Chap 3. Magnetic Aspect

- Circuit theory / Field theory

3.1 전자기장 요약

- Maxwell Equation :

$$\nabla \cdot \mathbf{B} = 0; \qquad \oiint_S \mathbf{B} \cdot d\mathbf{S} = 0$$

$$\nabla \times \mathbf{H} = \mathbf{J}; \qquad \oint_c \mathbf{H} \cdot d\mathbf{l} = I$$

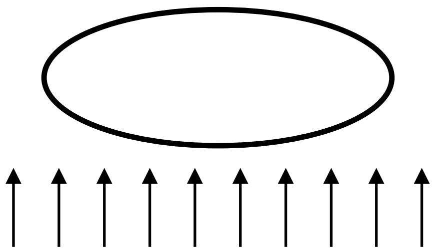
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}; \qquad \oint_c \mathbf{E} \cdot d\mathbf{l} = -\iint_S \frac{\partial \mathbf{B}}{\partial t} \cdot d\mathbf{S}$$

- Current Continuity :

$$\nabla \cdot \mathbf{J} = 0; \qquad \oiint_S \mathbf{J} \cdot d\mathbf{S} = 0$$

KVL / KCL

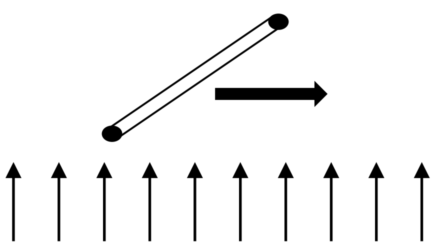
- **Faraday's Law :** $\nabla \times \mathbf{E} = -\dfrac{\partial \mathbf{B}}{\partial t}$ $\qquad \oint_c \mathbf{E} \cdot d\mathbf{l} = -\iint_S \dfrac{\partial \mathbf{B}}{\partial t} \cdot d\mathbf{S}$



$$\boxed{e = -\frac{d\phi}{dt} \text{ or } -\frac{d\lambda}{dt}}$$

$$\phi = \iint_S \mathbf{B} \cdot d\mathbf{S}$$

$$\lambda = N\phi$$

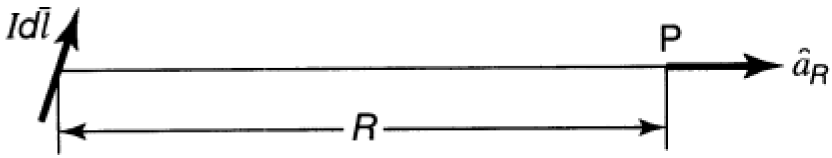


$$\text{Motional emf} = \oint_c (\mathbf{U} \times \mathbf{B}) \cdot d\mathbf{l}$$

$$= BlU$$

3.2 자기장과 자력

- ***I → H → F***



$$d\mathbf{H} = \frac{Id\mathbf{l} \times \hat{a}_R}{4\pi R^2}$$

$$\mathbf{H} = \int \frac{Id\mathbf{l} \times \hat{a}_R}{4\pi R^2}$$

$$d\mathbf{F} = Id\mathbf{l} \times \mathbf{B}$$

$$\mathbf{B} = \mu\mathbf{H}$$

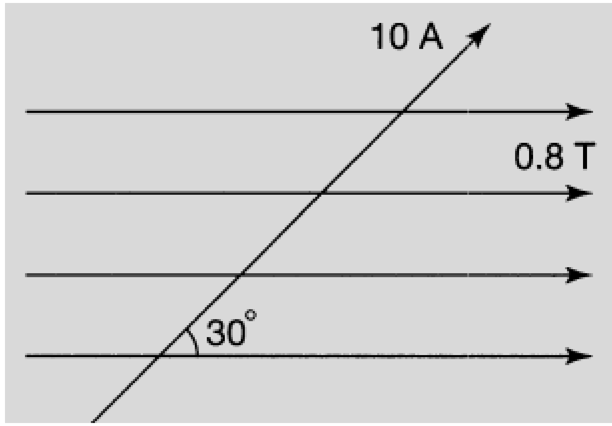
$$\mu_0 = 4 \times 10^{-7}\ \mathrm{H/m}$$

$$F = BIL$$

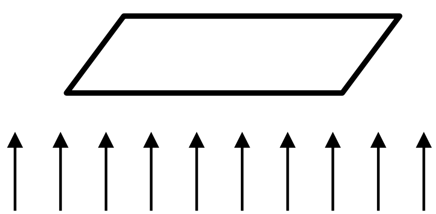
$$\phi = \int_S \mathbf{B} \cdot d\mathbf{S}$$

$$= \mathbf{B} \cdot \mathbf{S} = BS\cos\theta$$

< Ex 3.2.1> $B=0.8T$, $L=2m$, $I=10A$, $\Theta=30°$ → $F=?$



< Ex 3.2.2> $B=0.5T$, $L=20cm$ → $\Phi=?$

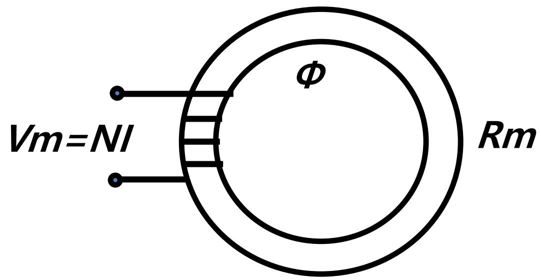


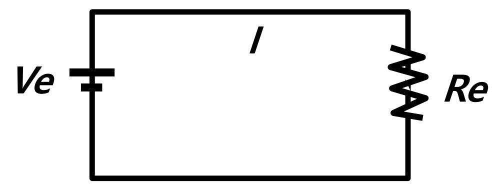
$$\phi = \int_S \mathbf{B} \cdot d\mathbf{S}$$

$$= \mathbf{B} \cdot \mathbf{S} = BS \cos \theta$$

3.3 기자력

- Magneto-Motive Force (mmf) / Electro-Motive Force (emf)





$$\text{mmf} = \oint \mathbf{H} \cdot d\mathbf{l} = IN$$

$$emf = \int E \cdot dl = Ve$$

$$Vm = Rm \cdot \Phi \qquad \phi = \frac{\mathbf{F}}{\mathbf{R}}$$

$$Rm = \frac{L}{\mu S}$$

$$Ve = Re \cdot I \qquad I = \frac{Ve}{Re}$$

$$Re = \frac{L}{\sigma S}$$

$$mmf = \boxed{N \cdot I = H \cdot L = Rm \cdot \Phi}$$

<Ex 3.3.1>
N=500, for H=2kA/m
→ I=?

3.4 자성체

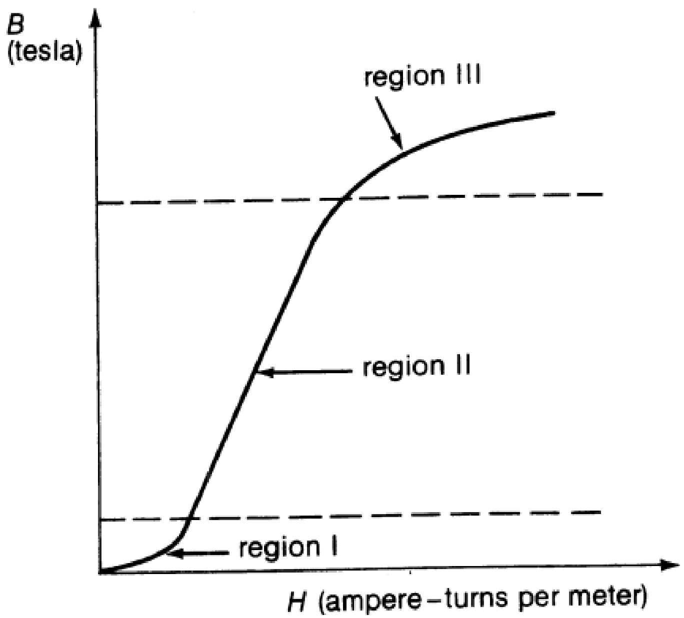
- Magnetic Materials :
  - Diamagnetic / Paramagnetic / Ferromagnetic , Super-paramagnetic / Ferrimagnetic
  - Magnetic Saturation (Linear / Nonlinear) , Magnetic Hysteresis
  - Isotropic / Anisotropic
  - Ferrofluidic (Magnetic Fluid)
  - Curie Temperature

Trade Name	Saturation Flux Density (T)	Maximum Relative Permeability ($\times 10^3$)	Electrical Resistivity (ohm-meter $\times 10^{-6}$)	Curie Temperature (°C)
Carpenter				
Silicon core iron	2–2.1	4–5	0.25–0.60	800
Electrical iron	2.15	2.2–5.5	0.10	760
430F solenoid quality	1.47	1.1–1.6	0.60	671
High-permeability 49	1.6	30–120	0.48	450
Hy mu 80	0.78	70–75	0.58	460
Hiperco 27	2.36	2.8	0.19	925
Silectron	1.97	10–20	0.50	732
2 V Permendur	2.30	8	0.40	932
Monimax	1.45	40–100	0.65	398
Deltamax	1.60	100–200	0.45	499
4-79 Molybdenum permalloy	0.80	100–400	0.55	454
Ferrite	0.22–0.45	0.16–10	$(0.1 \times 10^6) - (10 \times 10^6)$	135–500

- **Permeability , Magnetic Saturation , B-H Curve :**
  - **μ_init, μ_max, μ_2.0**
  - **DC curve / AC curve (60Hz)**

$$\mathbf{B} = \mu \mathbf{H} \qquad \mu = \mu_r \mu_0$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ henry/meter} = 1.257 \times 10^{-6} \text{ H/m}$$



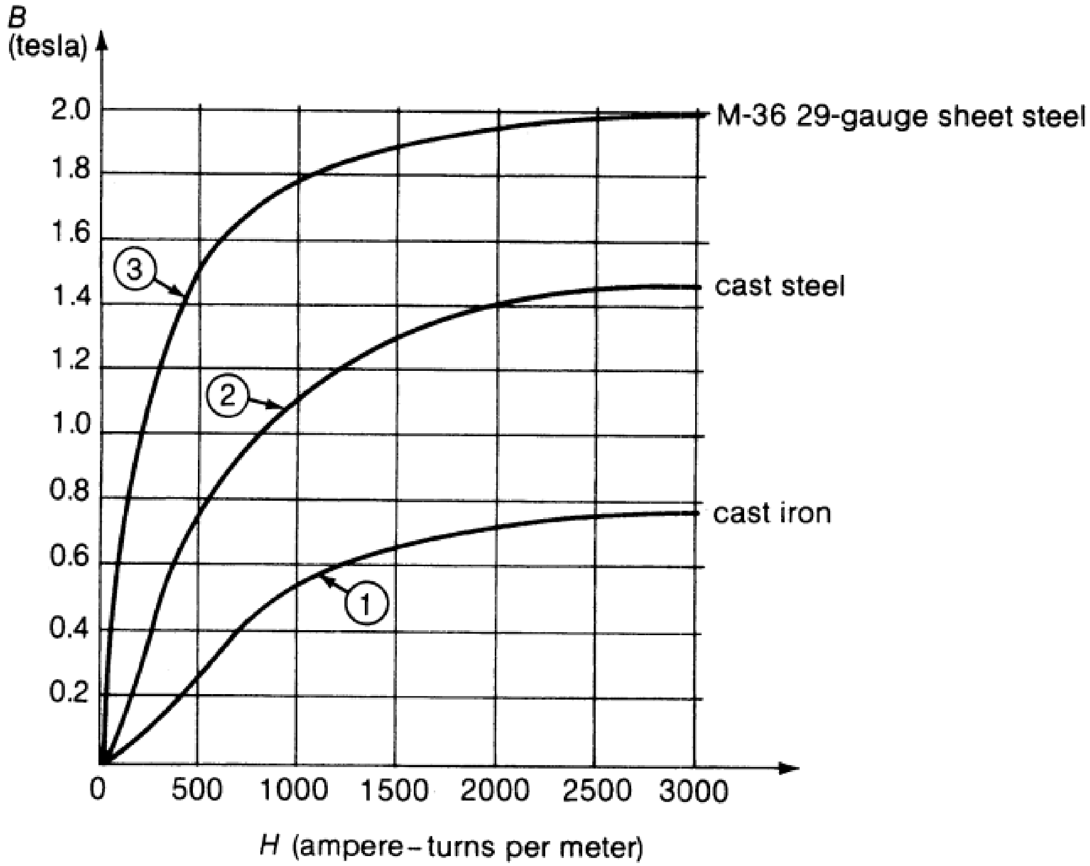
$$B = \frac{aH}{1 + bH}$$

$$B = \frac{a_0 + a_1 H + a_2 H^2 + \cdots}{1 + b_1 H + b_2 H^2 + \cdots}$$

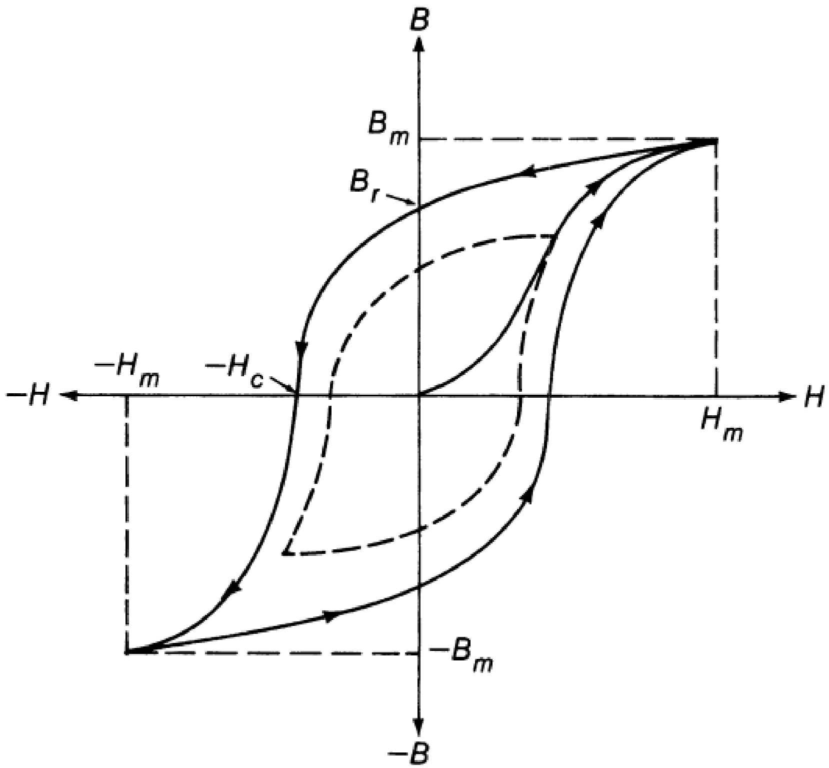
$$H = [k_1 \exp(k_2 B^2) + k_3]\, B$$

표 3.4.2 • 일부 물질의 투자율과 유형

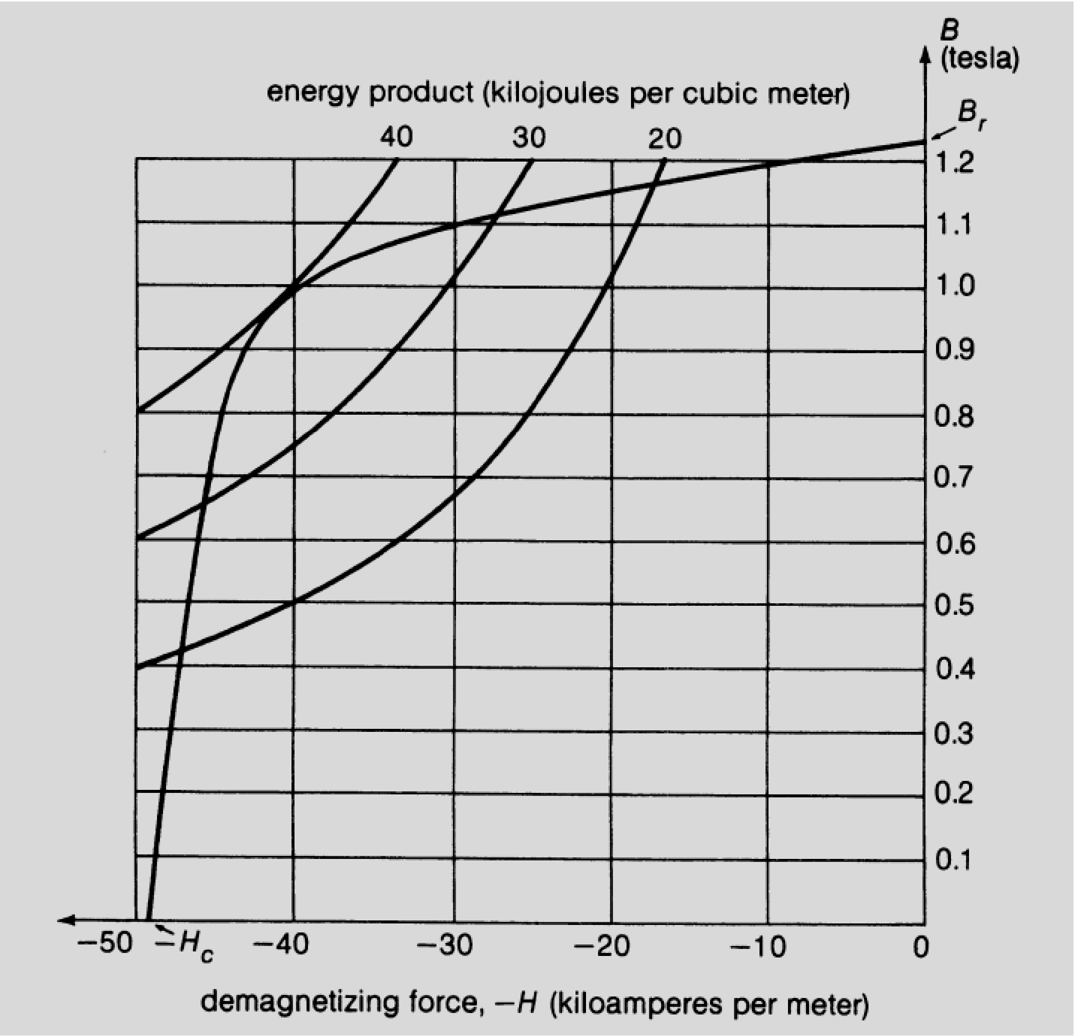
Material	Classification	Relative Permeability, μ_r
Bismuth	diamagnetic	0.99983
Silver	diamagnetic	0.99998
Lead	diamagnetic	0.999983
Copper	diamagnetic	0.999991
Water	diamagnetic	0.999991
Vacuum	nonmagnetic	1
Air	paramagnetic	1.0000004
Aluminum	paramagnetic	1.00002
Palladium	paramagnetic	1.0008
2-81 Permalloy powder (2 Mo, 81 Ni, Iron)	super-paramagnetic	130
Cobalt	ferromagnetic	250
Nickel	ferromagnetic	600
Ferroxcube 3 (Mn-Zn-ferrite powder)	ferrimagnetic	1,500
Ferrites	ferrimagnetic	160~10,000
Mild steel (0.2 C)	ferromagnetic	2,000
Iron (0.2 impurity)	ferromagnetic	5,000
Silicon iron (4 Si)	ferromagnetic	7,000
78 Permalloy (78.5 Ni)	ferromagnetic	100,000
Mumetal (75 Ni, 5 Cu, 2 Cr)	ferromagnetic	100,000
Purified iron (0.05 impurity)	ferromagnetic	200,000
Superalloy (5 Mo, 79 Ni)	ferromagnetic	1,000,000


B
(tesla)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
500
1000
1500
2000
2500
3000
H (ampere-turns per meter)
M-36 29-gauge sheet steel
cast steel
cast iron
3
2
1

- **Magnetic Hysteresis Curve :**
  - **- Bs , Br , Hc , S , S***
  - **- Major loop / Minor Loop / History dependent tracer**
  - **- Hysteresis Loss, Steinmetz**
  - **- Magnetic energy, Permanent Magnet**

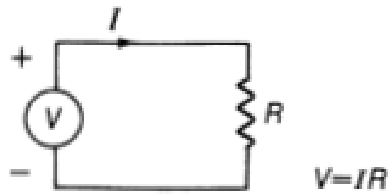
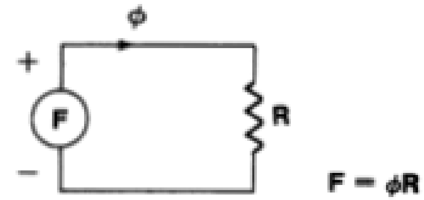


- **Magnetization / Demagnetization**
- **Degaussing / Deperming**



B
(tesla)
energy product (kilojoules per cubic meter)
40
30
20
B_r
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
−50
$-H_c$
−40
−30
−20
−10
0
demagnetizing force, −H (kiloamperes per meter)

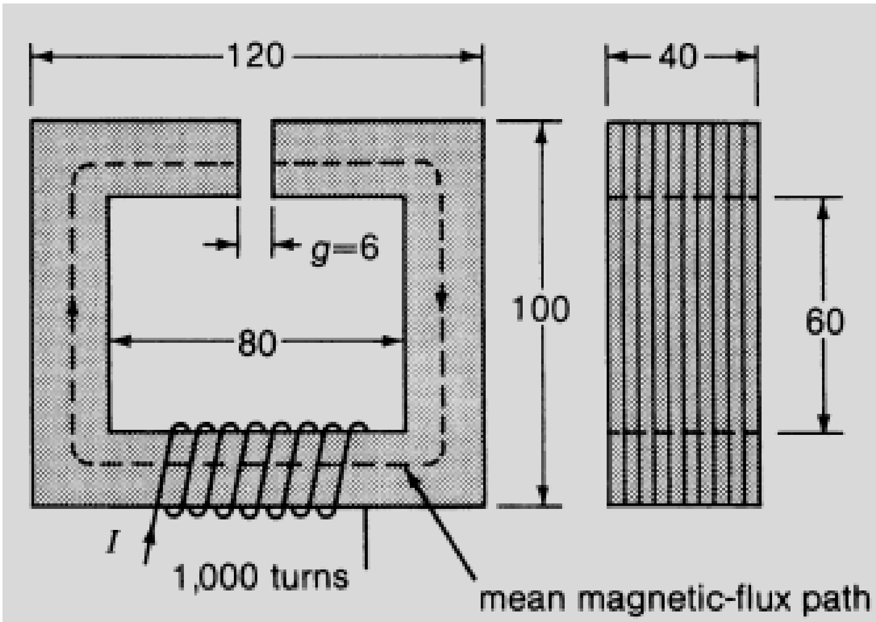
3.5 자기회로

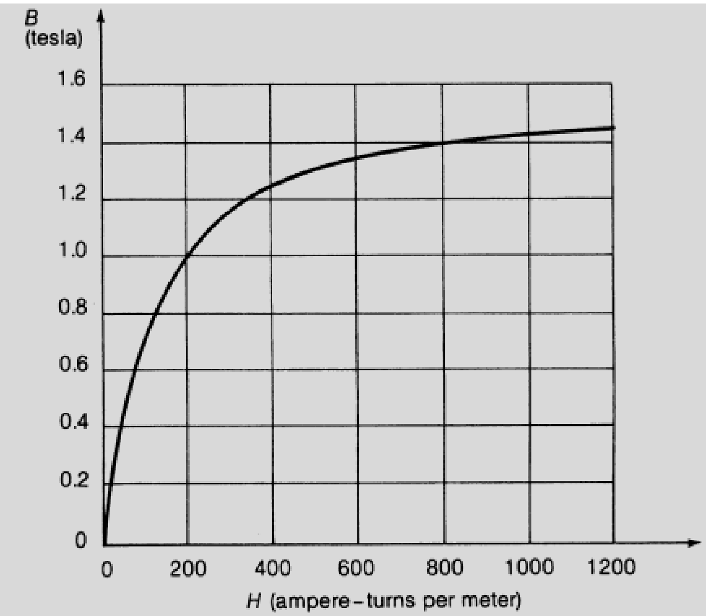
	Electric Circuit	Unit	Magnetic Circuit	Unit
Driving force	emf (V)	V	mmf ($\mathbf{F}$)	At
Response	current (I)	A	flux (ϕ)	Wb
Impedance	resistance (R)	Ω	reluctance ($\mathbf{R}$)	1/H
Equivalent circuit				
Field intensity relationship	$\oint \mathbf{E} \cdot d\mathbf{l} = V$	V	$\oint \mathbf{H} \cdot d\mathbf{l} = I$	A
Potential difference	$V = IR$	V	$\mathbf{F} = \phi\mathbf{R}$	At
Other relations	$J = \frac{I}{A} = \frac{V}{AR} = \frac{El}{A(\rho l/A)}$ $= \frac{E}{\rho} = \sigma E$ or $E = \rho J = J/\sigma$, where J is the current density, ρ is the resistivity, and σ is the conductivity	 $\mathrm{A/m^2}$ $\Omega \cdot \mathrm{m}$ $1/(\Omega \cdot \mathrm{m})$	$B = \frac{\phi}{A} = \frac{\mathrm{F}}{A\mathbf{R}} = \frac{Hl}{A(l/\mu A)}$ $= \mu H = H/\nu$ or $H = B/\mu = \nu B$, where B is the flux density, μ is the permeability, and ν is the reluctivity	 T or $\mathrm{Wb/m^2}$ H/m m/H
Admittance	conductance $G = 1/R$	S	permeance $\mathbf{P} = 1/\mathbf{R}$	H

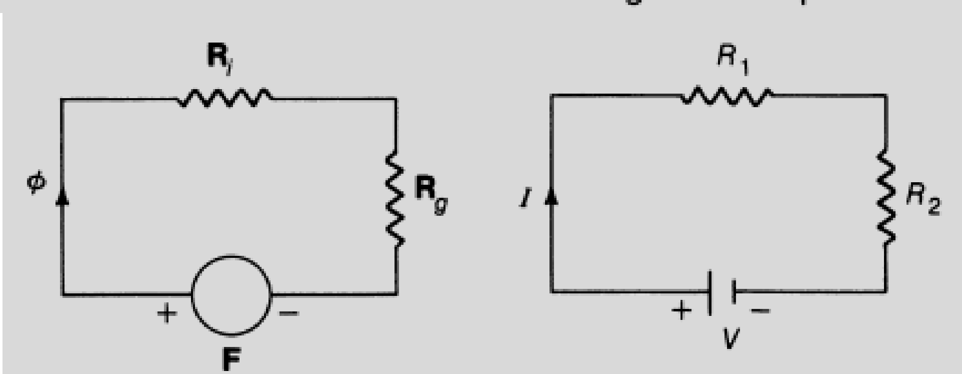
$$N \cdot I = H \cdot L = Rm \cdot \Phi$$

<Ex 3.5.1> A=10mm2, L=20cm, μr=500 → (a) Rm=?, (b) Φ, B=?

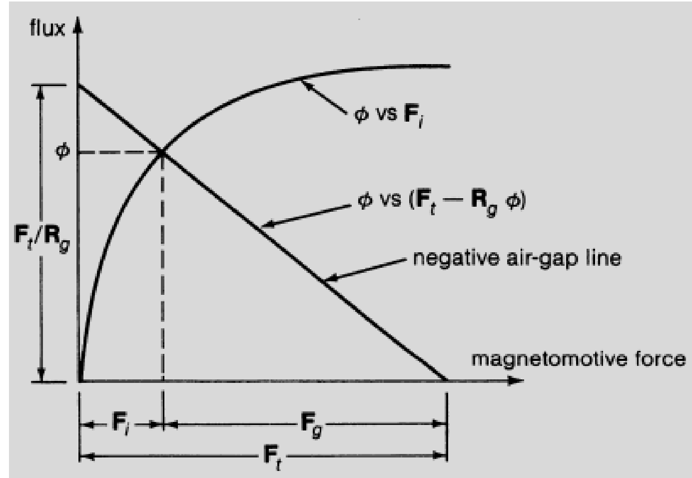
<Ex 3.5.2> USS 변압기, Φ → NI ?
적층율 0.94, B_H curve, Φ = 1mWb → I=??



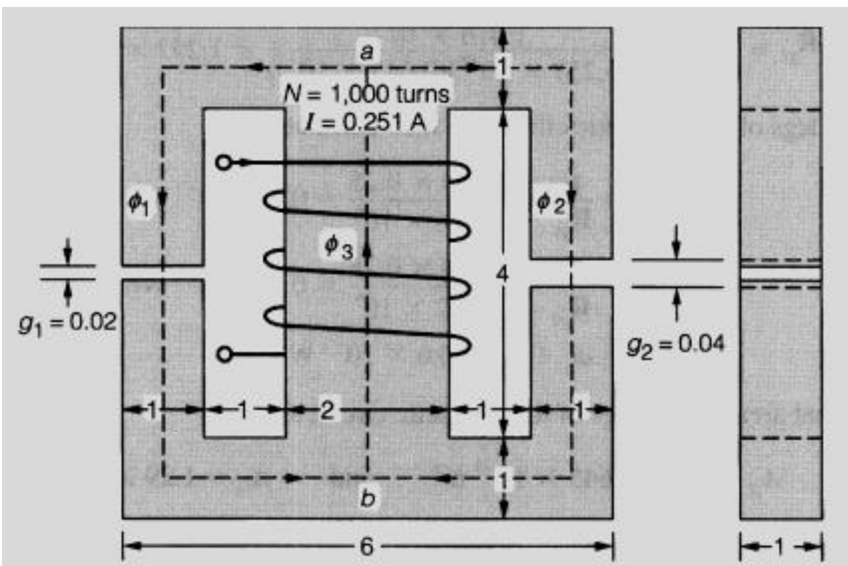


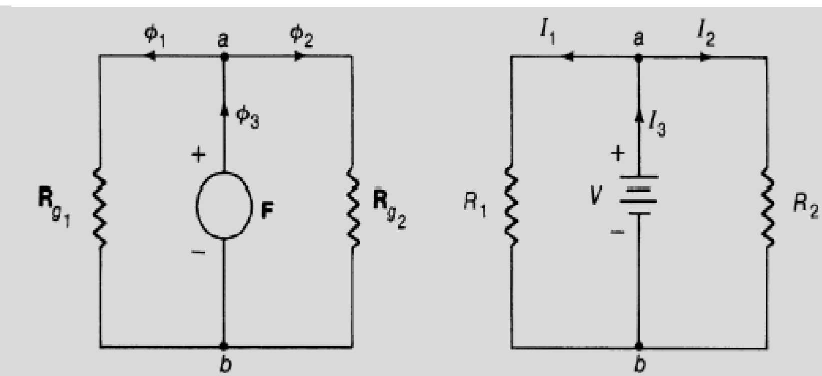


<Ex 3.5.3> Ex 3.5.2 : NI → Φ ?



<Ex 3.5.4> 2개의 병렬공극 :





<Ex 3.5.5> Ex 3.5.4 : 철심 B-H curve : B in each leg =?

Lab. of Applied ElectroMagnetics

<u><Problems></u>

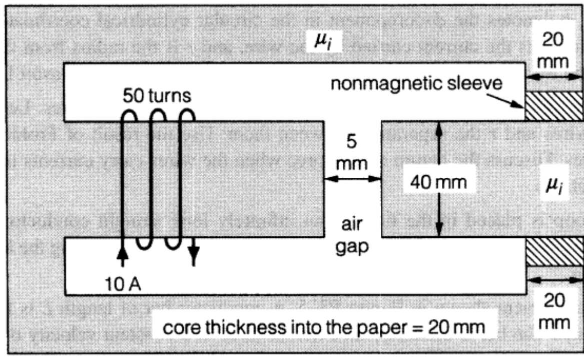


그림 P3-7

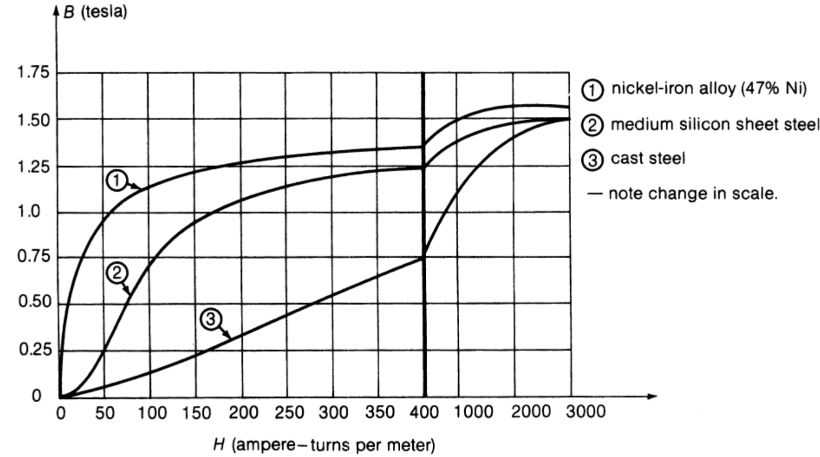


그림 P3-8

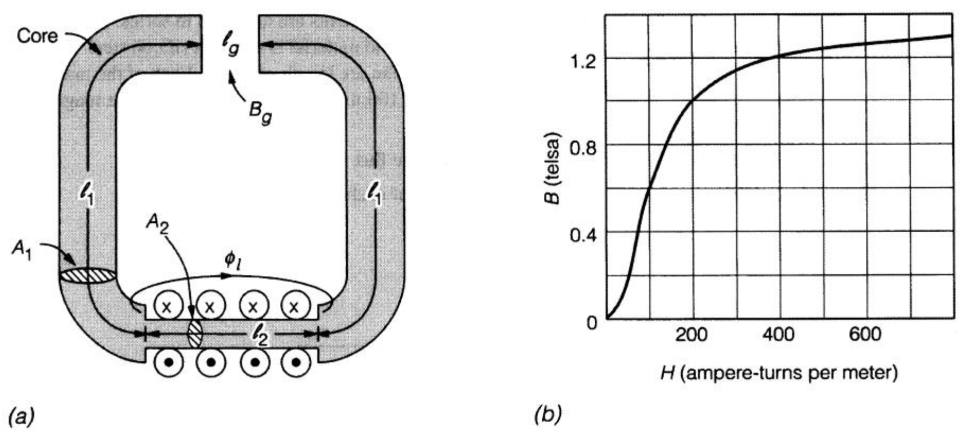


그림 P3-10

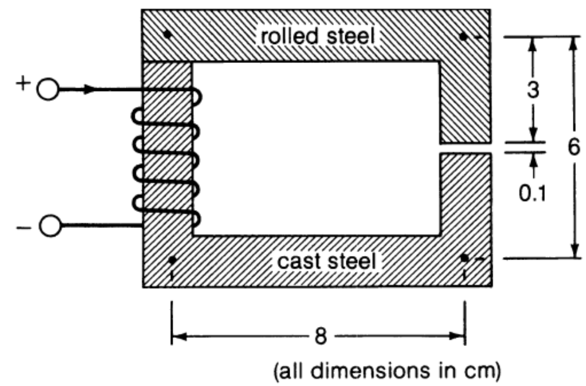


그림 P3-11

<Problems>

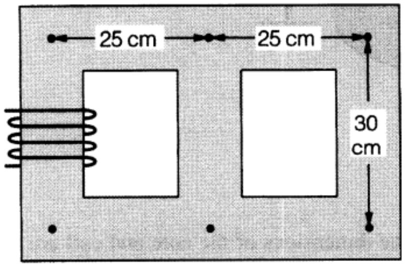


그림 P3-14

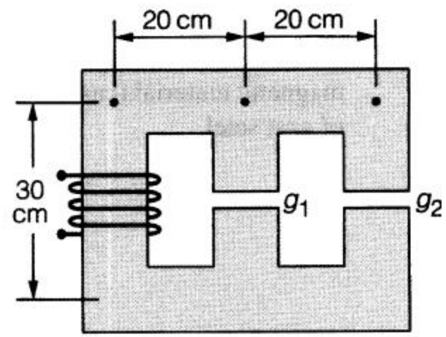


그림 P3-18

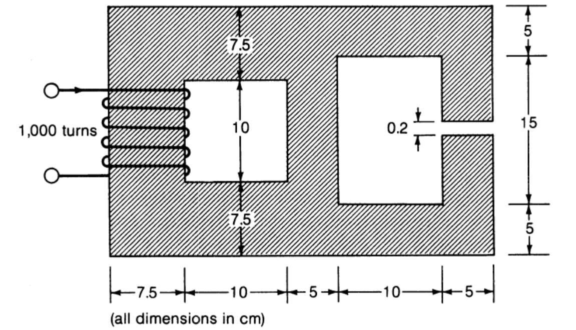
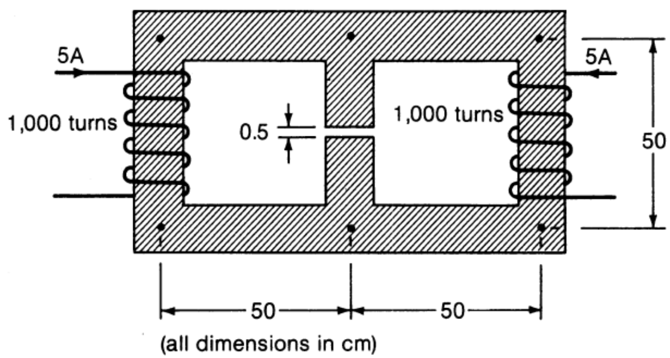


그림 P3-13



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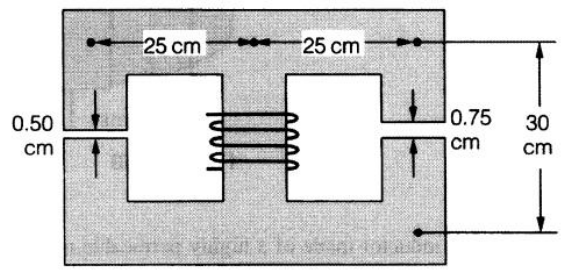
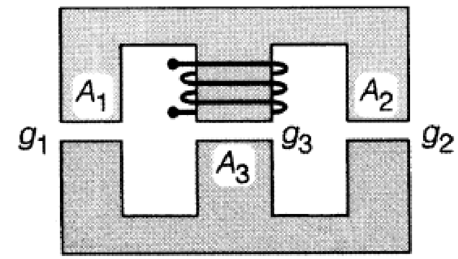


그림 P3-15



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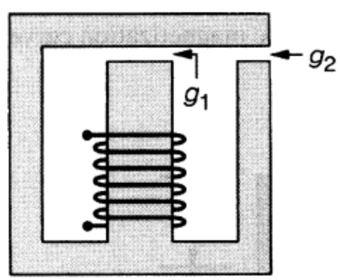

그림 P3-16

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<Problems>

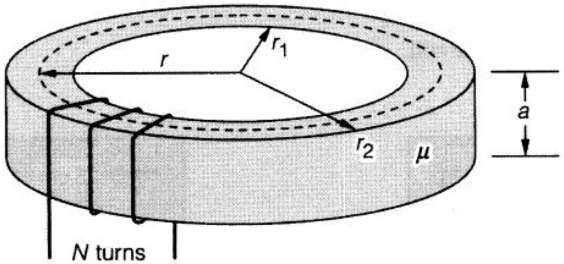


그림 P3-19

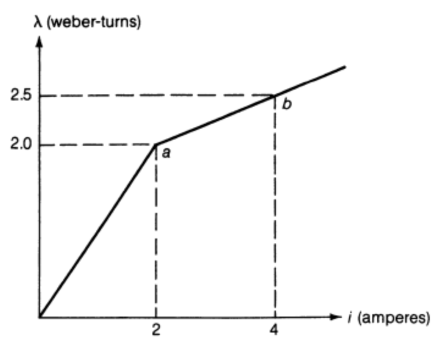


그림 P3-23

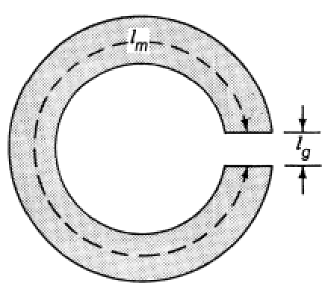
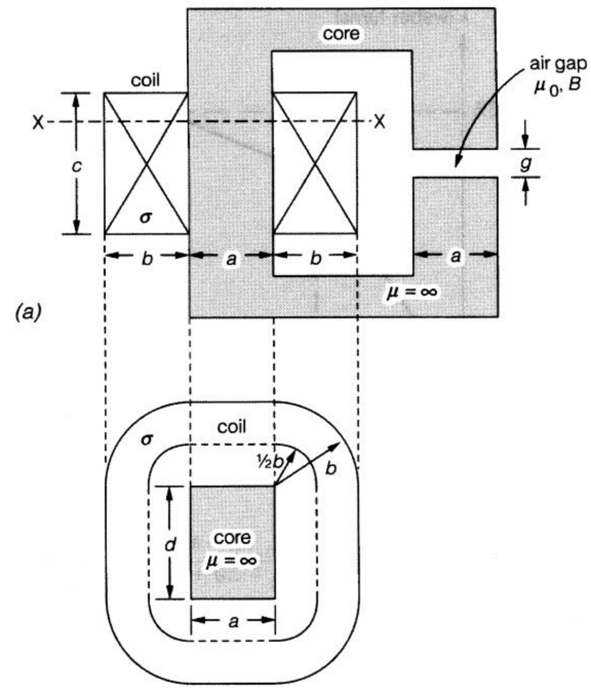


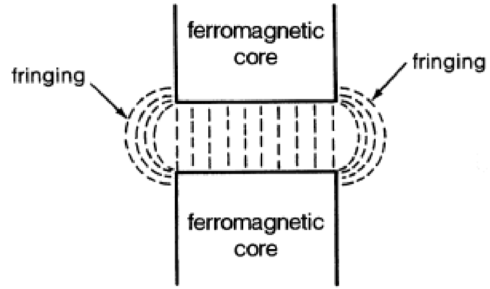
그림 P3-32

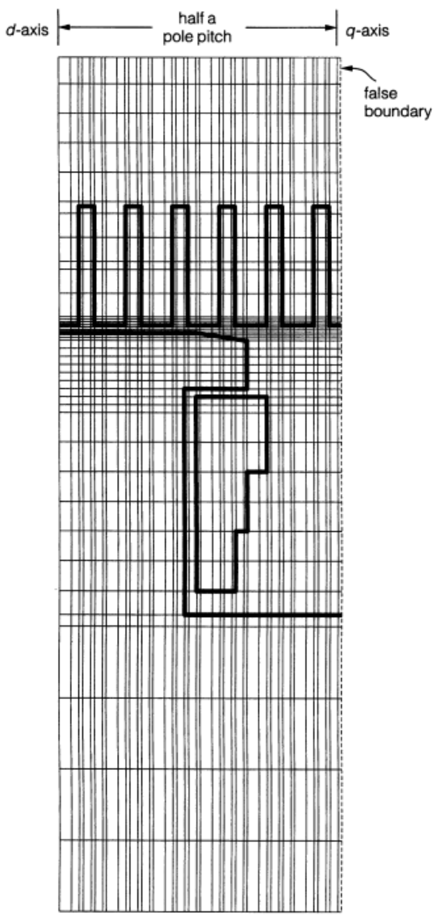


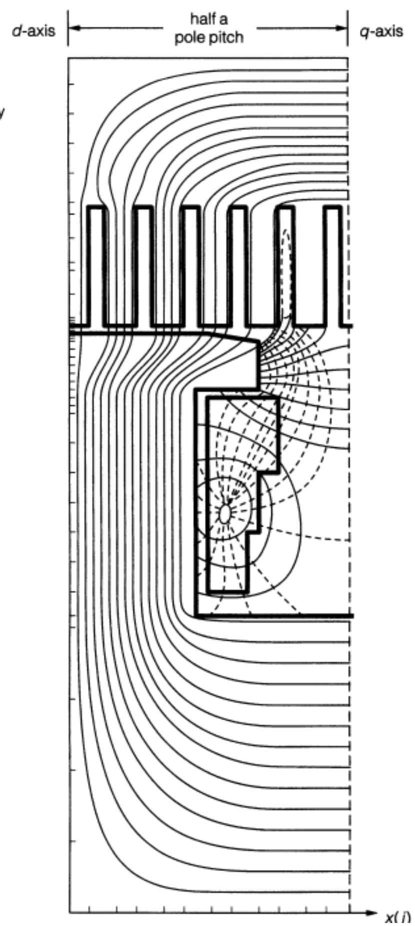
(b) Cross section at XX

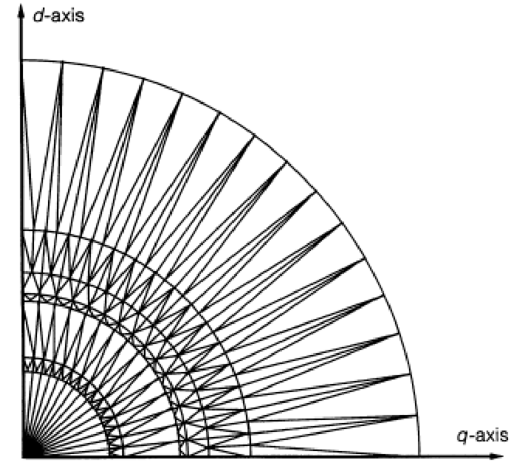
그림 P3-20

- **Fringing, Leakage :**

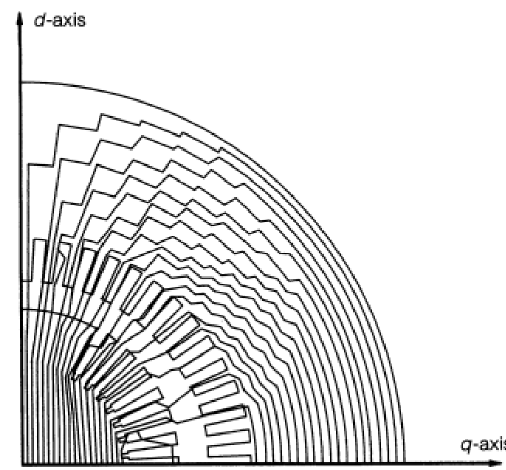






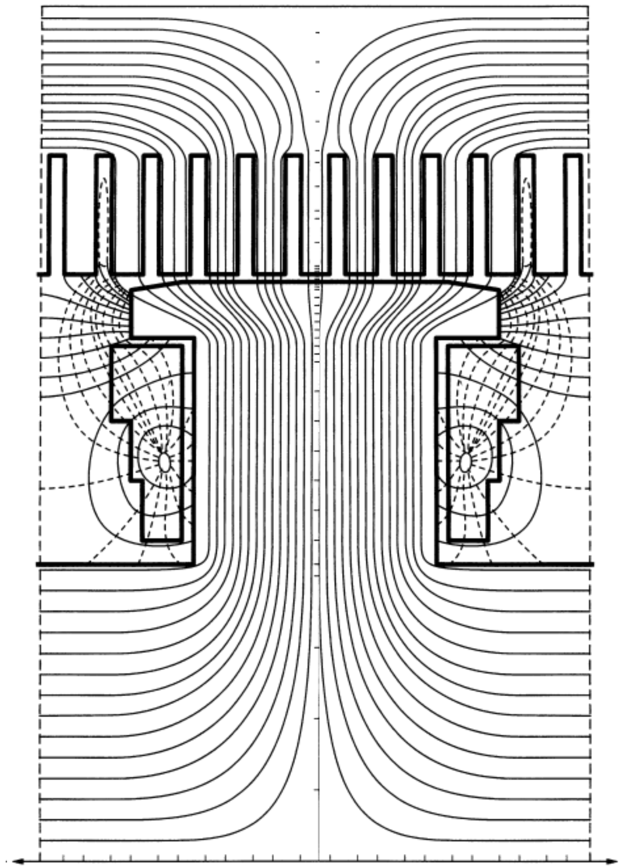


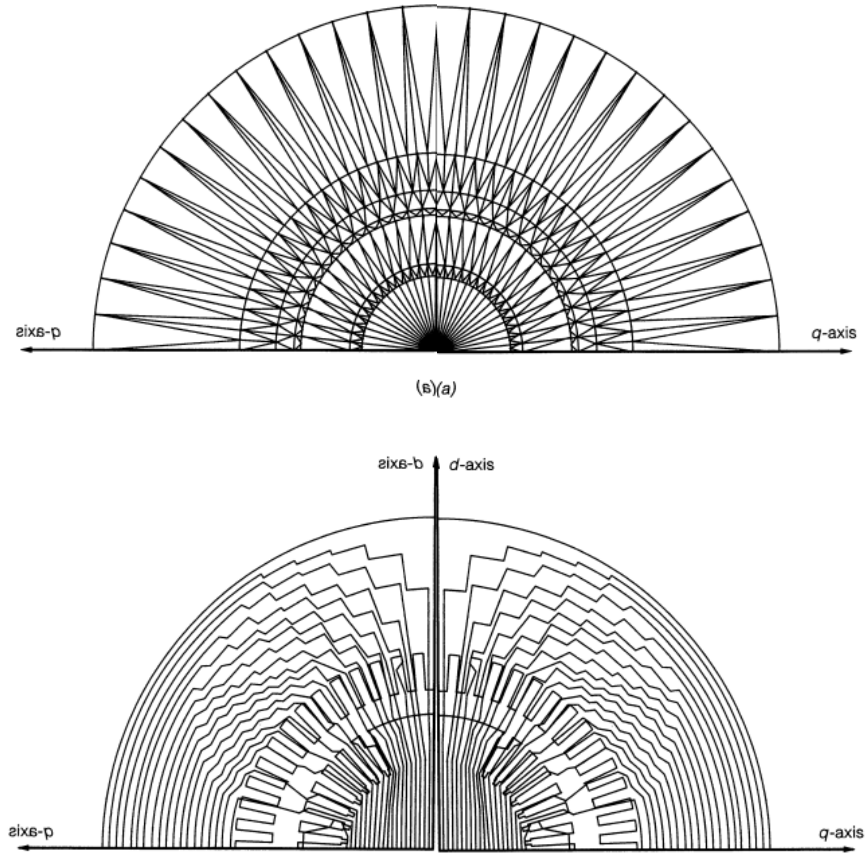
(a)



(b)

- ***I → H → F***

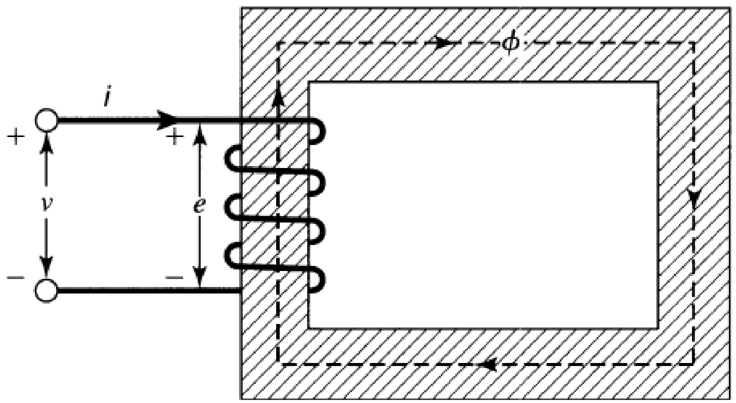




Lab. of Applied ElectroMagnetics

3.6 AC 자기회로

- 유도기전력 :



$$\boxed{N \cdot I = H \cdot L = Rm \cdot \Phi}$$

$$i(t) = I_m \sin(\omega t)$$

$$\phi(t) = \frac{\text{mmf}}{\mathbf{R}} = \frac{Ni(t)}{\mathbf{R}} = \frac{NI_m \sin(\omega t)}{\mathbf{R}} = \phi_m \sin(\omega t)$$

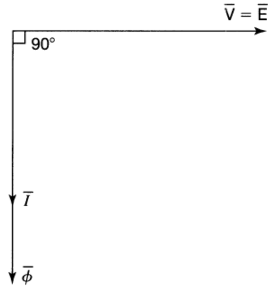
$$\phi_m = \frac{NI_m}{\mathbf{R}}$$

$$\lambda(t) = N\phi(t) = N\phi_m \sin(\omega t)$$

$$e = \frac{d\lambda(t)}{dt} = \frac{d}{dt}(N\phi_m \sin(\omega t)) = \omega N\phi_m \cos(\omega t) = \underline{\omega N\phi_m} \sin(\omega t + 90^\circ) = Em\ sin(wt+90°)$$

- 유도기전력, rms :

$$\boxed{E = \frac{\omega N\phi_m}{\sqrt{2}} = \frac{2\pi f N\phi_m}{\sqrt{2}} = 4.44 N\phi_m \mathbf{f}}$$



- 철손(Iron Loss) = 히스테리시스 손실(Hysteresis Loss) + 와전류 손실(Eddy Current Loss)

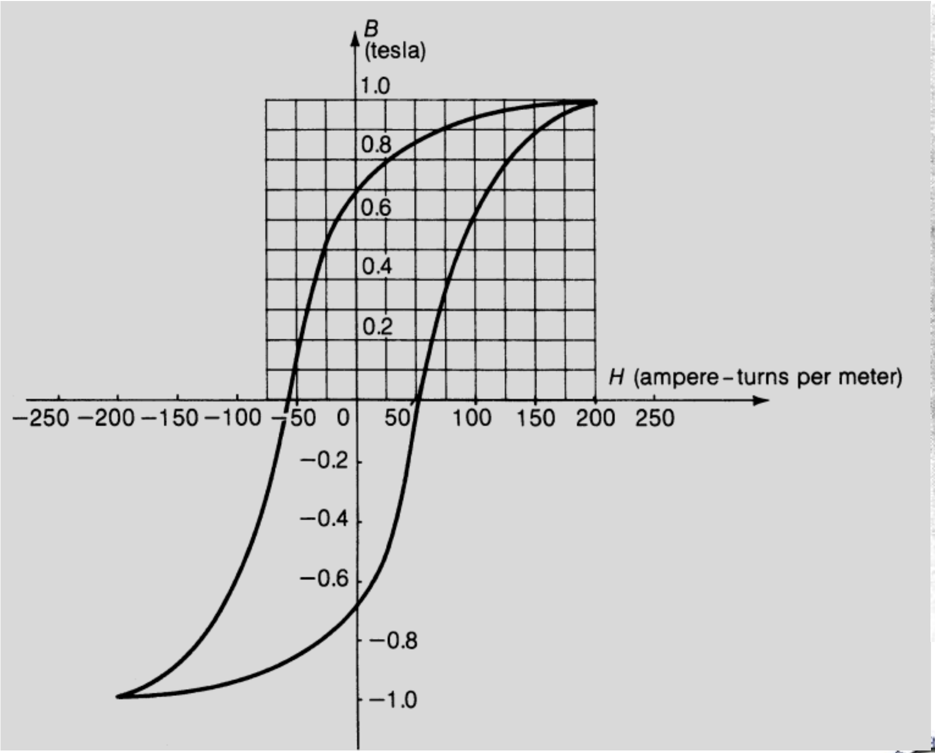
$$P_h \text{ per cycle} = \mathrm{Vol} \oint H\, dB$$

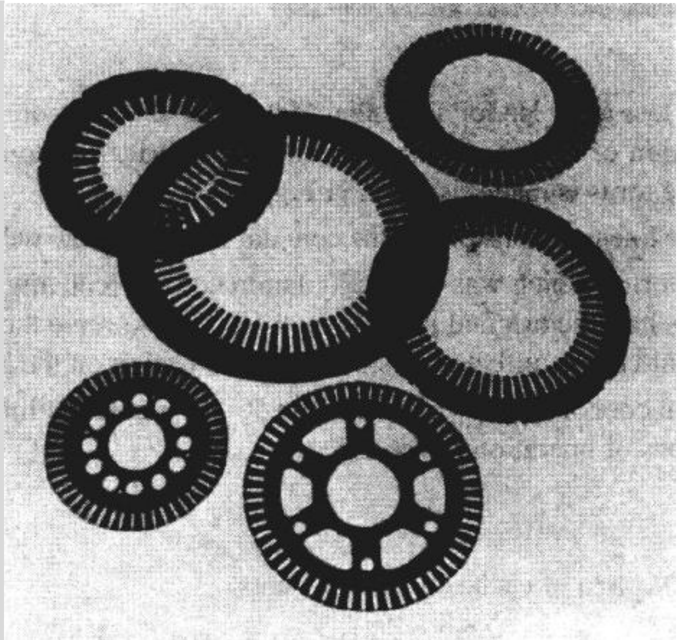
$$P_h = k_h \cdot \mathrm{Vol} \cdot f \cdot B_m^n$$

$$(\propto f \cdot B_m^n)$$

$$P_e = k_e \cdot \mathrm{Vol} \cdot f^2 \cdot \tau^2 B_m^2$$

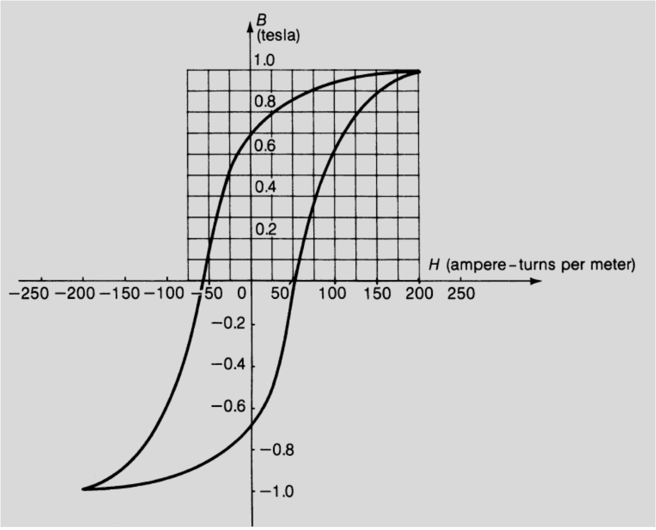
$$(\propto f^2 \cdot B_m^2)$$





<Ex 3.6.1> 사각단면 도넛 코어의 히스테리시스 손실 :

b. 모든 방향으로 코어의 크기가 2배씩 커졌을 때, 히스테리시스 손실은 어떻게 달라지는가?
c. 코어의 적층 두께를 원래 두께의 반으로 줄였다. 측적 계수는 동일하게 1이라고 가정하면 이러한 변화가 히스테리시스 손실에는 어떤 영향을 주는가?
d. 코어가 50 Hz에서 동작할 경우 히스테리시스 손실은 어떻게 변화하는지 계산하시오.



$$P_h = k_h \cdot \mathrm{Vol} \cdot f \cdot B_m^n$$

b. $\propto$ V
d. $\propto$ f

<Ex 3.6.2> f=50Hz, B=0.8T → 철손 1000W : Ph=?, Pe=?
f=75Hz, // → 철손 1800W : Ph=?, Pe=?

P = af + bf2 , P/f = a + bf , a=?/b=? , Ph & Pe

3.7 에너지 저장

- **Magnetic Energy, Energy Density :**

$$w_m = \frac{1}{2}\mathbf{B}\cdot\mathbf{H}$$

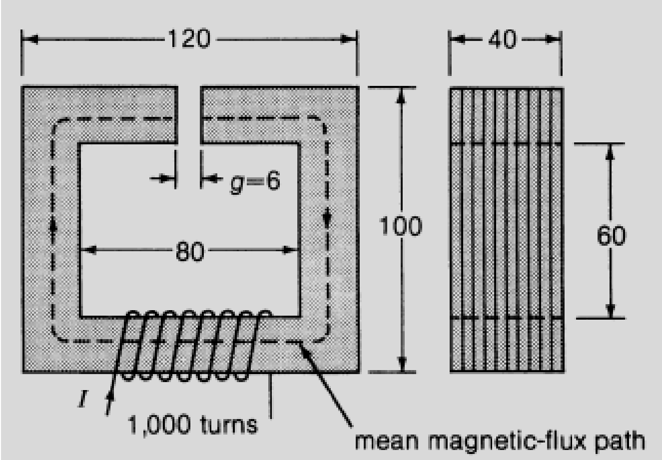
$$W_m = \frac{1}{2}\int_{\text{Vol}} \mathbf{B}\cdot\mathbf{H}\,dv$$

$$w_m = \frac{1}{2}BH = \frac{1}{2}\frac{B^2}{\mu} = \frac{1}{2}\frac{B^2}{\mu_r\mu_0}$$

- **Air gap Energy :**

$$W_{m\,\text{air}} = \frac{1}{2}\left(\frac{B_g^2}{\mu_0}\right)\text{Vol} = \frac{1}{2}\mathbf{F}\phi = \frac{1}{2}\mathbf{R}\phi^2 = \frac{1}{2}i\lambda$$

Ex3.5.2. :

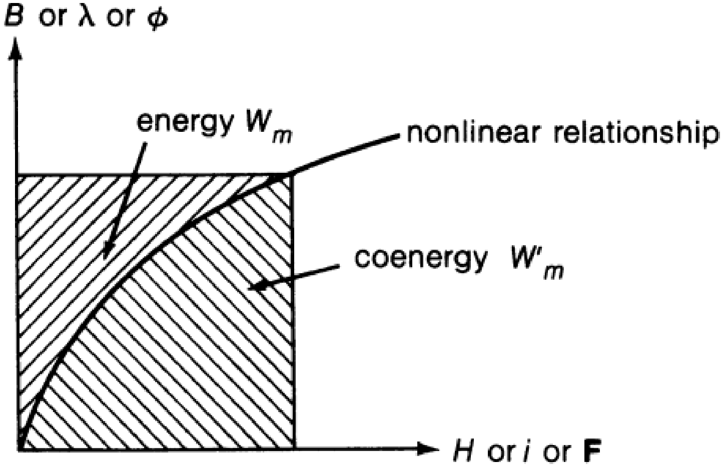


$$W_{m\,\text{air}} = \frac{1}{2}\left(\frac{B_g^2}{\mu_0}\right)\text{Vol} = 1.995\text{ J}$$

W_air = $\frac{1}{2}$ F_gap Φ = 1.995 J

W_iron = $\frac{1}{2}$ F_iron Φ = 0.1 J (!!)

- **Magnetizing Energy :**



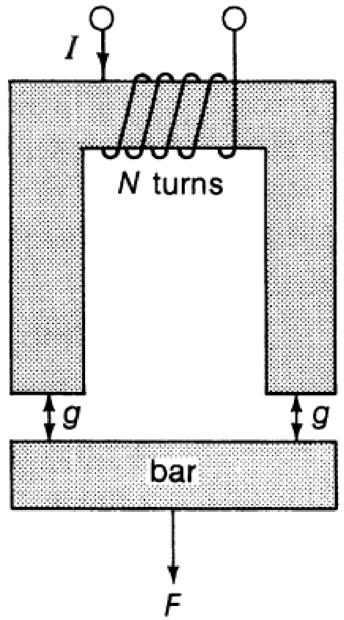
- **Manetic Energy :** $W_m = \text{Vol}\int_0^B H\,dB = \int_0^\lambda i(\lambda)\,d\lambda = \int_0^\phi \mathbf{F}(\phi)d\phi$

- **Co-Energy :** $W'_m = \text{Vol}\int_0^H B\,dH = \int_0^i \lambda(i)\,di = \int_0^F \phi(\mathbf{F})\,d\mathbf{F}$

$$W'_m + W_m = \text{Vol}\cdot BH = \lambda i = \phi\mathbf{F}$$

- **Magnetic Force :**

$$dW_m = \frac{1}{2}(\mathbf{B}\cdot\mathbf{H})\,dv$$



$$dv = A\,dg$$

$$dW_m = \frac{1}{2}BH\,dv = \frac{1}{2}BHA\,dg = \frac{1}{2}\left(\frac{B^2}{\mu_0}\right)A\,dg$$

Definition : $dW = \mathbf{F}\cdot d\mathbf{l} = F\,dg$ $\qquad dW_m = dW$

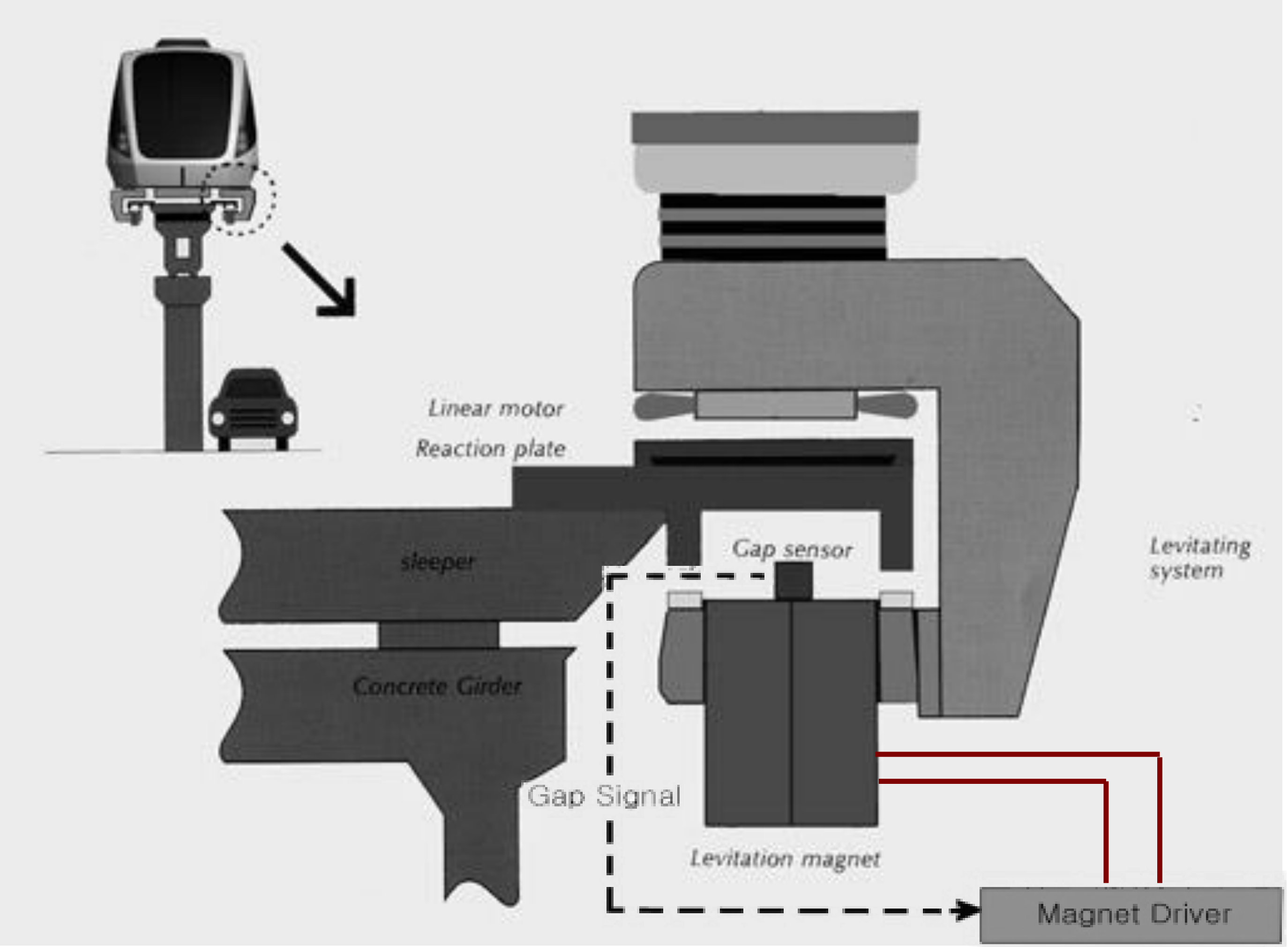
So, $\frac{1}{2}\left(\frac{B^2}{\mu_0}\right)A\,dg = F\,dg$

Which gives : $F = \frac{1}{2}\left(\frac{B^2}{\mu_0}\right)A$

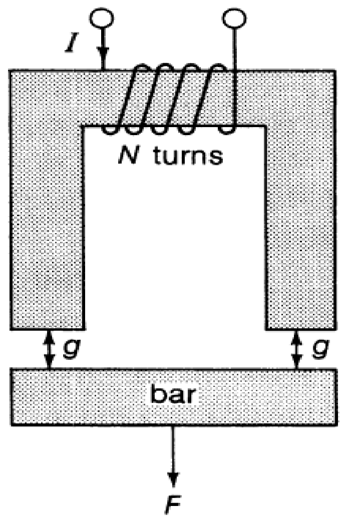
Total force on the bar : $F_{\text{total}} = 2\left(\frac{1}{2}\right)\left(\frac{B^2}{\mu_0}\right)A = \left(\frac{B^2}{\mu_0}\right)A$

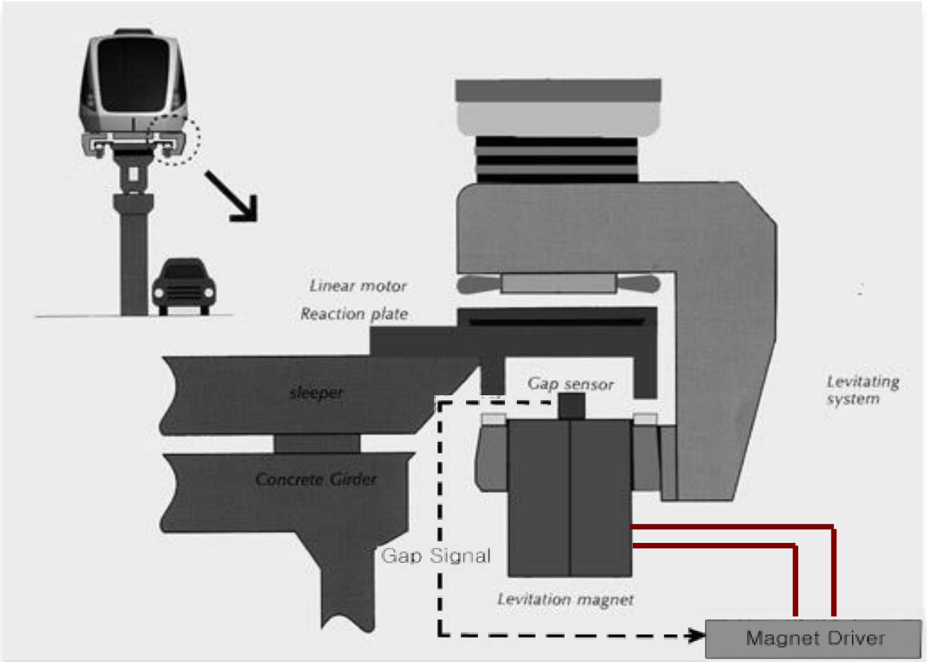
<Ex 3.7.1> Iron ring : L=10 m, A=20cm2, N=100, B=0.8T → W=0.102 J

• 자기 부상 열차


Linear motor
Reaction plate
sleeper
Gap sensor
Levitating system
Concrete Girder
Gap Signal
Levitation magnet
Magnet Driver

- **Magnetic Force :**





$$dW_m = \frac{1}{2}(\mathbf{B}\cdot\mathbf{H})\,dv \quad = \frac{1}{2}BH\,dv = \frac{1}{2}BHA\,dg = \frac{1}{2}\left(\frac{B^2}{\mu_0}\right)A\,dg$$

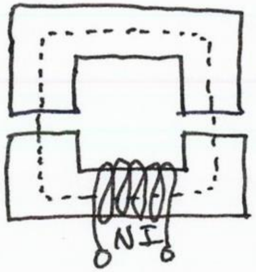
$$dW = \mathbf{F}\cdot d\mathbf{l} = F\,dg$$

$$\frac{1}{2}\left(\frac{B^2}{\mu_0}\right)A\,dg = F\,dg \qquad \boxed{F = \frac{1}{2}\left(\frac{B^2}{\mu_0}\right)A}$$

Total force on the bar : $F_{\text{total}} = 2\left(\frac{1}{2}\right)\left(\frac{B^2}{\mu_0}\right)A = \left(\frac{B^2}{\mu_0}\right)A$

<Ex 3.7.1> Iron ring : L=10 m, A=20cm2, N=100, B=0.8T → W=0.102 J

◎ 자기 부상열차의 부상력 (Lifting Force)



$$\int \vec{H}\cdot d\vec{l} = NI$$

$$H_c \cdot l_c + H_g \cdot l_g = NI$$

$$NI = \frac{B_c}{\mu_c}\cdot l_c + \frac{B_g}{\mu_0}\cdot l_g \simeq B_g\left(\frac{l_c}{\mu_c} + \frac{l_g}{\mu_0}\right) \quad (\because B_g \simeq B_c)$$

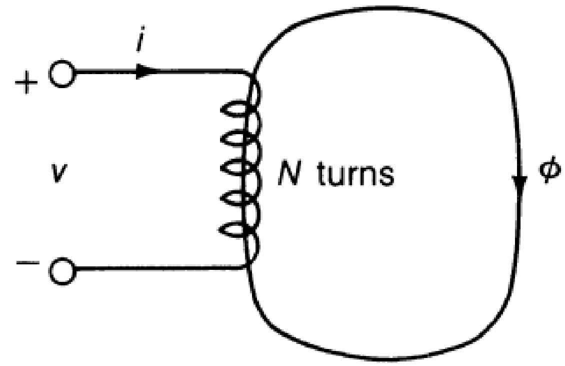
$$\therefore B_g = \frac{NI}{\frac{l_c}{\mu_r\mu_0} + \frac{l_g}{\mu_0}} = \frac{\mu_r\mu_0 \cdot NI}{l_c + \mu_r \cdot l_g}$$

Force $F = \int \frac{B^2}{2\mu_0}\cdot ds \simeq \frac{B_g^2}{2\mu_0}\cdot S$

$$= \frac{S}{2\mu_0}\cdot\left(\frac{\mu_r\mu_0 \cdot NI}{l_c + \mu_r \cdot l_g}\right)^2 = \frac{\mu_0 \cdot S}{2}\cdot\left(\frac{\mu_r \cdot NI}{l_c + \mu_r l_g}\right)^2 //$$

3.8 AC exitation & L

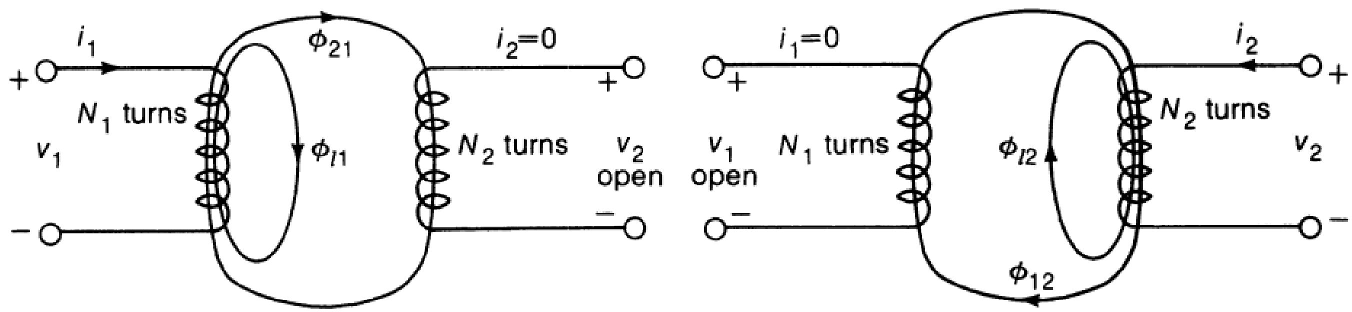
- I → Φ → self Induction L :



$$L = \frac{\lambda}{i} = \frac{N\phi}{i} = \frac{N^2}{\mathbf{R}} = N^2\mathbf{P}$$

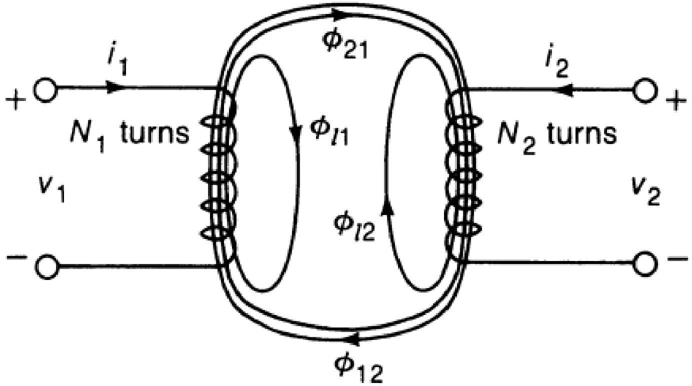
$$W_m = \frac{1}{2} i\lambda = \frac{Li^2}{2}$$

- I → Φ → mutual Induction M :



$$L_{11} = \frac{\lambda_{11}}{i_1} \qquad L_{21} = \frac{\lambda_{21}}{i_1} \qquad L_{12} = \frac{\lambda_{12}}{i_2} \qquad L_{22} = \frac{\lambda_{22}}{i_2}$$

- I → Φ → L/M → v :



$$\lambda_1 = \lambda_{11} + \lambda_{12} = L_{11} i_1 + L_{12} i_2 = L_{11} i_1 + M i_2$$

$$\lambda_2 = \lambda_{21} + \lambda_{22} = L_{21} i_1 + L_{22} i_2 = M i_1 + L_{22} i_2$$

$$v_1 = p\lambda_1 = \frac{d\lambda_1}{dt} = L_{11}\frac{di_1}{dt} + M\frac{di_2}{dt}$$

$$v_2 = p\lambda_2 = \frac{d\lambda_2}{dt} = M\frac{di_1}{dt} + L_{22}\frac{di_2}{dt}$$

- If non-linear : $\lambda_1 = f_1(i_1, i_2)$

  $\lambda_2 = f_2(i_1, i_2)$

- Leakage flux : $\phi_{l1} = \phi_{11} - \phi_{21}$

  $\phi_{l2} = \phi_{22} - \phi_{12}$

- 결합계수 : (0~1) $k = \sqrt{k_1 k_2}$, $k_1 = \phi_{21}/\phi_{11}$

  $k_2 = \phi_{12}/\phi_{22}$

- mutual Induction M :

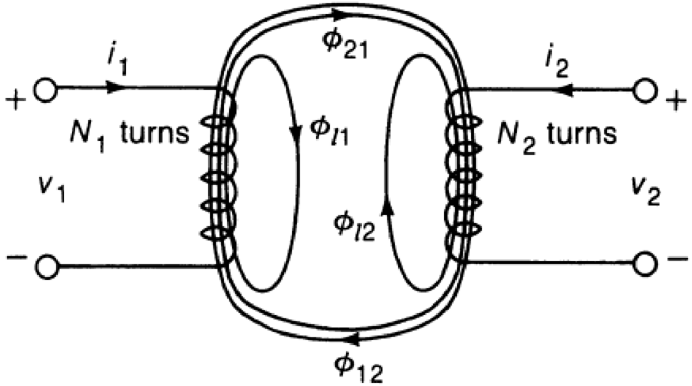
$$M = L_{12} = L_{21} = k\sqrt{L_{11} L_{22}}$$

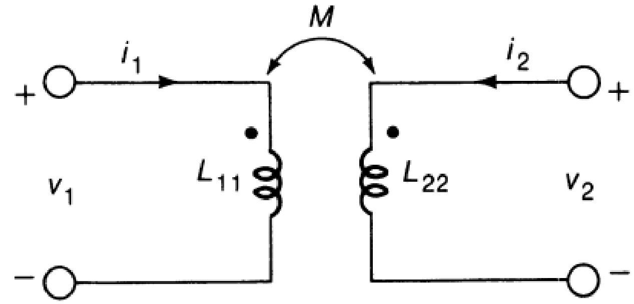
- Energy , Inductance :

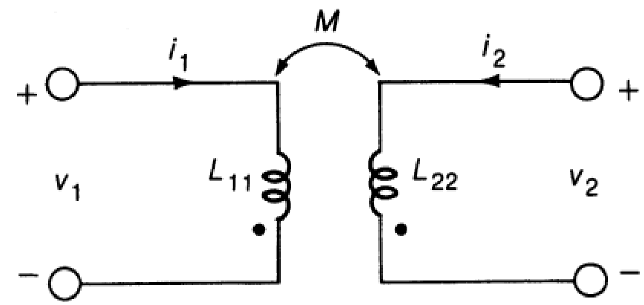
$$W_m = \frac{i_1 \lambda_1}{2} + \frac{i_2 \lambda_2}{2}$$

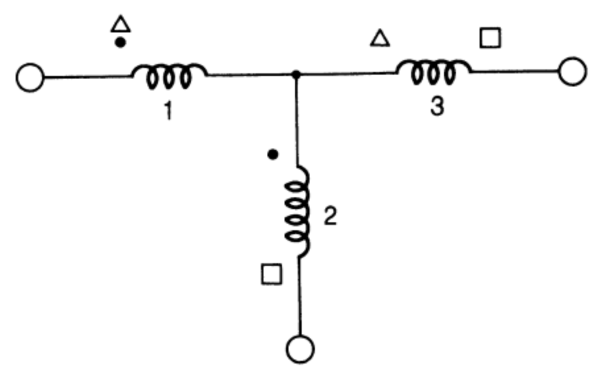
$$\boxed{W_m = \frac{1}{2} L_{11} i_1^2 + M i_1 i_2 + \frac{1}{2} L_{22} i_2^2}$$

- If multi : $W_m = \sum_{j=1}^{n} \sum_{k=1}^{n} \frac{1}{2} L_{jk} i_j i_k$







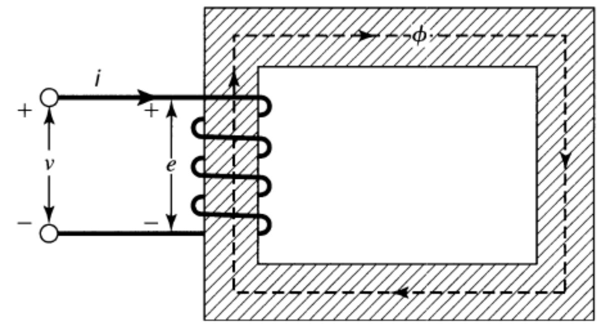


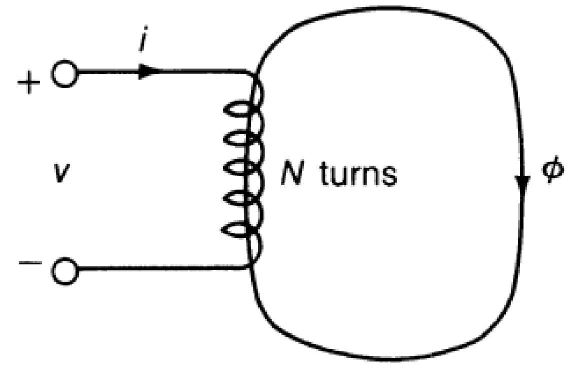
$$v_1 = \frac{d\lambda_1}{dt} = L_{11}\frac{di_1}{dt} + M\frac{di_2}{dt}$$

$$v_2 = \frac{d\lambda_2}{dt} = M\frac{di_1}{dt} + L_{22}\frac{di_2}{dt}$$

$$W_m = \frac{1}{2}L_{11}i_1^2 + Mi_1i_2 + \frac{1}{2}L_{22}i_2^2$$

- **Equivalent circuit :**





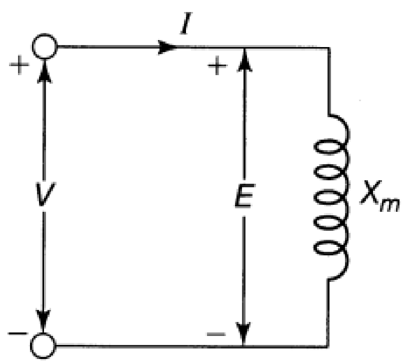


그림 3.8.5 • AC 여자 코일의 등가회로.

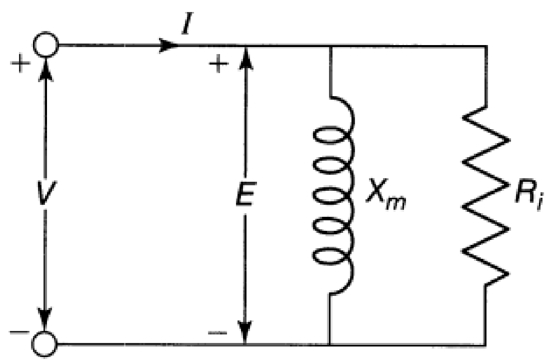


그림 3.8.6 • 철손이 있는 AC 여자 코일의 등가회로.

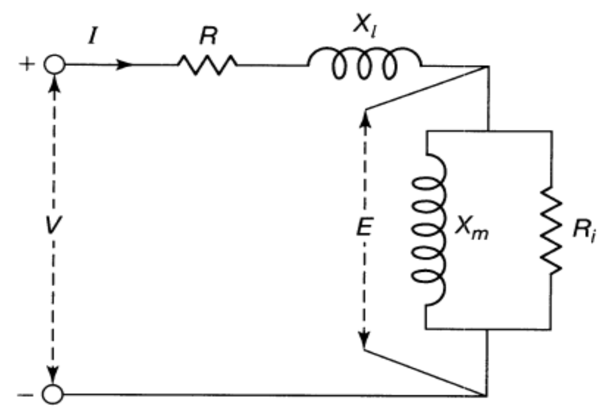


그림 3.8.7 • AC 여자 코일의 전체 등가회로.

$$X_m = \frac{E}{I} = \omega L_m$$

$$P_h = k_h \cdot \mathrm{Vol} \cdot f \cdot B_m^n$$

$$P_e = k_e \cdot \mathrm{Vol} \cdot f^2 \cdot \tau^2 B_m^2$$

- **R**
- **Xl**
- **Xm**
- **Ri**

<Ex 3.8.1> Cast Steel, B-H curve, B=1.1T → I, Ls, Ll

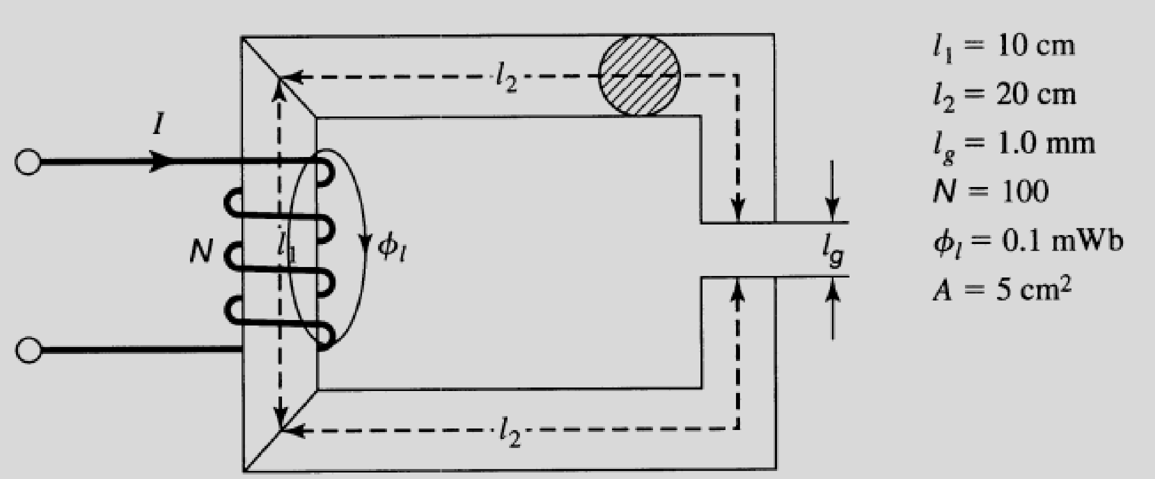
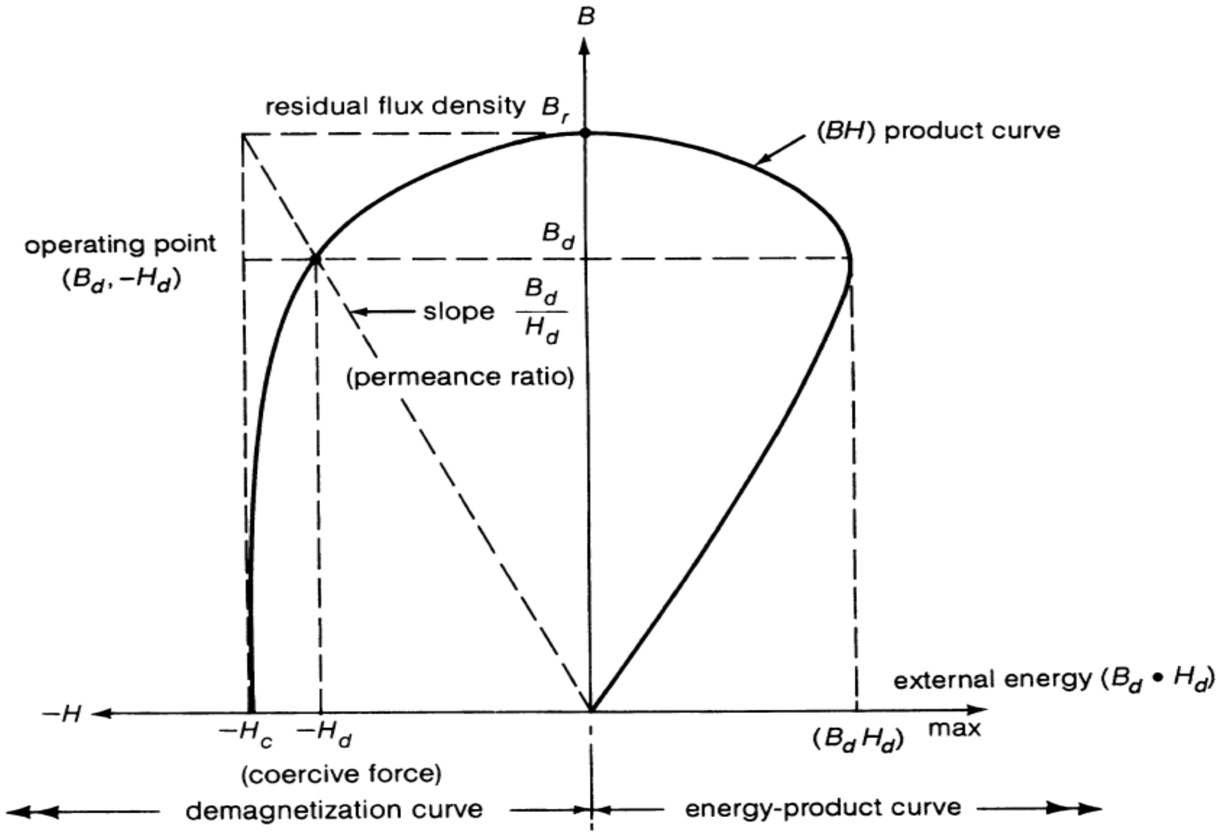


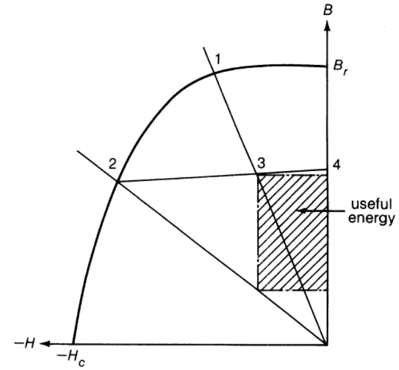
그림 3.8.8 • 예제 3.8.1의 자기회로.

3.9 영구자석 응용

- Permanent Magnet : Iron base magnet, Ferrite, AlNiCo, Rare Earth Magnet(NdFeB, SmCo)
- Magnetizing, Demagnetizing
- Hysteresis Characteristics, Energy Product

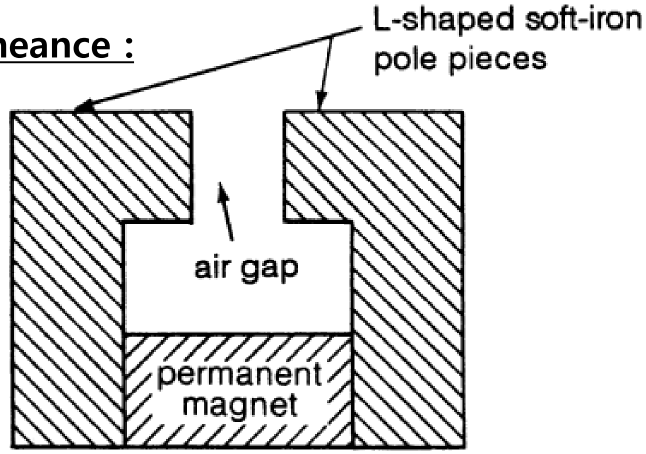


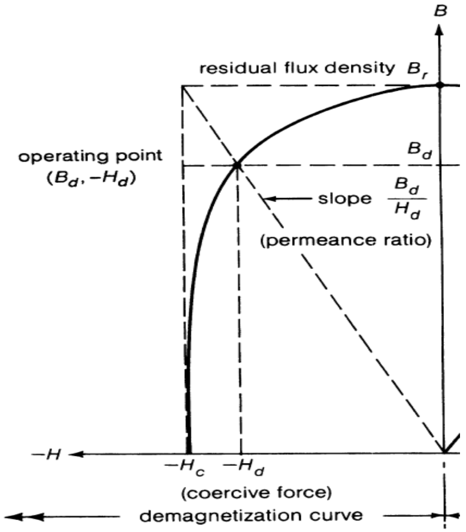
- Magnetizing , Demagnetizing
- Permeance , Load line, Bg
- Major loop , Minor loop ,
- Recoil line , Recoil Permeability



Material (Trade name)		Residual Flux Density B_r (T)	Coercive Force H_c (kA/m)	Maximum Energy product (kJ/m³)	Average Recoil Permeablility (H/m × 10^{-6})
Cast alnico	5	1.28	51	44	2.1
	5–7	1.34	58	60	1.9
	6	1.05	62	31	5.0
Sintered alnico	5	1.09	49	31	2.0
	6	0.94	64	23	5.0
Cunife		0.55	42	11	1.7
Indox	1	0.22	145	8	1.15
	2	0.29	193	14	1.15
	3	0.335	187	21	1.1
	4	0.255	183	12	1.1
Rare-earth–cobalt	18	0.87	637	143	1.05
Incor	16	0.81	629	127	1.05
36% Cobalt steel		1.04	18	8	10

- How many B ?
- <u>Magnetic Permeance :</u>





$$\boxed{N \cdot I = H \cdot L = Rm \cdot \Phi}$$

$$\sum HL = 0$$

(Bd, -Hd)
Hm=-Hd

$$H_d l_m = H_g l_g$$

- f : 철심의 자기저항 보정계수 (1.1~1.5)

$$H_d L_m = f H_g L_g = f B_g L_g / \mu_0$$

$$l_m = \frac{f B_g l_g}{\mu_0 H_d}$$

$$\boxed{V_m = A_m l_m = \frac{f F B_g^2 V_g}{\mu_0 B_d H_d}}$$

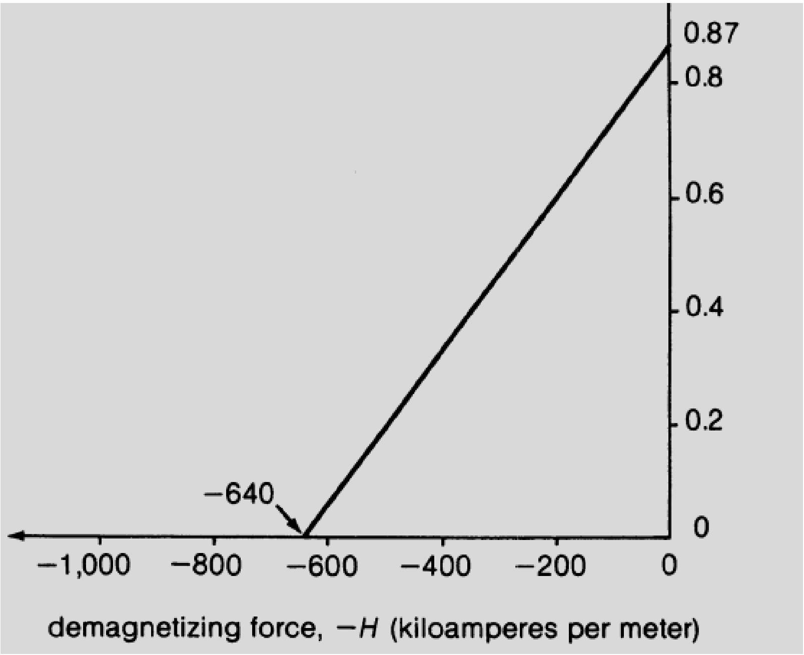
- F : 누설계수 (1.2~60)

$$\Phi = B_d A_m = F B_g A_g$$

$$A_m = \frac{F B_g A_g}{B_d}$$

$$\boxed{P_c = \frac{B_d}{H_d} = \frac{F}{f} \cdot \frac{l_m}{A_m} \cdot \frac{A_g}{l_g} \cdot \mu_0}$$

<Ex 3.9.1> 영구자석 크기결정 : B=0.5T → Am=?, Lm=?



<Ex 3.9.2> 영구자석 크기결정 : 도넛모양의 AlNiCo, for BHmax → Lg=?

<Problems>

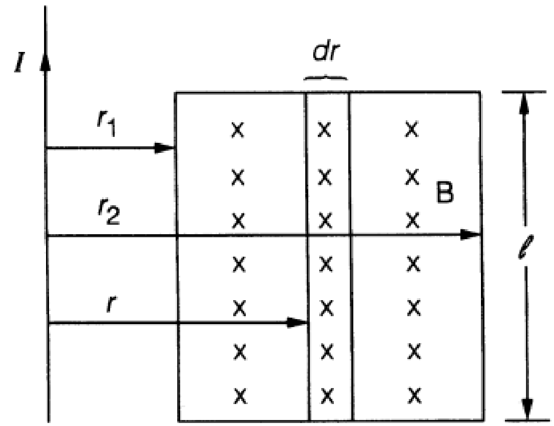


그림 P3-4

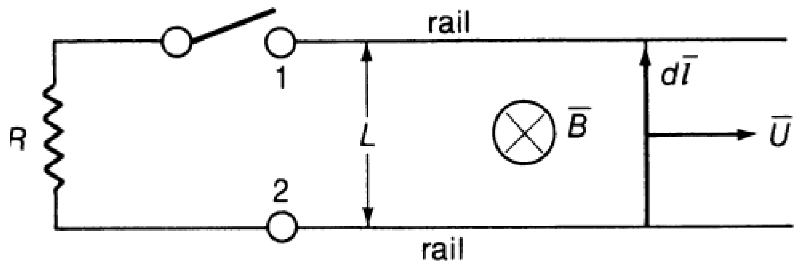


그림 P3-5

<Problems>

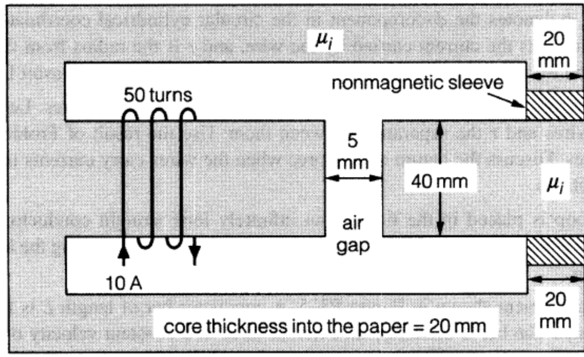


그림 P3-7

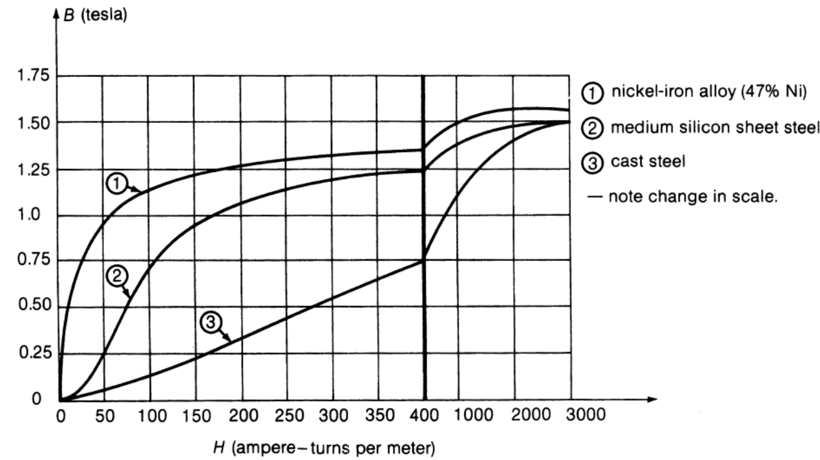


그림 P3-8

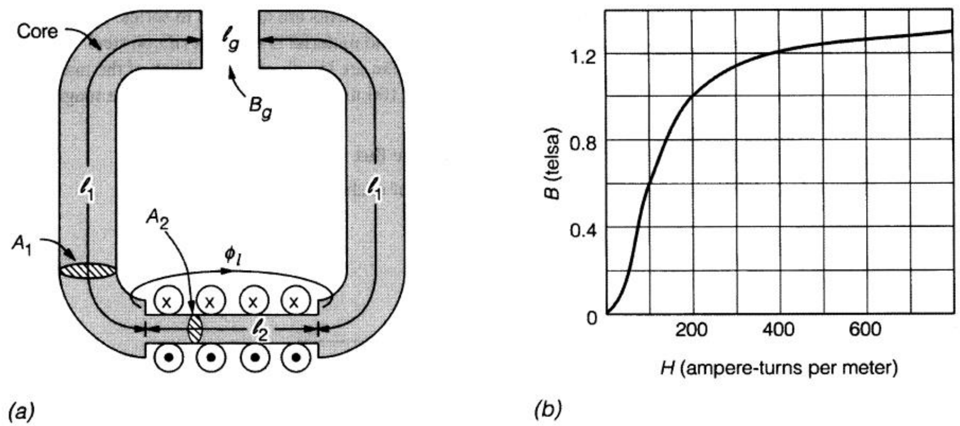


그림 P3-10

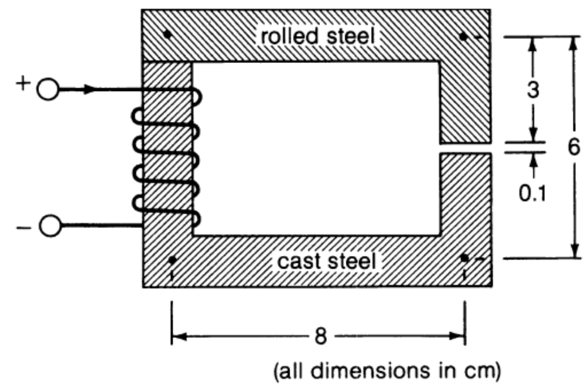


그림 P3-11

<Problems>

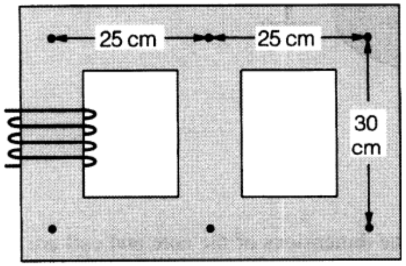


그림 P3-14

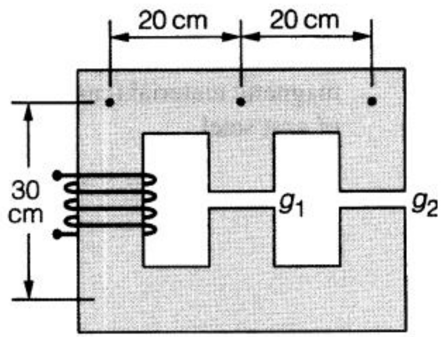


그림 P3-18

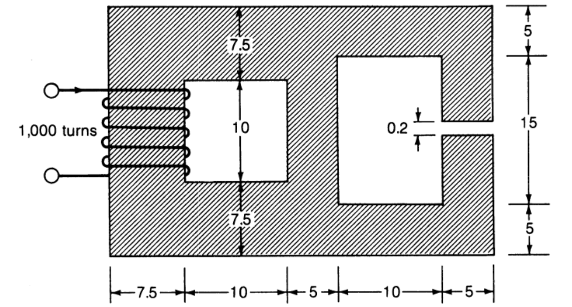


그림 P3-13

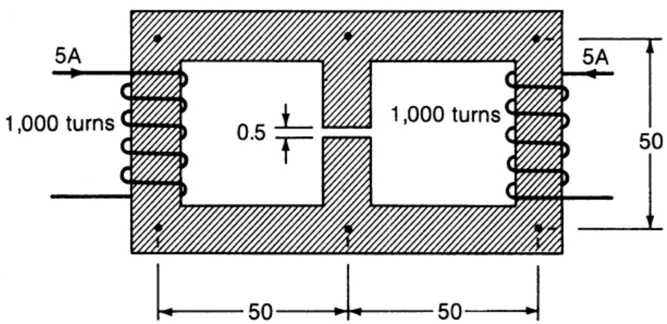


그림 P3-12

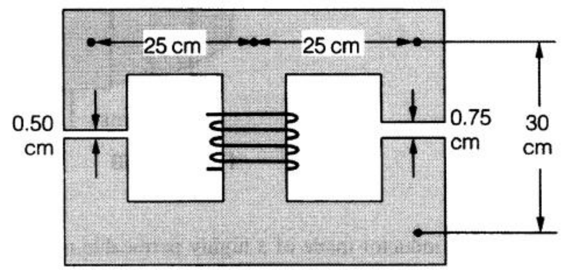
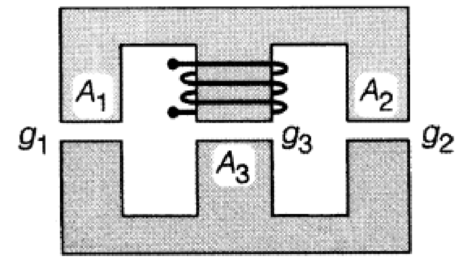


그림 P3-15



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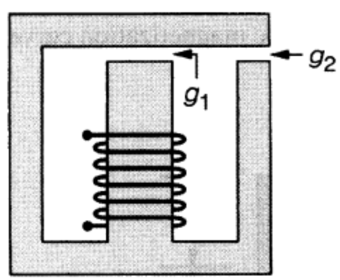

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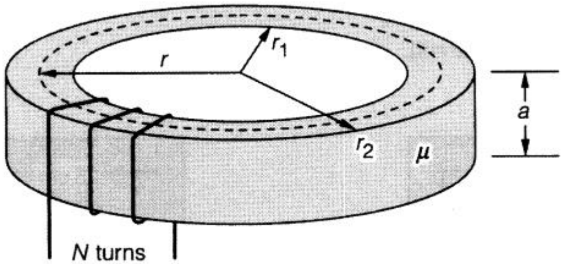

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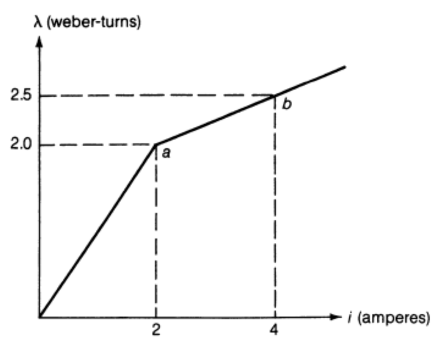

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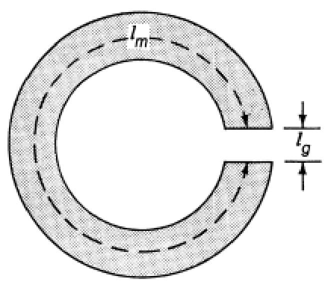

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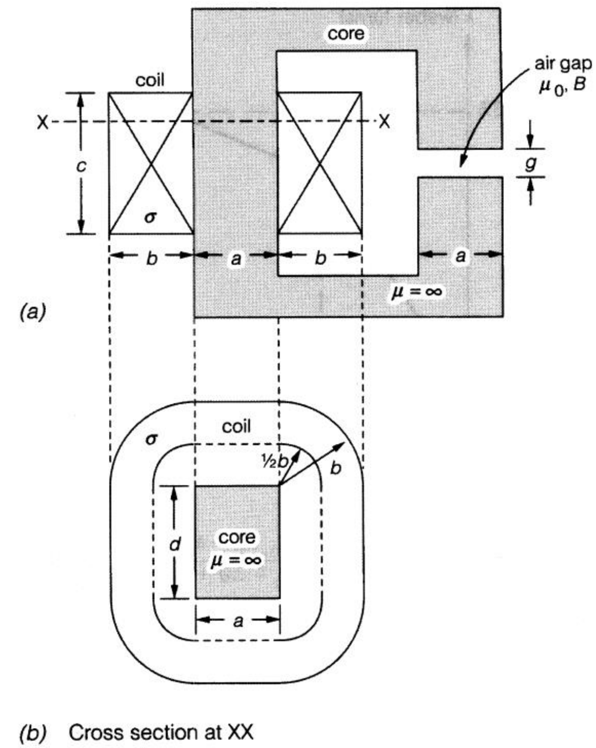

(b) Cross section at XX

그림 P3-20

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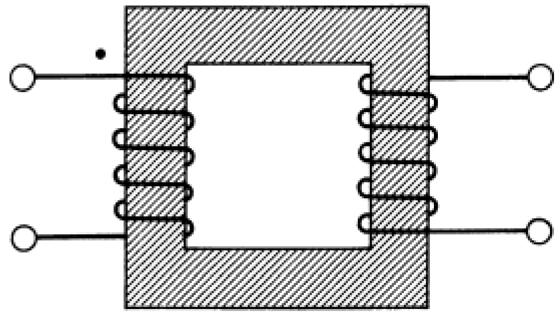

그림 P3-27

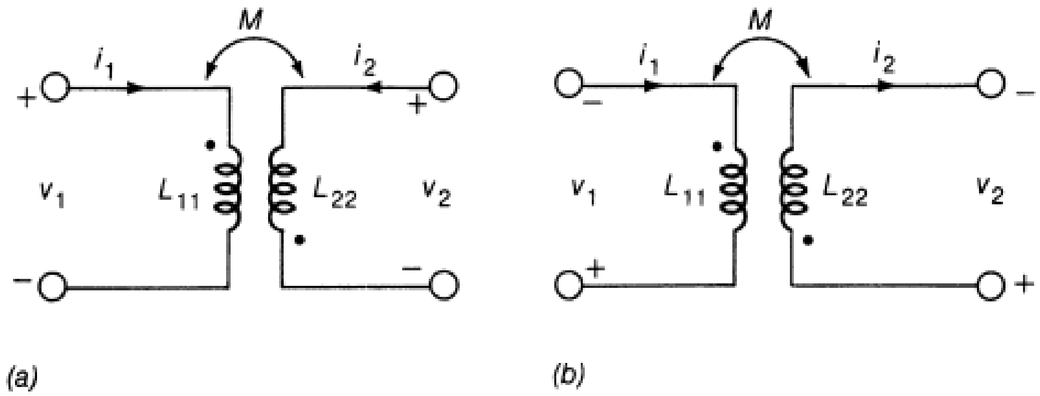

그림 P3-28