVP to Help Us Order Pizza!

THE UNIVERSITY OF TENNESSEE KNOXVILLE 

## Magnetic Circuits



$\oint \mathbf{H} \cdot d\mathbf{l} = V$   
potential between  
two points independent  
of path  
( $\mathbf{H}$  or  $\Phi$  conservative)  
KVL

$$G = \frac{\sigma A}{l}$$

$$R = \frac{1}{G} = \frac{l}{\sigma A}$$

$$= \mu_0 A$$

$$R = \frac{l}{\mu_0 A}$$

$i$   $\rightarrow$   $\Phi$

$\oint \Phi \cdot d\mathbf{l} = i$   
always flows in loop  
no point source/sink  
divergence of  $\Phi$  = 0  
curl

$i_1$   $\rightarrow$   $i_2$   $\rightarrow$   $i_3$   
 $i_3 = i_1 + i_2$   
 $i_3$  or  $\Phi$ 's

$$V = IR$$

$$\oint \Phi \cdot d\mathbf{l} = \Phi R$$

THE UNIVERSITY OF TENNESSEE KNOXVILLE 

## Inductor Magnetic Circuit Model

$$\text{FBD: } \sum \Phi = \frac{l_m}{\mu A_c} \quad \Phi = \frac{\Phi}{R} = \frac{n i A_c}{l_m}$$

$$v(t) = n \frac{d\Phi}{dt} = n \frac{d}{dt} \left[ \frac{n i A_c}{l_m} \right]$$

$$v(t) = \underbrace{\frac{n^2 A_c}{l_m}}_L \frac{di}{dt} \quad \checkmark$$

THE UNIVERSITY OF  
TENNESSEE   
KNOXVILLE

## Saturation Limits

Assume  $B_{sat}$  (unsaturated behavior) then analyze go back & check that  $\max |B| < B_{sat}$

Typical  $B_{sat} = \begin{cases} 0.3 - 0.8 T & \text{for ferrite} \\ 1 - 2.2 T & \text{for laminated iron} \end{cases}$

Previous example inductor (gapless)

$$L = \frac{n^2 A_c}{l_m} \rightarrow \text{if we saturate } \mu \rightarrow \mu_0$$

$$v(t) = n \frac{d\Phi(t)}{dt} = n A_c \frac{dB(t)}{dt} \rightarrow B(t) > \frac{1}{n A_c} \int_0^t v(t) dt$$

$$v(t) > L \frac{di(t)}{dt} \rightarrow i(t) = \frac{1}{L} \int_0^t v(t) dt$$


$$L i(t) = n A_c B(t)$$

At saturation  $B = B_{sat}$

$$I_{sat} = \frac{n A_c}{L} B_{sat} = \underline{\underline{\frac{l_m}{\mu n} B_{sat}}}$$

To increase  $I_{sat}$ :

- (1)  $\uparrow B_{sat}$
  - (2)  $\uparrow l_m$
  - (3)  $\downarrow \mu$
  - (4)  $\downarrow n$
- } Also  $\downarrow L$

THE UNIVERSITY OF  
TENNESSEE   
KNOXVILLE

## Example: Gapped Inductor

Faraday's Law:

$$v(t) = n \frac{d\Phi}{dt} = nA_c \frac{dB}{dt}$$

Ampere's Law:

$$\int H dl = I_{coil} = ni$$

b Assume B-H (unsaturated)

$$ni = H_c (l_m - l_g) + H_g l_g$$

$$ni = \frac{B}{m} (l_m - l_g) + \frac{B}{\mu_0} l_g$$

$$ni = B \left( \frac{l_m}{m} + \frac{l_g}{\mu_0} \right)$$

neglect fringing  
 $l_g$  is very small

Cross-sectional area  $A_c$

Air gap ( $\mu_0$ )

Magnetic path length  $l_m$

$v(t) = nA_c \frac{d}{dt} \left[ \frac{nil(t)}{\frac{l_m}{m} + \frac{l_g}{\mu_0}} \right]$

$v(t) = \frac{n^2 A_c}{\frac{l_m}{m} + \frac{l_g}{\mu_0}} \frac{di}{dt}$

L

THE UNIVERSITY OF TENNESSEE KNOXVILLE T

## Gapped Inductor Magnetic Circuit

$R_c = \frac{l_m}{mA_c}$

$R_g = \frac{l_g}{\mu_0 A_c}$

$\Phi = \frac{\Phi}{R_c + R_g} = \frac{ni}{\frac{l_m}{mA_c} + \frac{l_g}{\mu_0 A_c}}$

$v = n \frac{d\Phi}{dt} = \frac{n^2 A_c}{\frac{l_m}{m} + \frac{l_g}{\mu_0}} \frac{di}{dt}$

$L \propto \frac{n^2 A_c \mu_0}{l_g} \rightarrow \approx \text{independent of } \mu$

Generally:

$l_g \ll l_m$

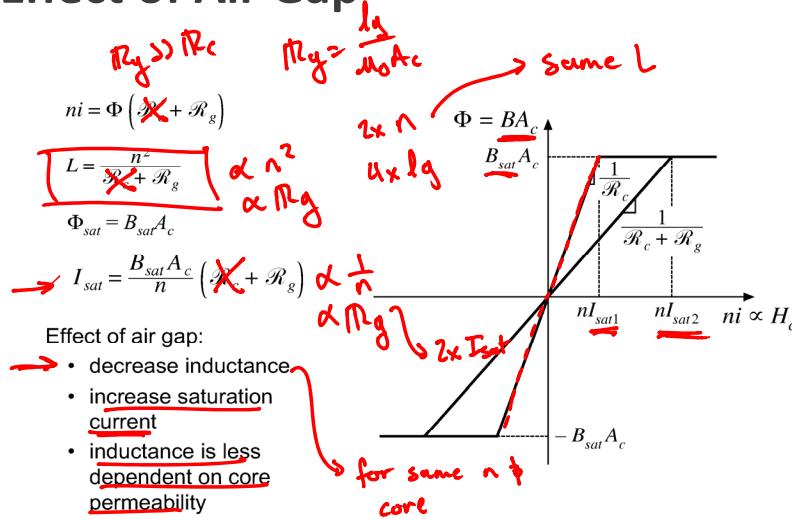
$\mu \gg \mu_0$

$R_g \gg R_c$

$\frac{l_g}{\mu_0} \gg \frac{l_m}{m}$

THE UNIVERSITY OF TENNESSEE KNOXVILLE T

## Effect of Air Gap



Fundamentals of Power Electronics

26

Chapter 13: Basic Magnetics Theory