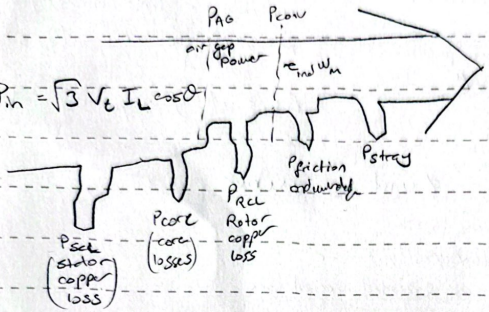
CCW +
CW -

EMEC

1- intro

Energy is capacity to do work (joules)

Power flow in electric motor



angular velocity (ω) = rpm

Newtons law of Rotation

$\tau = J\alpha$

τ = net torque applied to an object (N_m)
J = moment of inertia of the object ($kg \cdot m^2$)
α = resulting angular acceleration (rad/s^2)

Work (W)

$W = \int F\,dr \quad W = Fr \quad W = \int \tau \cdot d\theta$

torque constant: $W = \tau\theta$

Power (P)

P is joules/second (watt)

$P = \frac{dW}{dt} = \frac{d}{dt}(Fr) = F\frac{dr}{dt} = Fv$

$P = \frac{dW}{dt} = \frac{d}{dt}(\tau\theta) = \tau\frac{d\theta}{dt} = \tau\omega$

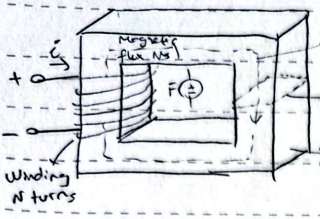
magnetic flux = ϕ

2) Magnetic Circuits

Production of a magnetic field

$\oint H \cdot dl = I_{net}$

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$$H = \frac{Ni}{l_c}$$

$$B = \mu H = \frac{\mu . Ni}{l_c}$$

H: magnetic field intensity

μ = magnetic permeability of meterial

B = resulting magnetic flux density

ϕ - B relation

$$\phi = \int_A B \cdot dA$$

ϕ unit is weber

$$\phi_c = B_c A_c$$

ϕ: flux in core

B_c flux density in core

A_c = cross sectional area of core

$$\phi_c = B_c . A_c = \frac{\mu . N . i . A_c}{l_c}$$

Magnetomotive Force (Ni)

$$F = Ni$$

$$F = \phi R$$

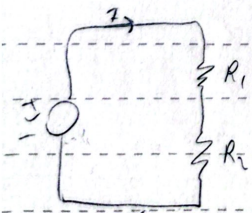
F: magnetomotive force of circuit

ϕ flux of circuit

R = reluctance of circuit

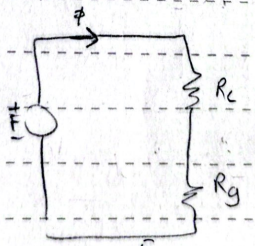
$$F = Ni = \oint H dl = H_c l_c \qquad R = \frac{l_c}{\mu A} \qquad F = \phi R$$

Electric circuit



$$I = \frac{V}{(R_1 + R_2)}$$

Magnetic circuit



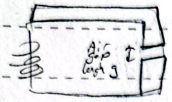
$$\phi = \frac{F}{(R_c + R_g)}$$

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μ_r = relative permeability of the core

$\phi = \frac{F}{R}$ (3)

- Magnetic circuit with air gap



μ_0 air gap permeability

A_g cross sectional area

g lenght

$B_c = \frac{\phi}{A_c}$

$B_g = \frac{\phi}{A_g}$

$$F = H_c l_c + H_g \cdot g$$

$$= \frac{B_c}{\mu} l_c + \frac{B_g}{\mu_0} g$$

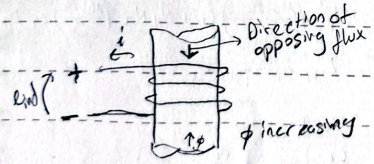
$$= \phi \left(\underbrace{\frac{l_c}{\mu A_c}}_{(R_c)} + \underbrace{\frac{g}{\mu_0 A_g}}_{(R_g)} \right)$$

- induced voltage from a time changing magnetic field Faraday's law

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

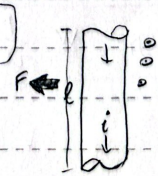
e_{ind} = voltage induced in the coil
N = number of turns of wire in coil
ϕ = flux passing through coil

$$e_{ind} = -N\frac{d\phi}{dt} = -\frac{d\lambda}{dt} \quad | \quad \lambda = N\phi \text{ the flux linkage of the coil}$$



- Production of Induced Force on a wire

$$F = i(L \times B) = ilB\sin\theta$$



l lenght of the wire
i current flowing through wire
B magnetic flux density
θ angle between the wire and flux density vector

bes pomel = F vocerte force
iqorct = i current
erte pomel = B magnetic field

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- Induced voltage on a conductor moving in a magnetic field

$e_{ind} = (v \times B)^{sin\theta} \cdot l \cos\theta$

v: velocity of the wire
B: magnetic flux density vetor
l: length of conductor in the magnetic field

$(v \times B . \sin\alpha) . l . \cos\theta$

α = v ve B arasindaki açı
θ = telin yönü ile $(v \times B)$ arasındaki açı

- Flux Linkage Inductance and Energy

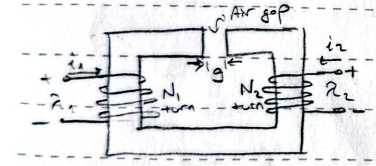
$L = \frac{\lambda}{i}$ $\quad L = \frac{N^2}{R_{tot}}$

inductance is measured in henrys (H) or weber turns per ampere

$L = \frac{N^2}{(g/\mu_0 A_g)} = \frac{N^2 \mu_0 A_g}{g}$

L = inductance
N = turn

- Magnetic circuit with two windings



→ the total mmf

$F = N_1 i_1 + N_2 i_2$

$\phi = (N_1 i_1 + N_2 i_2) \frac{\mu_0 A_c}{g}$

$\lambda_1 = N_1 \phi = N_1^2 \left(\frac{\mu_0 A_c}{g}\right) i_1 + N_1 N_2 \left(\frac{\mu_0 A_c}{g}\right) i_2$

$L_{11} = N_1^2 \frac{\mu_0 A_c}{g}$ $\quad L_{12} = N_1 N_2 \frac{\mu_0 A_c}{g}$ $\quad \lambda_1 = L_{11} i_1 + L_{12} i_2$

Power And Energy

$P = ie = i \frac{d\lambda}{dt}$ watt

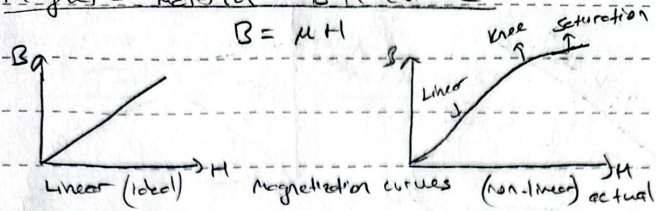
$\Delta W = \int_{t_1}^{t_2} p\,dt = \int_{\lambda_1}^{\lambda_2} i\,d\lambda$

total magnetic stored energy $W = \frac{1}{2L} \lambda^2 = \frac{L}{2} i^2$

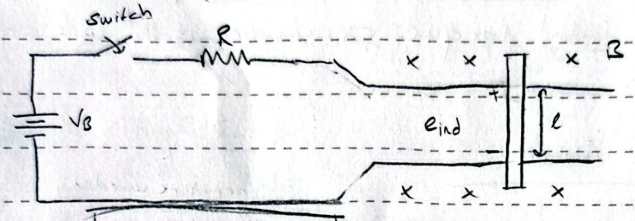
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Magnetic material B-H curve

$B = \mu H$



Linear DC machine



Boş $\rho = F$
İşaret $\rho = i$
arte $\rho = B$

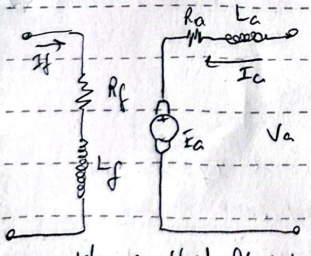
$F = i(l \times B)$

$e_{ind} = (v \times B)\, l$

Kirchoff voltage law $V_B = e_{ind} + iR = 0$

Newton law $F_{net} = ma$

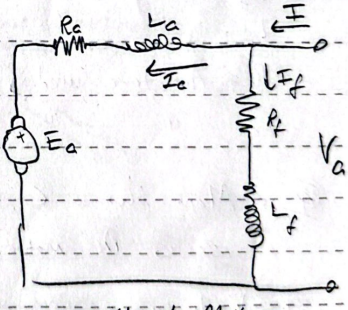
$i = \frac{V_B - e_{ind}}{R}$



Separately excited DC motor

$I_f = \frac{V_f}{R_f}$

$V_a = R_a \cdot I_a + E_a$



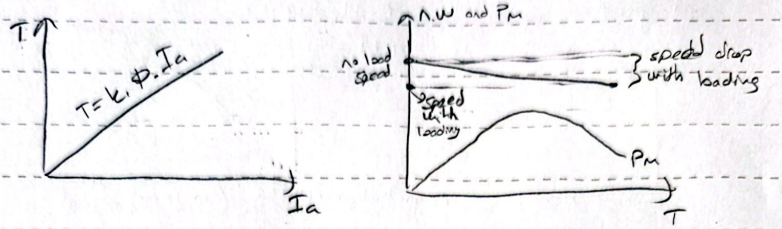
Shunt Motor

I : network current

$I = I_a + I_f$

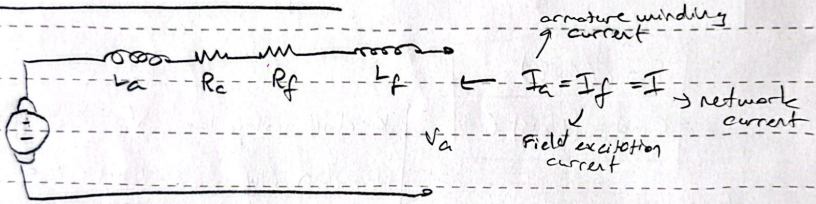
$V_a = E_a + R_a \cdot I_a$

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- both derand constant speed and torque
- Lower initial torque specification is the week side of these motors

DC series Motor



Rs = Field excitation winding Resistor
Ls = " " " inductance (producing main flux)
Ra = Armature winding resistor
La = " " inductance

Φ = Main flux = $C_1 I_f = C_1 I_a$ because $I_f = I_a$ in series DC motor winding structure

$T = k_1 \phi . I_a$ when we put Φ into torque equation

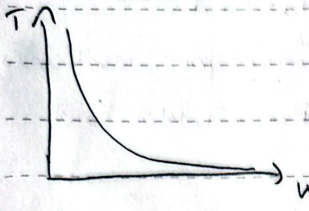
$T = k_1 C_1 I_a^2 \Rightarrow \boxed{T = K_1 I_a^2}$

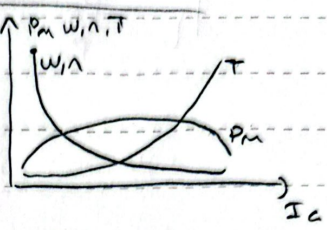
DC series motors preffered by high torque requiring application

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$V_a = E_a + (R_a + R_s) \cdot I_a$ $\quad E_a = k \cdot \Phi \cdot \omega$ $\quad \omega = \frac{2\pi \cdot n}{60}$

DC series Motor Characteristics



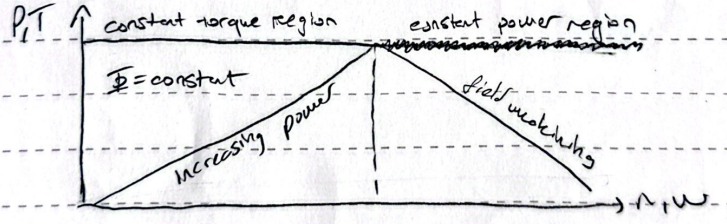


$$\frac{V_a - E_a}{R_a + R_s} = I_a \qquad T = k \cdot \Phi \cdot I_a$$

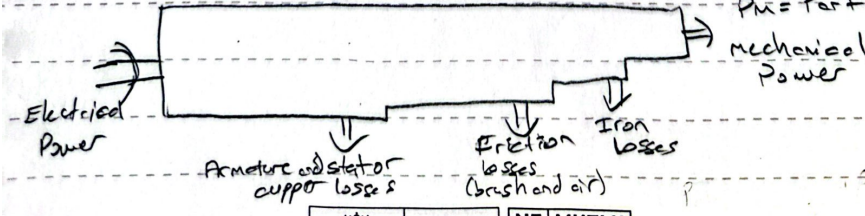
$$\omega = \frac{V_a - (R_a + R_s) I_a}{k \cdot \Phi}$$

* No load operation mode is so dangerous for DC series motor
* Important for DC series motor is high initial torque capability during starting

Operation Mode of All Type of Motors



Loss Types on Efficiency in DC motor



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$$P_{elec} = P_{cu} + P_{fe} + P_{fric} + P_M$$

$$\eta = \frac{P_M}{P_{elec}} \cdot \%$$

$P_a = E_a \cdot I_a$

↓

produced power in/of motor

$P_M = T \cdot W = P_{out}$

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