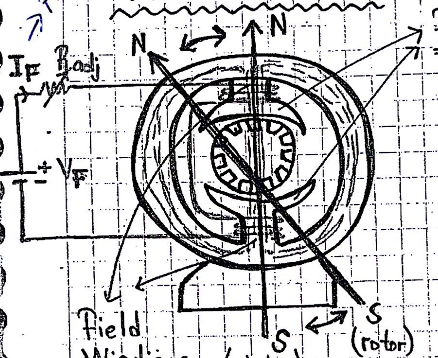
→ Field current!

DC Machines

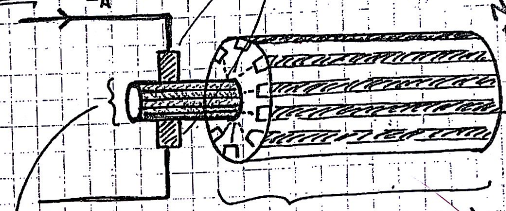
$\propto NI_F$



Poles

I_A

Brushes



armature (rotor) → motor

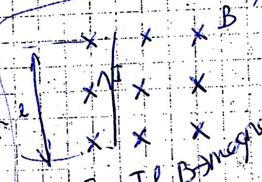
Commutator

Field Windings (stator)

S (rotor)

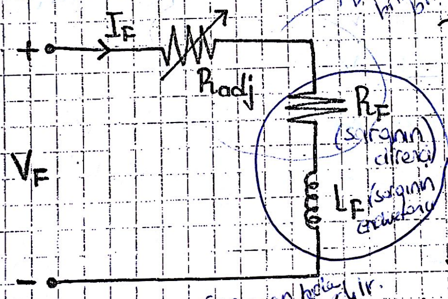
$\left.\begin{array}{l} R_F \\ I_F \\ L_F \end{array}\right\}$ manyatik alan sabit

manyetik alan değişken (hareketli)



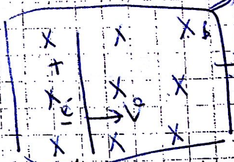
$F = I\,l\,B$ → magnetic field density

I: current; l: length of conductor



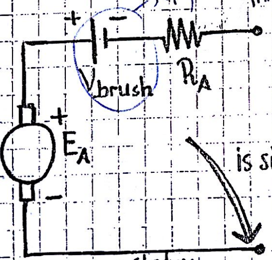
→ bu iki direnç birleştirilip tek bir direnç olarak gösterilebilir

Equivalent Circuit of Field Windings



→ generator

$e = lBv$

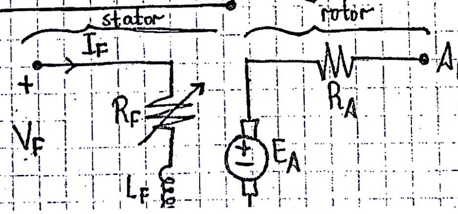


→ çoğu zaman hala ihmal edilir.

R_A: Armature winding resistance

E_A: Induced Voltage

is simplified



Equivalent circuit of DC Machine

DC Machines

Motor — Generator

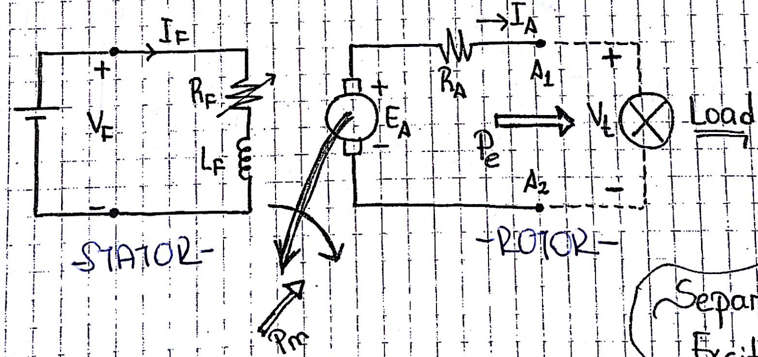
$P_e \rightarrow$ Motor $\rightarrow P_m$ (mekanik güç)

$P_m \rightarrow$ Generator $\rightarrow P_e$ (elektriksel güç)

DC Generators

There are five major types of dc generators:

1. Separately Excited dc generator ✓ (rotor ile stator devresi ayrıdır)
2. Shunt (paralel) dc generator ✓
3. Series dc generator ✓
4. Cumulatively Compounded dc generator ✓
5. Differentially Compounded dc generator ✓

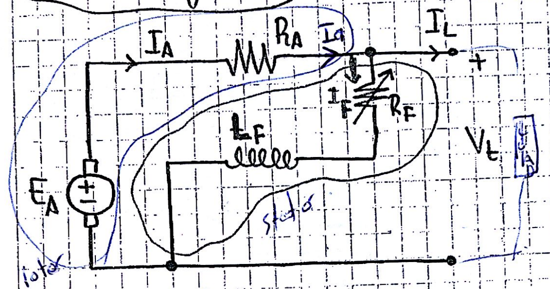


$$I_F = \frac{V_F}{R_F}$$

$$E_A = V_t + R_A I_A$$

Separately Excited dc generator ✓

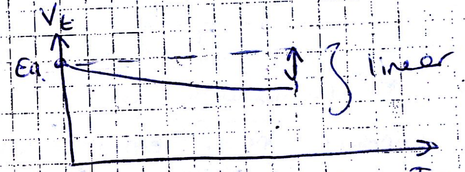
Shunt DC generator



Rotor ile stator devresi shunt bağlantılıdır.

$$\begin{cases} I_F = \dfrac{V_t}{R_F} \\ E_A = R_A I_A + V_t \\ I_A = I_F + I_L \end{cases}$$

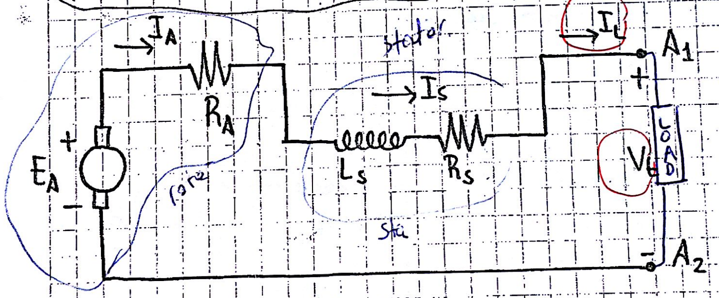
$$V_t = E_a - R_a I_a$$
$$= E_a - R_a (I_F + I_L)$$
$$= E_a - R_a I_F + R_a I_L$$



} lineer

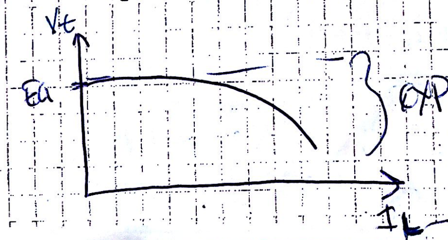
Yük akımı arttıkça terminal voltajı azalmaktadır.

Series DC Generator



$$\begin{cases} I_A = I_s = I_L \\ E_A = (R_A + R_s) I_A + V_t \end{cases}$$

R_E ile R_{adj} seri olmalı



} exponential

Yük akımı arttıkça terminal voltajı daha hızlı düşmekte

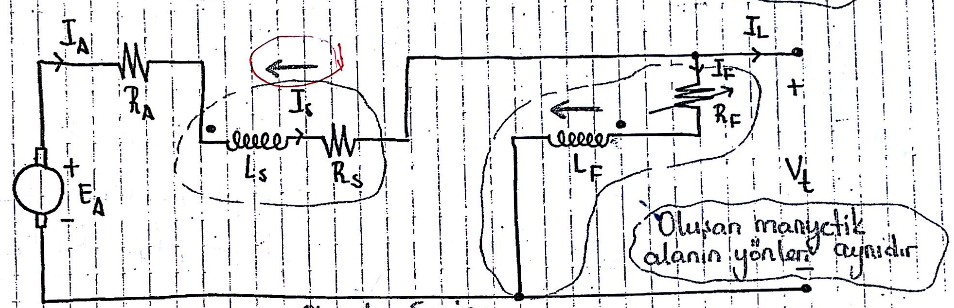
29 Mart Salı 2011

DC Generators # (... konuya devam)

$E_A = V_t + I_A(R_S + R_A)$

$I_A = I_L + I_F$

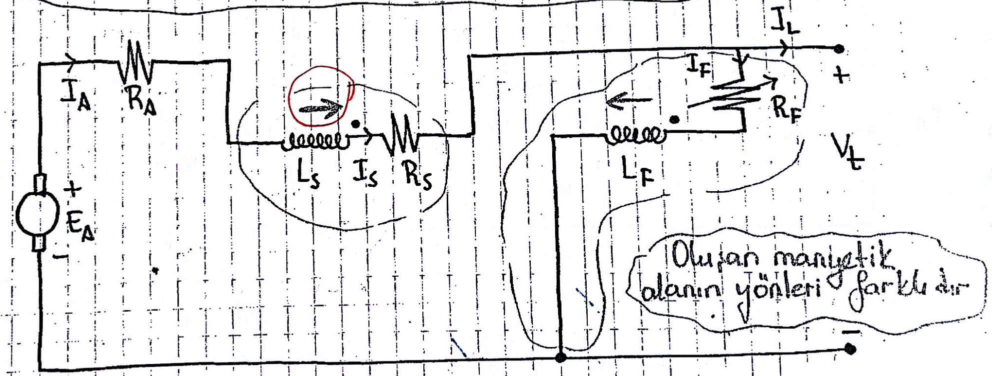
Cumulatively Compounded DC Generators



→ Shunt + Series

* In Compounded dc machines there are two field windings. One of them is series with the armature winding and the other is parallel.

Differentially Compounded DC Generators

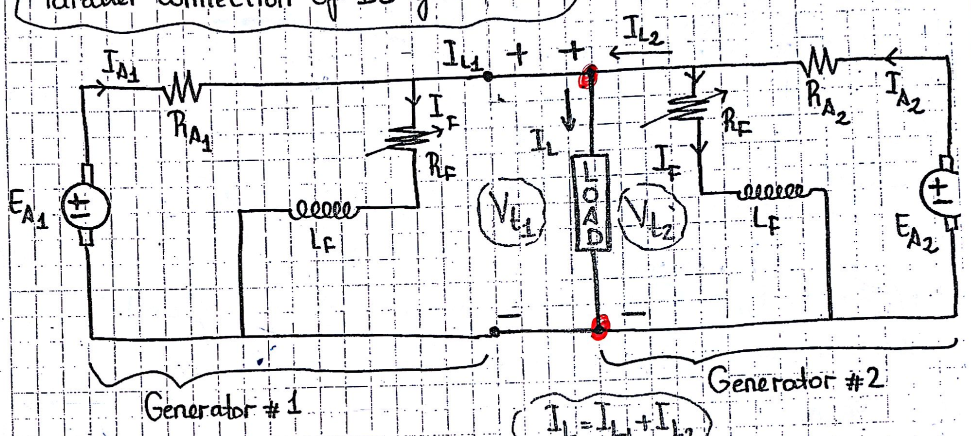


$E_A = V_t + I_A(R_S + R_A)$

$I_A = I_L + I_F$

Seyran hagle ilk okulu
C. T. pa
9:30 9:30

Parallel Connection of DC generators



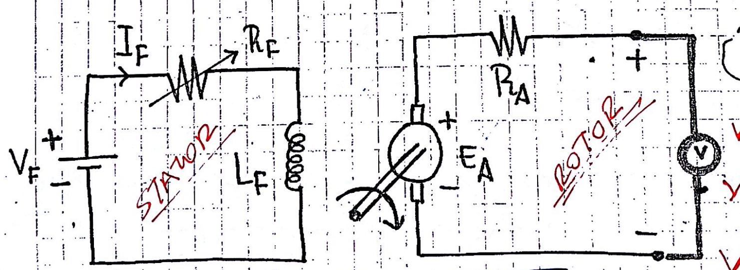
$I_L = I_{L_1} + I_{L_2}$

$P_L > P_{gen_1}$ OR $P_L > P_{gen_2}$

(**) The requirements which are needed to connect two generator in parallel are as;

1. The voltage polarites of two generators should be same
2. The voltage level of two generators should be approximately equal.

The Magnetization Curve of a DC Generator



$E_A = K\phi\omega$

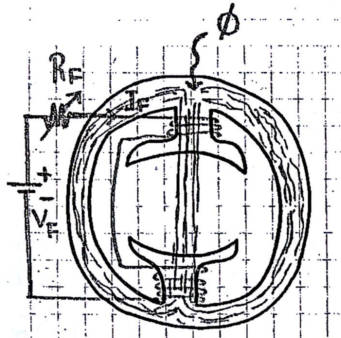
constant magnetic flux inside machine

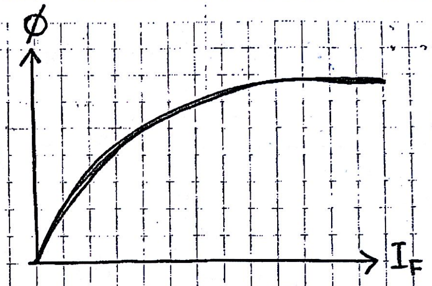
angular velocity

✓ K: constant
✓ ϕ: Magnetic flux
✓ ω: Angular Velocity of armature (rad/sec)

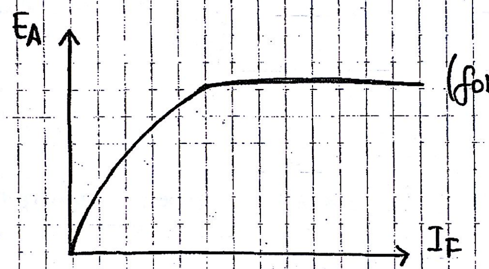
$$\boxed{\frac{E_{A_1}}{E_{A_2}} = \frac{\cancel{K}\phi_1\omega_1}{\cancel{K}\phi_2\omega_2} = \frac{\phi_1}{\phi_2} \times \frac{n_1}{n_2}}$$

$E_A = K\phi\omega$





Since $E_A \propto \phi$ $\Rightarrow$ The relationship between "E_A and I_F" is similar to that of "ϕ and I_F"



(for a constant speed)

Example: A separately excited dc generator is rated at 172 kW, 430V, 400A and 1800 r/min. The magnetization curve is shown below. The machine, has the following characteristics:

Rating Parameters

$R_A = 0.05\,\Omega$

$R_F = 20\,\Omega$

$R_{adj} = 0$ to $300\,\Omega$

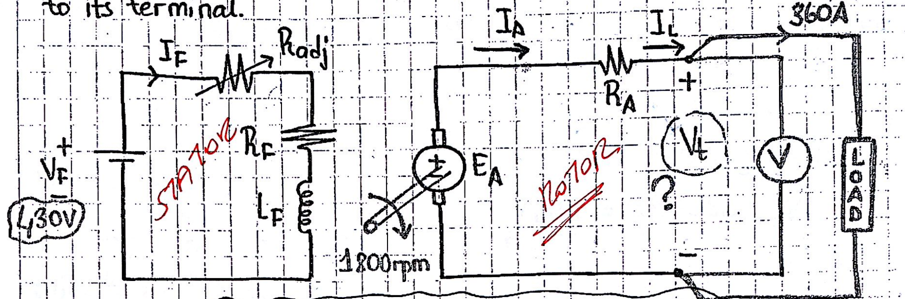
$V_F = 430V$

$N_F = 1000$ turns/pole

turns number of field windings

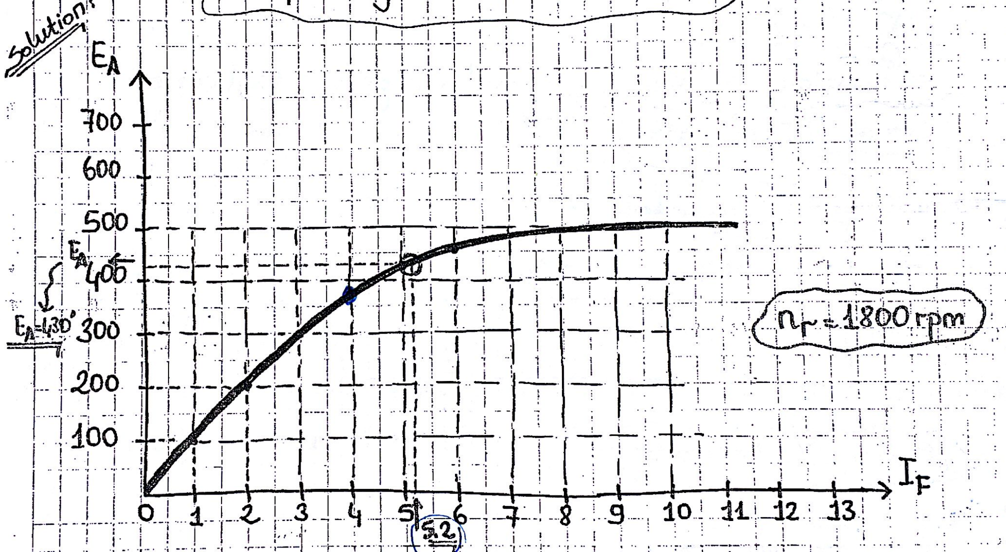
a) If the variable resistance, R_{adj} in the generator's field circuit is adjusted to $63\,\Omega$ and the generator's prime mover is driving it at 1600 r/min, what is the generator's no-load terminal voltage

b) What ~~what~~ would its voltage be if a 360-A load were connect to its terminal.



Separately Excited DC Generator

Solution:



a) $I_F = \dfrac{430}{R_F + R_{adj}} = \dfrac{430}{20 + 63} = 5.2A$

E_A at 1800rpm ⇒ 430

E_A at 1600rpm ⇒ ? $\longrightarrow$ $\boxed{E_A = K\phi\omega}$ $\rightarrow$ (rad/sec)

$$\left.\begin{aligned} E_{A_1} &= K\phi_1\omega_1 \\ E_{A_2} &= K\phi_2\omega_2 \end{aligned}\right\} \Rightarrow \frac{E_{A_1}}{E_{A_2}} = \frac{K\phi_1\omega_1}{K\phi_2\omega_2} = \frac{\phi_1}{\phi_2} \times \frac{\omega_1}{\omega_2} = \boxed{\frac{\phi_1}{\phi_2} \times \frac{n_1}{n_2}}$$

actual hız

1800 rpm → nominal value

E_A at 1600 rpm $\Rightarrow 430 \times \frac{1600}{1800} = \underline{\underline{382\,V}}$

b) For load current of 360 A, find the terminal voltage, V_t.

$$\boxed{E_A = V_t + R_A I_A}$$

$$382 = V_t + 0.05 \times 360$$

$$V_t = 382 - 18 = \underline{\underline{364\,V}}$$

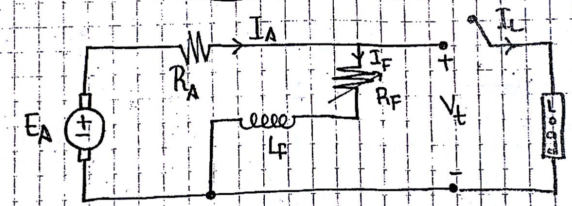
30 Mart 2011 Crş

DC Generators:

⇒ Relationship between terminal voltage and load current → $V_t - I_L$

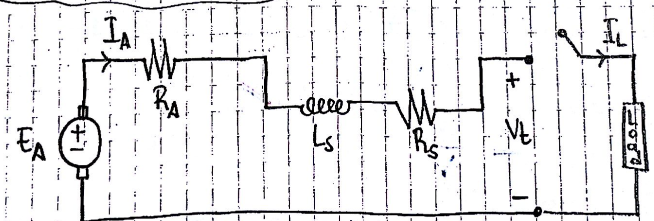
Shunt DC generator

(i)



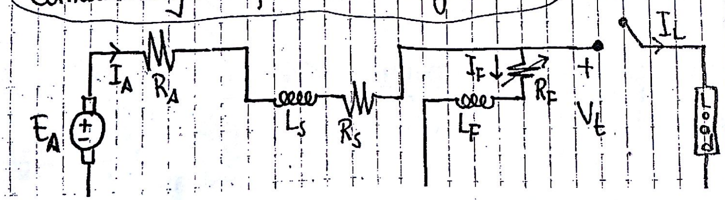
Series DC Generator

(ii)



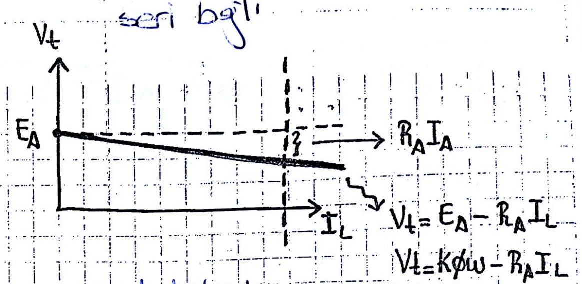
Comulatively Compounded DC generator

(iii)



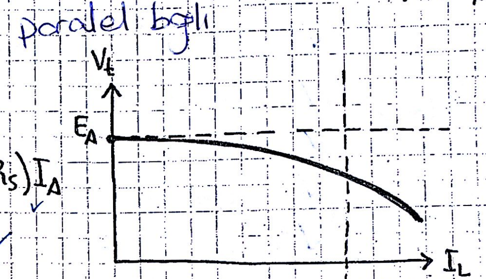
(i) $I_A = I_F + I_L$

$$\begin{cases} V_t = E_A - R_A I_A \\ V_t = K\phi\omega - R_A I_A \end{cases}$$



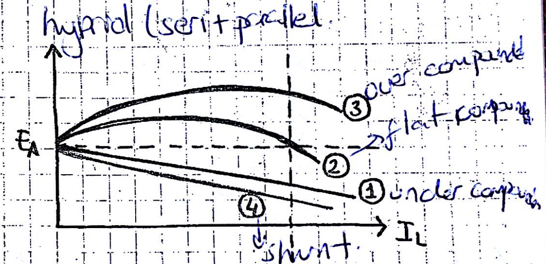
(ii) $I_A = I_L$

$$\begin{cases} V_t = E_A - (R_A + R_S) I_A \\ V_t = [E_A \Rightarrow K\phi\omega] - (R_A + R_S) I_A \\ V_t = K\phi\omega - (R_A + R_S) I_A \end{cases}$$



(iii) $I_A = I_F + I_L$

$$\begin{cases} V_t = E_A - (R_A + R_S) I_A \\ V_t = K\phi\omega - (R_A + R_S) I_A \end{cases}$$



(i) ⇒ The output voltage of a shunt dc generator decreases with increasing in "Load Current"

(iii) 1. Under Compounded
2. Flat Compounded
3. Over Compounded
4. Shunt

⁂ In DC generators: The output voltage can be controlled
1. Varying the field current
2. Varying the speed of rotation

Power Flow and Losses in DC Machines

$$\eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{P_{in} - \sum P_{losses}}{P_{in}} \times 100$$

P_{losses}
- 1- Electrical or Copper Losses (RI^2) ($R_A I_A^2$) ($R_F I_F^2$)
- 2- Brush Loss
- 3- Core Loss
- 4- Mechanical Loss
- 5- Stray Load Loss

1. Electrical or Copper Losses

$$\underbrace{R_A I_A^2}_{\text{loss of armature winding}} + \underbrace{R_F I_F^2}_{\text{loss of field winding}}$$

2- Brush Loss

$$P_{BD} = V_{BD} I_A$$

1 volt olarak düşünülsek

P_{BD}: Brush power loss

V_{BD}: Brush voltage drop

I_A: Armature resistance

3- Core Loss

a- Hysteresis Loss

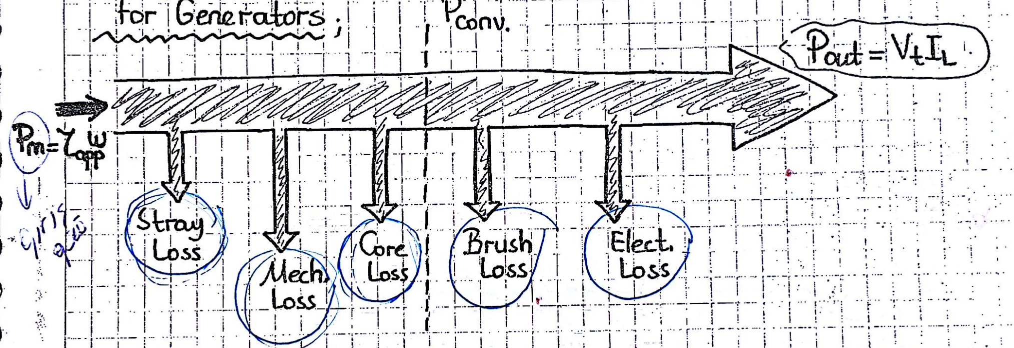
b- Eddy Current Loss

4- Mechanical Loss

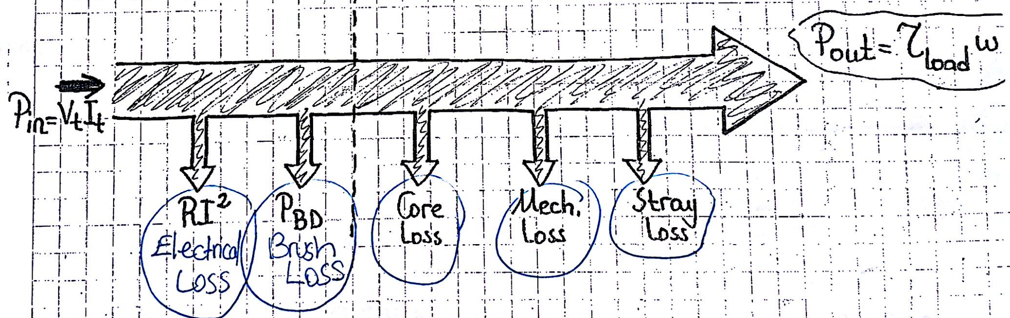
- a- Frictional Loss (sürtünme kayıpları)
- b- Windage Loss (aradaki rüzgardan dolayı kayıp)

5- Stray Load Loss : the losses can not be placed in one of the previous categories
Bilinmeyen kayıplar
⇒ It is about 1% of full load

For Generators ;



For Motors ;



Power Flow Diagram for Generators and Motors

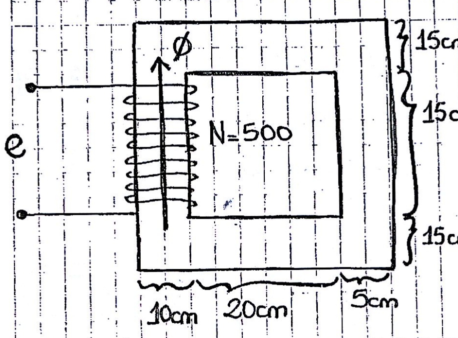
30-a

31 Mart 2011 Perşembe

⇒ ϕ'nin genliği "önemli değildir, değişimi "önemlidir"!

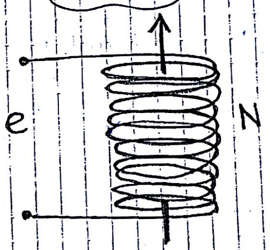
Quiz #1

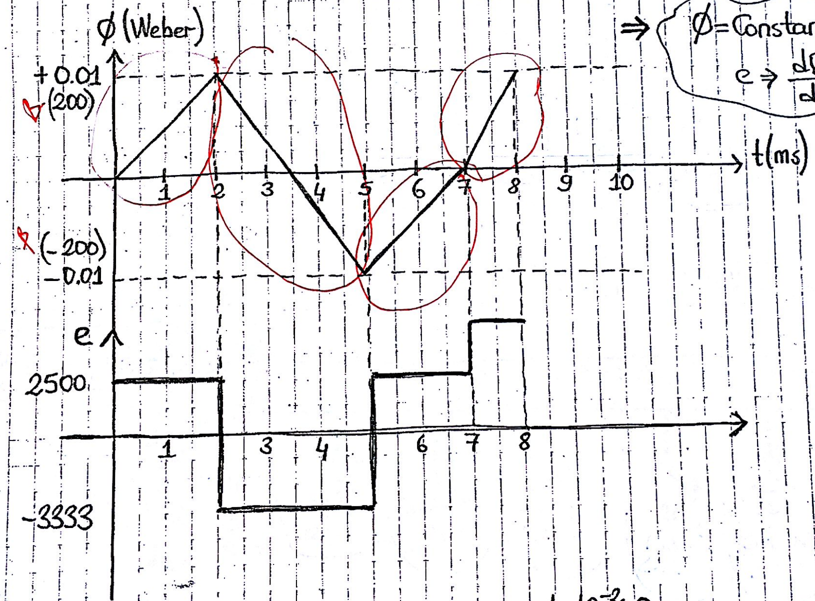
Soru #2 :



Faraday Yasası

$$e = -N\frac{d\phi}{dt}$$





⇒ ϕ = Constant = 100 Web

$e \Rightarrow \frac{d\phi}{dt} = 0$

$$0 \leqslant t \leqslant 2 \rightarrow e = 500 \times \frac{d\phi}{dt} = 500\, \frac{1\times10^{-2} - 0}{2\times10^{-3}} = \underline{2500\,V}$$

$$2 \leqslant t \leqslant 5 \rightarrow e = 500 \times \frac{-0.01 - 0.01}{3\times10^{-3}} = \frac{-2\times10^{-2}\times500}{3\times10^{-3}} = \underline{-3333\,V}$$

$5 \leqslant t \leqslant 7 \longrightarrow e = 500 \times \frac{0-(-0.01)}{2\times10^{-3}} = 2500\,V$

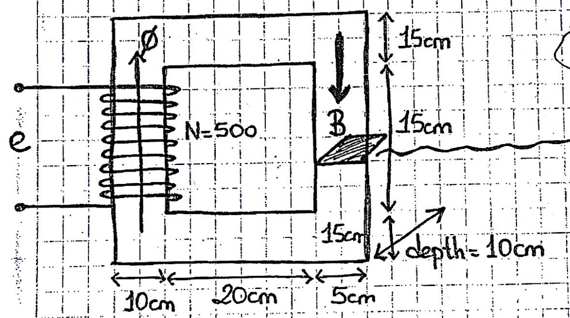
$7 \leqslant t \leqslant 8 \longrightarrow e = 500 \times \frac{0.01-0}{1\times10^{-3}} = 5000\,V$

Example:

Draw the waveform of "e" considering B given in the figure shown below.

(yandaki sorunun ϕ grafiği bu soruda artık B(tesla))

$\mathcal{E}$ grafiğin sınırları 200 ile -200 arasındadır...



$\phi = A_1 . B_1 = A_2 . B_2$

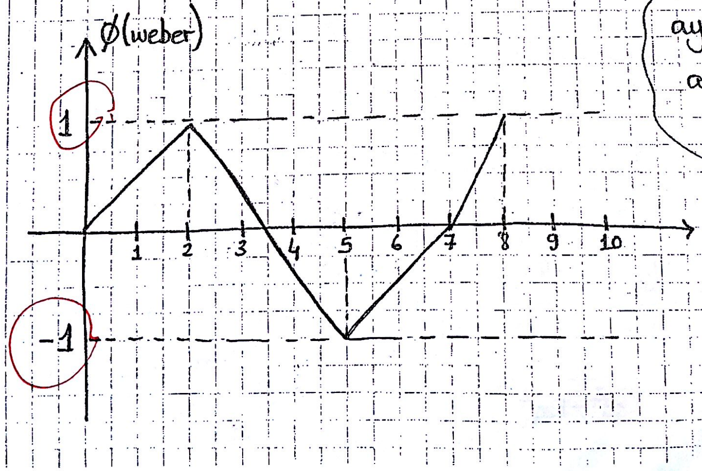
$\phi = 10\times5\times10^{-4}\times B$

$\phi = 5\times10^{-3}B$

$\phi = 5\times10^{-3}\times200 = 1$

B'den ϕ hesabı yapıldığında ϕ'nin grafiğide aynı çıkar sadece (max-min) sınırlar değişir --> (1,-1)

ϕ nüvenin her yerinde aynıdır, B ise değişkendi alanların değişikliğinden dolayı...



Soru#1:

For a 2000 VA, 230/115 transformer;

$V_{oc} = 230V$ $V_{sc} = 13.2V$ → r_{eq}, x_{eq}

$I_{oc} = 0.45A$ $I_{sc} = 6A$

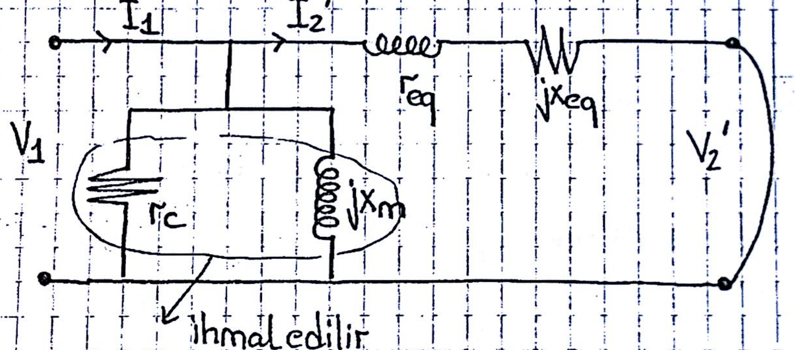
$\underbrace{P_{oc} = 30W}_{\text{open-circuit}}$ $\underbrace{P_{sc} = 20.1W}_{\text{short circuit}}$

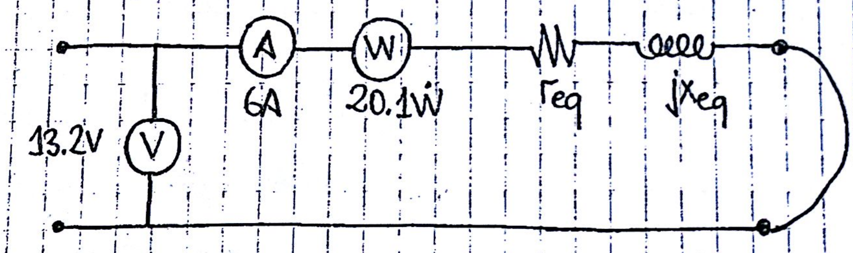
a) equivalent circuit

b) for pf = 0.8 lagging at rating conditions $V_R = ?$

c) for pf = 0.8 lagging at rating conditions $\eta = ?$

(use approximate equivalent circuit)





$$r_{eq} I_{sc}^2 = P_{sc}$$

$$* \; r_{eq} = \frac{20.1}{6^2}$$

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} = \frac{13.2}{6}$$

$$X_{eq} = \sqrt{Z_{sc}^2 - r_{eq}^2}$$

TR 29 0006 4000 0014 2780 1036 33

⇒ r_c and x_m are derived using the open circuit test results.

$$\cos\theta_{oc} = \frac{P_{oc}}{V_{oc}\times I_{oc}} = \frac{30}{230\times 0.45}$$

$$\theta_{oc} = \cos^{-1}\frac{30}{230\times 0.45}$$

$$\frac{I_{oc}\angle -\theta_{oc}}{V_{oc}\angle 0^\circ} = \frac{1}{r_c} + \frac{1}{jx_m}$$

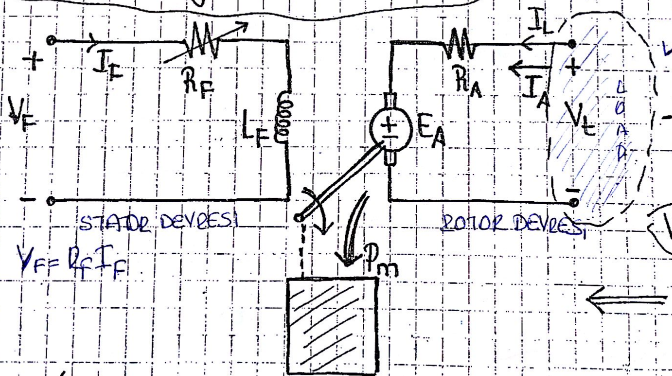
—o— SINAV BURAYA KADAR.

DC Motors

1. Separately excited dc motors
2. Shunt dc motors
3. Series dc motors
4. Compounded dc motors → a. Cumulatively Compound dc motors / b. Differentially Compound dc motors
5. Permanent magnet dc motors

NOTE: Generatorde alımın gönd yüke doğrudur

1. Seperately excited dc Motors



$V_F = R_F I_F$

$V_t = E_A + R_A I_A$
$I_L = I_A$

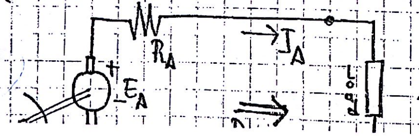
→ DC Source

$E_A = K\phi\omega$

$V_t = K\phi\omega + R_A I_A$

⟸ DC Source
P_e

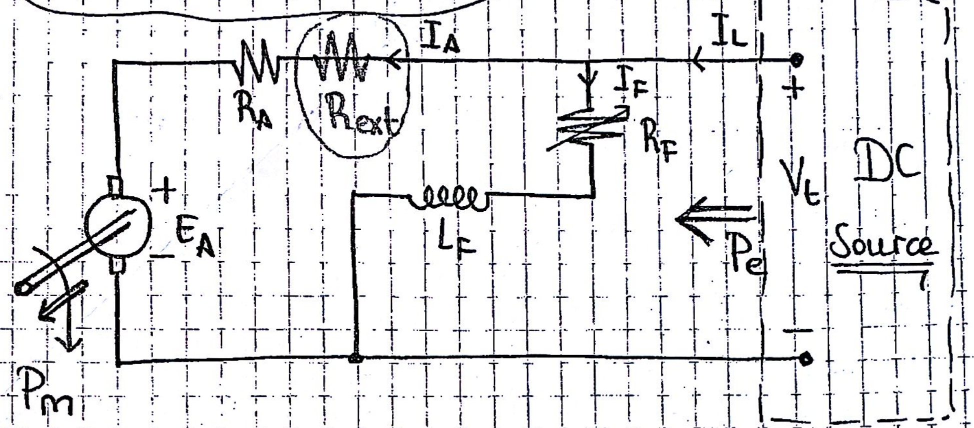
(There is needed for two separate DC Sources)



⇝ Generator

2. Shunt DC Motors

★ sınav sorusu.



$$P_e = P_{in} = V_t I_L$$

$$P_{out} = P_m = \tau_m \omega$$

$\omega \longrightarrow$ angular velocity (rad/sec)

$\tau_m \rightarrow$ Torque (N.m.)

$I_L = I_a + I_f$

TORQUE-SPEED CHARACTERISTICS OF SHUNT DC MOTOR

$$\boxed{V_t = R_A I_A + E_A}$$

$$\tau = K\phi I_A$$

$$I_A = \frac{\tau}{K\phi}$$

** $E_A = K\phi\omega$ → açısal hız of rotor

E_A → induced voltage

$\tau = K\phi I_A$ → Armature current

τ → Torque

K → Constant

ϕ → magnetic field produced by field windings.

$$V_t = R_A \underbrace{\frac{\tau}{K\phi}}_{I_A} + K\phi\omega$$

$$\underbrace{K\phi\omega}_{E_A} = V_t - R_A \frac{1}{K\phi}\tau$$

$$\boxed{\underset{\text{hız}}{\omega} = \frac{1}{K\phi} V_t - \frac{R_A}{(K\phi)^2} \underset{\text{moment}}{\tau}}$$

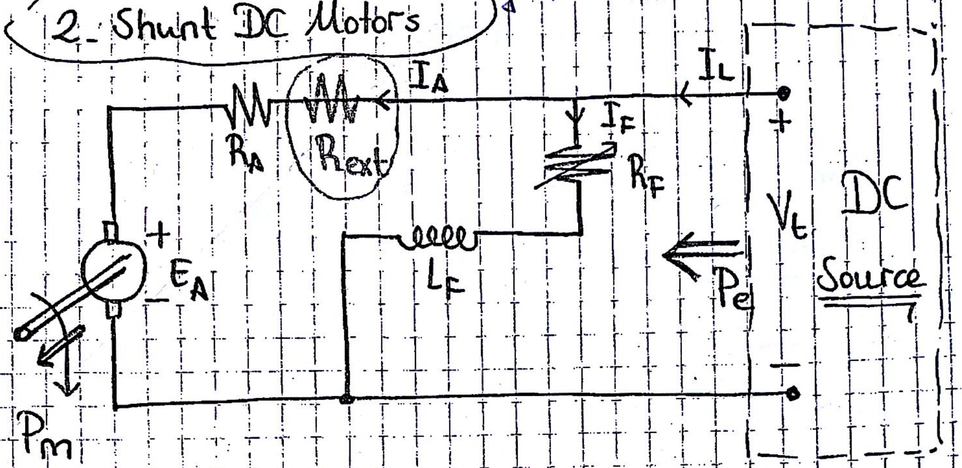
{ terminal voltajı, alan, direnç

The relationship between torque and speed of a shunt dc motor

R_F } $\phi = \frac{V_F}{R_F}$

2- Shunt DC Motors

* sınav sorusu.



$P_e = P_{in} = V_t I_L$

$P_{out} = P_m = \tau_m \omega$ → angular velocity (rad/sec)

Torque (N.m.)

$I_L = I_A + I_F$

TORQUE-SPEED CHARACTERISTICS OF SHUNT DC MOTOTOR

$$\boxed{V_t = R_A I_A + E_A}$$

$\tau = K\phi I_A$

$I_A = \dfrac{\tau}{K\phi}$

** $E_A = K\phi\omega$ → açısal hız of rotor

$\tau = K\phi I_A$ → Armature current

induced voltage; Torque; constant; magnetic field produced by field windings.

$V_t = R_A \dfrac{\tau}{K\phi} + K\phi\omega$ (I_A)

$$\underbrace{K\phi\omega}_{E_A} = V_t - R_A \frac{1}{K\phi}\tau$$

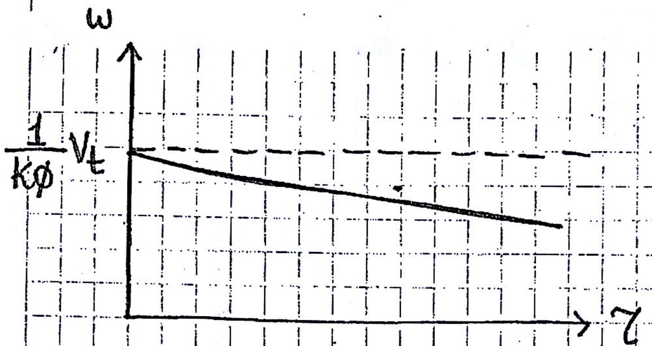
$$\boxed{\underset{hız}{\omega} = \frac{1}{K\phi} V_t - \frac{R_A}{(K\phi)^2} \underset{moment}{\tau}}$$

← terminal voltajı, alan, direnç

The relationship between torque and speed of a shunt dc motor

$(\tau-\omega)$ characteristic depends on ϕ, R_A, V_t

R_F, I_F → $\underbrace{\phi}_{I_F} = \dfrac{V_F}{R_F}$

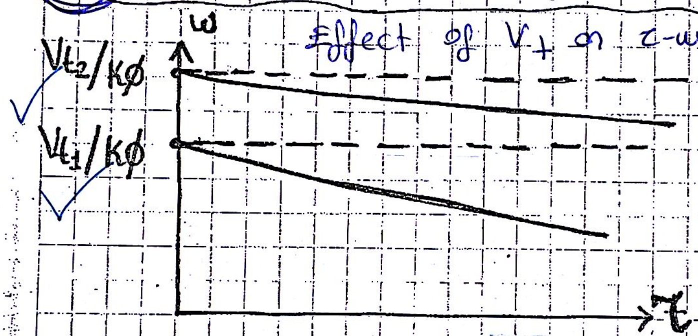


hız azaldıkça
yüke gönderilen güç ↑
değişim lineer

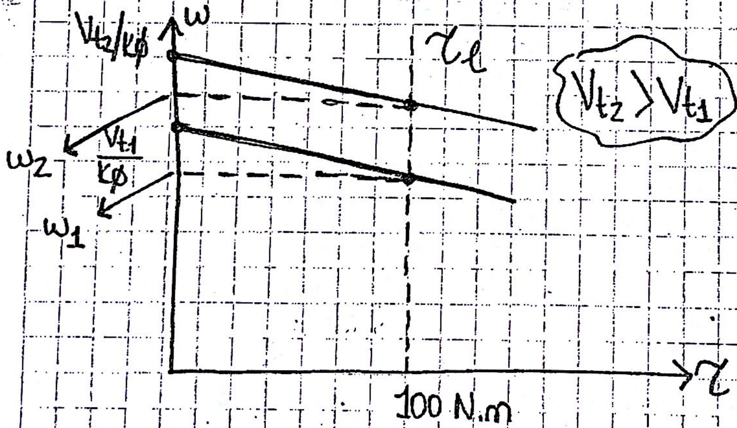
The torque speed characteristics
of a shunt dc motor

i) Effect of terminal voltage on the torque speed characteristics

Effect of V_t on τ-ω characteristics



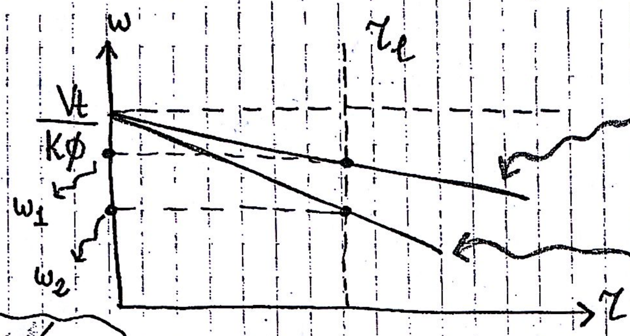
$V_{t_2} > V_{t_1}$



$V_{t_2} > V_{t_1}$

terminal voltajı ↑
hız (motor için) ↑
ya da tam tersi

ii) Effect of R_A on (τ-ω) Characteristics



$\left(-\frac{R_A}{K\phi}\right)$ eğim $\frac{-R_A}{(K\phi)^2}$ mi olmalı ?

$R_A = R_{A_1}$

$R_A = R_{A_2}$

$\omega_2 < \omega_1$

$R_{A_2} > R_{A_1}$

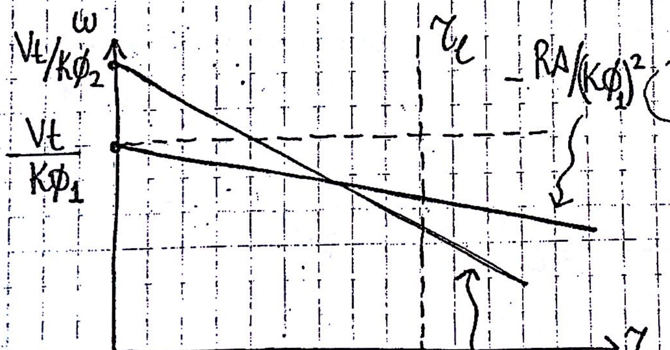
$R_A \uparrow \Rightarrow \left|\left(-\frac{R_A}{K\phi}\right)\right| \uparrow$

rotorun direnci

$R_A \uparrow \Rightarrow \omega \downarrow$

Rext devreye direnci eklendiğinde $\Rightarrow \omega = \frac{1}{K\phi} V_t - \frac{(R_A + R_{ext})}{(K\phi)^2} \tau$

iii) Effect of R_F (~~Rext~~) on (τ-ω) Characteristics



τ_L : load torque

is assumed to be constant

$\omega = \frac{1}{K\phi} V_t - \frac{R_A}{(K\phi)^2} \tau$

$I_F = \frac{V_F}{R_F} = \frac{V_t}{R_F}$

$R_F \uparrow \Rightarrow I_F \downarrow \Rightarrow \phi \downarrow$

$R_F \Rightarrow R_{F_1} \nearrow R_{F_2}$

$\Downarrow$

$\phi \Rightarrow \phi_1 \longrightarrow \phi_2$

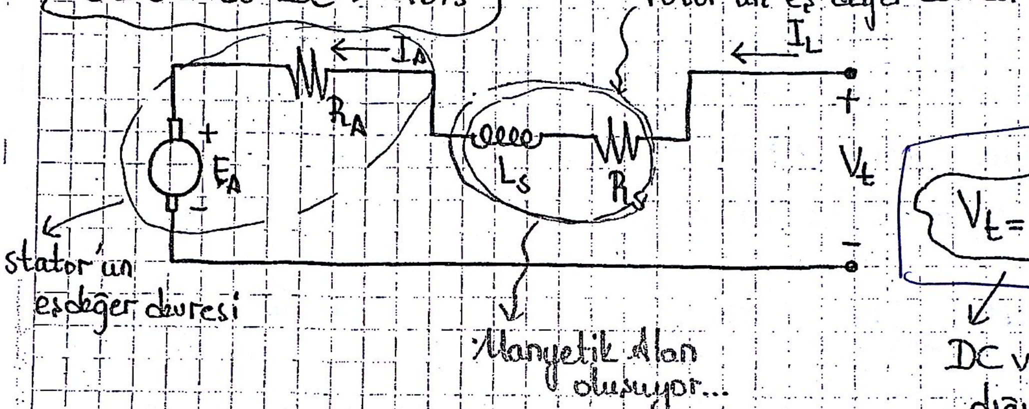
** The speed of a shunt DC Motor can be adjusted by;

1) Varying terminal voltage (V_t)
2) Varying field circuit resistance (R_F)
3) Inserting external resistance in series with motor.

kayıplar yüksek $\Rightarrow$ $P_{loss} = R_{ext} I_A^2$

sınav sorusu

* 3_ Series DC Motors



$$V_t = E_A + (R_s + R_A) I_A$$

DC voltaj uygulandığı için L_s'nin üzerinde herhangi bir voltaj düşüşü yok, L_s hesaba katılmaz...

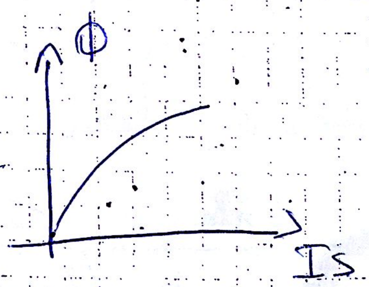
$$V_t = K\phi\omega + (R_s + R_A)\frac{\tau}{K\phi}$$

$$\tau = K\phi I_A = K K_1 I_A I_A \Rightarrow K K_1 I_A^2$$

$$I_A = \sqrt{\frac{\tau}{K K_1}}$$

$\phi \propto I_A \Rightarrow K_1$: constant value

$$\phi = K_1 I_A = K_1\sqrt{\frac{\tau}{K K_1}} = \sqrt{\frac{K_1 \tau}{K}}$$



$\phi = K_1 I_s$

$\hookrightarrow$ Linear Region

$$V_t = K\sqrt{\frac{K_1\tau}{K}}\,\omega + (R_s + R_A)\sqrt{\frac{\tau}{K K_1}}$$

ϕ I_A

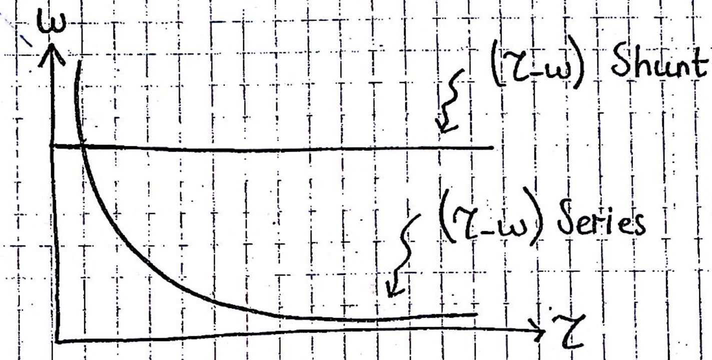
$$V_t = \sqrt{K K_1 \tau}\,\omega + (R_s + R_A)\sqrt{\frac{\tau}{K K_1}}$$

$$\sqrt{K K_1 \tau}\,\omega = V_t - (R_s + R_A)\sqrt{\frac{\tau}{K K_1}} \longrightarrow$$

haftaya ⇒ Çarşamba 2. saat Quiz

34-a

$$\omega = \frac{1}{\sqrt{KK_1 \tau}} V_t - \frac{(R_S + R_A)}{KK_1} \longrightarrow \tau = 0 \quad \omega = \infty$$



Torque-speed characteristic of a Series Motor

Sabit hız istersek tercihimiz Shunt olmalıdır çünkü hız, yükteki değişimlerde etkilenmiyor.

Ancak, Series de yükteki herhangi bir artış hızı etkiliyor, ve değişim oldukça fazla oluyor.

Seri DC Motor → yüksüz durumda, boşta çalıştırılmaz!

*** Series DC Motor is not used for no load operations

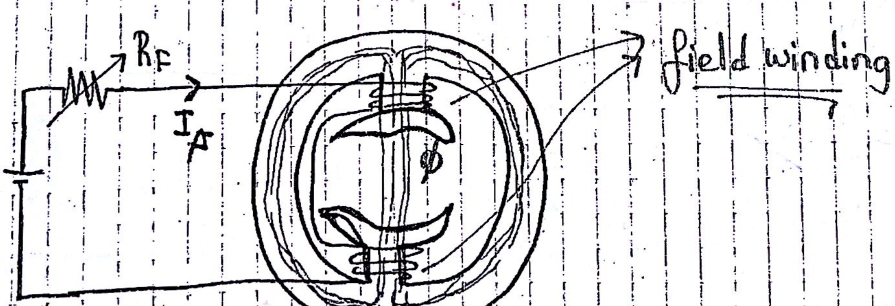
At no-load condition the speed of motor is very high.

$\tau = 0, \ \omega \nearrow \infty$

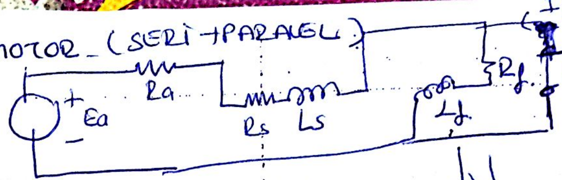
(τ: load ω: speed)

4- Permanent Magnet Motors (PMM)

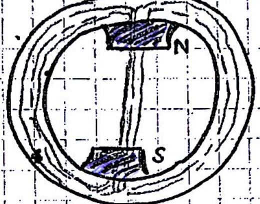
In this type motors there is no field winding. The magnetic field is produced using magnetic materials..



COMPOUNDED MOTOR (SERİ+PARALEL)



PMM



→ No field winding

Maliyeti düşük

Aynı güçte olan shunt motor ile PPM karşılaştırılırsa;

- PMM'nin volumu küçüktür
- Alan sargısı yok ⇒ $\boxed{P_{loss} = R I_F^2}$ yok
- PMM yüksek güçlerde kullanılmaz. (güç ≪ 1KW)

Shunt Motor	PMM
• Volume büyük	• Volume küçük ⇒ (aynı güçte)
• P_{loss} var	• P_{loss} yok
• yüksek güçlerde kullanılır.	• yüksek güçlerde kullanılmaz.
field winding var	field winding yok

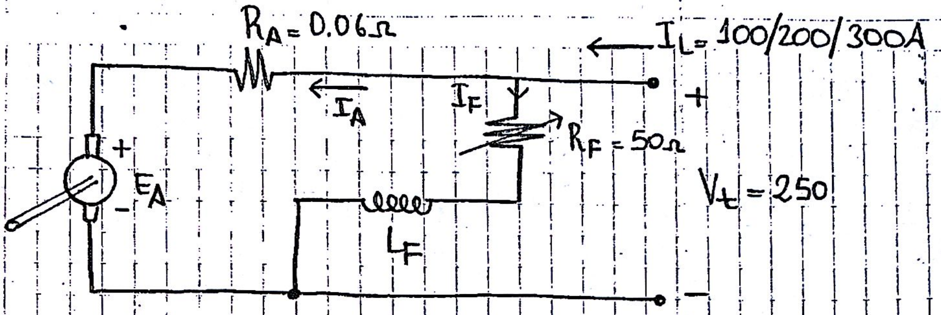
$\boxed{1hP = 746W}$

Example: A 50-hP, 250-V, 1200 r/min dc shunt motor has an armature resistance of 0,06Ω. It is field current has a total resistance of 50Ω, which produces a no-load speed of 1200 r/min. There are 1200 turns per pole on the shunt field winding.

a) Find the speed of this motor when its input current is 100A

b) 200A

c) 300A



$\left\{ \begin{array}{l} \text{At no load } n_r = 1200 \text{ rpm } (r/min) \\ \Rightarrow \tau = 0 \Rightarrow \tau = K\phi I_A = 0 \end{array} \right.$

$I_A = 0$

$V_t = R_A I_A + E_A = 0 + E_A \Rightarrow \boxed{E_A = 250V}$

$\left\{ \begin{array}{l} E_A = 250V \\ n_r = 1200 \text{ rpm} \end{array} \right.$

a) $I_F = \dfrac{250}{50} = 5A$ ✓

$I_A = I_L - I_F = 100 - 5 = 95$ ✓

$E_A = V_t - R_A I_A = 250 - 0.06 \times 95 = 244.3V$ ✓

$$\frac{E_{A1}}{E_{A2}} = \frac{K\phi_1 \omega_1}{K\phi_2 \omega_2} = \frac{\phi_1 n_1}{\phi_2 n_2} = \frac{1200}{n_2} = \frac{250}{244.3} \Rightarrow \boxed{n_2 = 1173 \text{ rpm}}$$

b) $I_L = 200A$

$I_A = 200 - 5 = 195$ ✓

$E_A = 250 - 0.06 \times 195 = 238.3V$ ✓

$$\frac{E_{A1}}{E_{A2}} = \frac{K\phi_1 \omega_1}{K\phi_2 \omega_2} = \frac{1200}{n_2} = \frac{250}{238.3} \Rightarrow \boxed{n_2 = 1144 \text{ rpm}}$$ ✓

c) $I_L = 300A \Rightarrow I_A = 300-5 = 295A$

$E_A = 250 - 0.06 \times 295 = 232.3V$

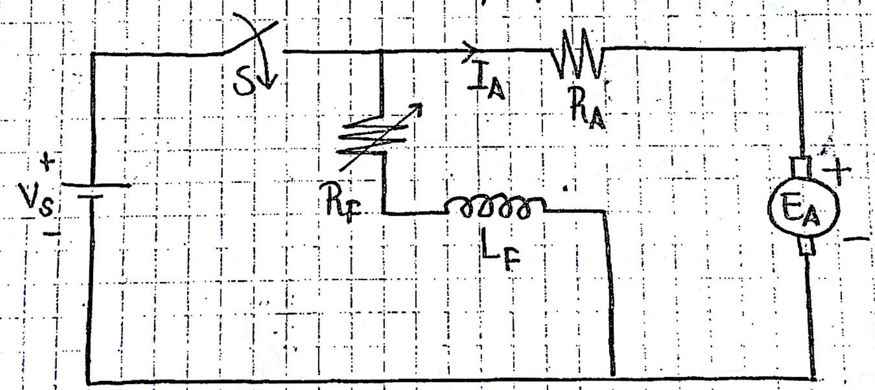
$$\frac{1200}{n_2} = \frac{250}{232.3} \Rightarrow n_2 = 1115 \text{ rpm}$$

	n(rpm)
$I_A = 0$ (no load)	1200 ✓
$I_A = 100$	1173 ✓
$I_A = 200$	1144 ✓
$I_A = 300$	1115 ✓

6 Nisan Çarşamba 2011

Starters in DC Motors:

The starting current of DC motors is very high and should be limited to obtain a proper operation.



Switch S is closed at $t=0$

$$V_s = R_A I_A + E_A \Rightarrow I_A = \frac{V_s - E_A}{R_A}$$

$$E = K\phi\omega \Rightarrow I_A = \frac{V_s - K\phi\omega}{R_A}$$

At starting $n=0$ or $\omega = 0 \Rightarrow E_A(t=0^+) = 0$

$$** \; I_A = \frac{V_s}{} \Longrightarrow I_A(\text{starting})$$

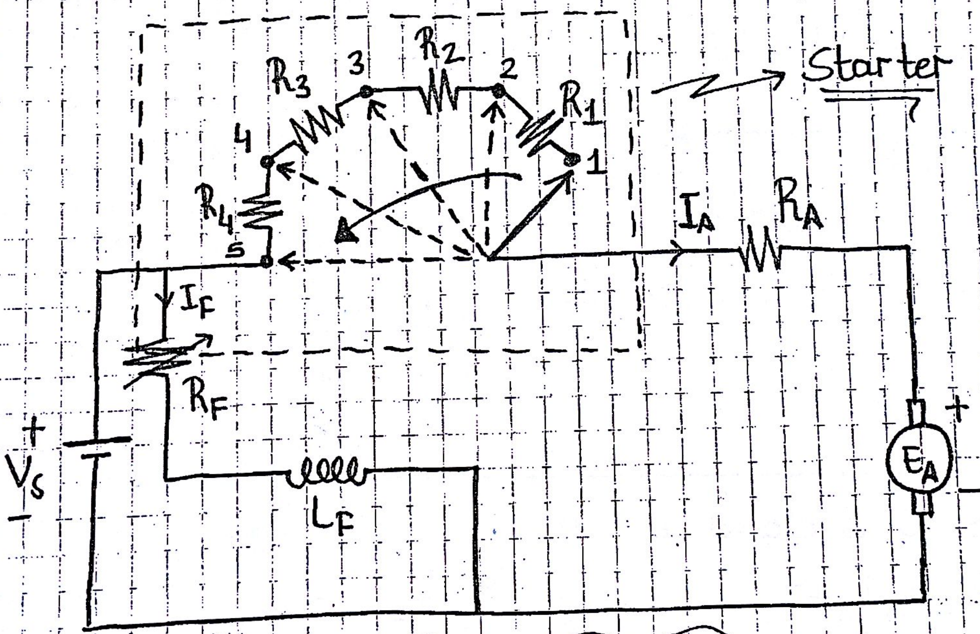
Example: For a shunt DC Motor with armature resistance of 0.2Ω find the starting current.
The motor is supply from a 200Vdc source

$$\left.\begin{aligned} V_S &= 200 \\ R_A &= 0.2 \end{aligned}\right\} \quad I_A(\text{starting}) = \frac{200}{0.2} = \underline{1000A}$$

Staters ⇒ DC motorlarda motorun başlangıç akımı çok yüksek olduğu için, bu durumun önüne geçmeye yarayan cihazlardır..

ex: DC motorun nominal akım değeri ⇒ 50A iken
starting akım değeri ⇒ 1000A

Starting akım değerini düşürmeye yarayan şey ⇒ starters



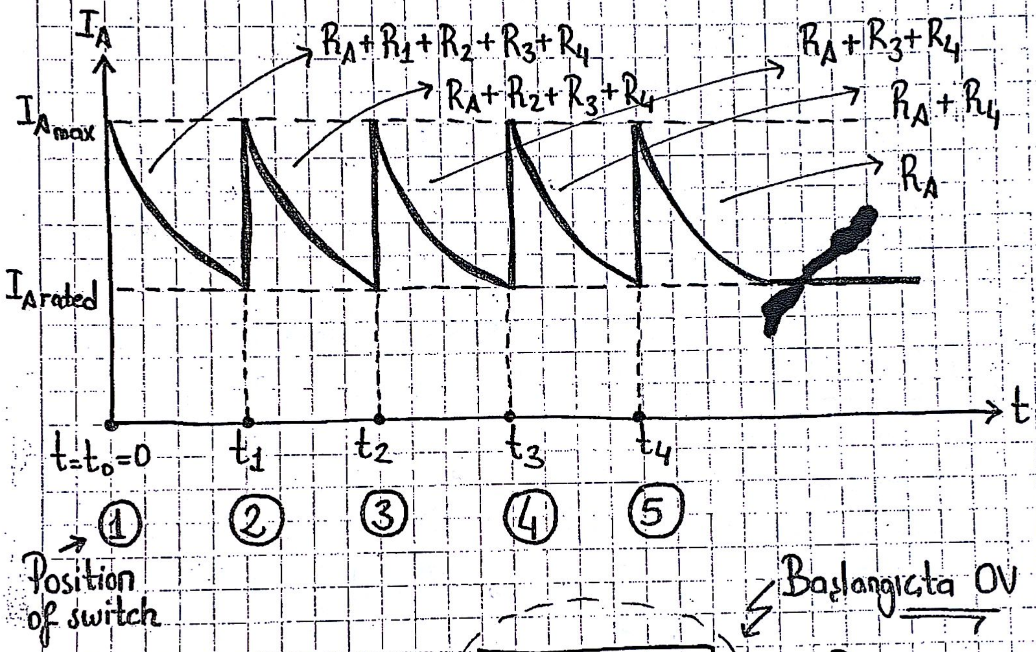
$$\text{At } t=0 \rightarrow I_A = \frac{V_S - K\phi\omega}{R_A + [R_1 + R_2 + R_3 + R_4]}$$

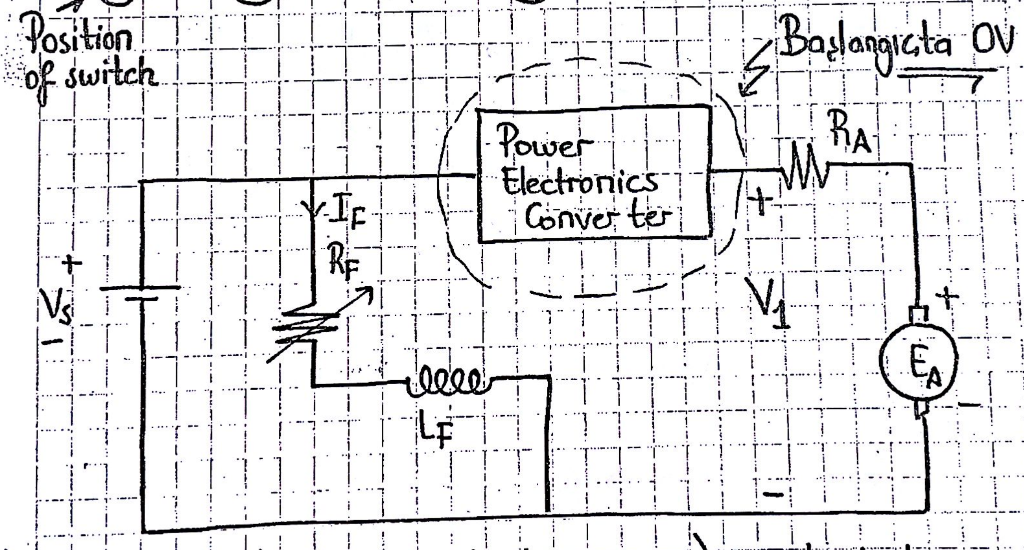
$$\omega(t=0) = 0 \rightarrow I_A(t=0) = \frac{V_S}{R_A + R_1 + R_2 + R_3 + R_4}$$

$\omega \uparrow \Rightarrow E_A \uparrow \Rightarrow I_A \downarrow$

with increasing of motor speed the armature current decreases

$$I_A = \frac{V_S - K\phi\omega}{(\text{-----})}$$

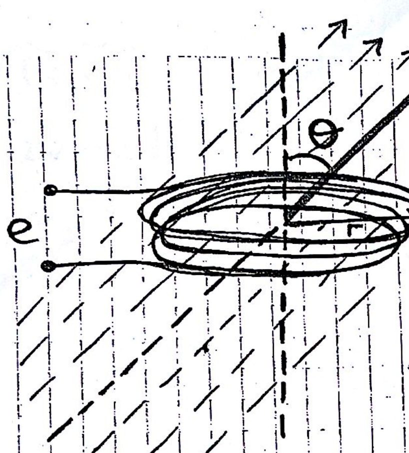




V_1 (voltage applied to motor) is adjusted using a converter.

V_1 is increased from zero up to voltage rating of motor.

Faraday's Law



$$e = -N \frac{d\phi}{dt}$$

N: turns number of coil

ϕ: magnetic flux (Weber)

$$B = \frac{\phi}{A}$$

Magnetic flux density (Tesla)

$$\phi = BA\cos\theta$$

$$e = -N \frac{d(BA\cos\theta)}{dt}$$

$$e = -NA \frac{d(B\cos\theta)}{dt}$$

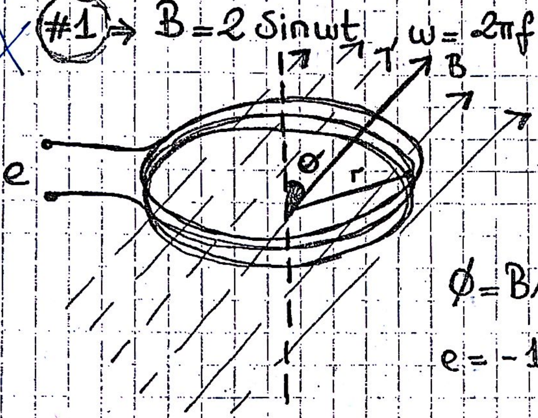
$\theta = 0° \Rightarrow \phi_{max}$

$\theta = 90° \Rightarrow \phi_{min}$

7 Nisan Perşembe 201

Quiz

#1 ⇒ $B = 2\,\mathrm{Sin}\,\omega t$, $\omega = 2\pi f$, $f = 50\,\mathrm{Hz}$, $N = 100$



$$e = -N\frac{d\phi}{dt}$$

$$\Rightarrow -100A\mathrm{Cos}\theta\frac{d\,2\mathrm{Sin}\omega}{dt}$$

$$\Rightarrow e = -200A\mathrm{Cos}\theta\,\omega\,\mathrm{Cos}\omega$$

$$e = -200A\,2\pi f\,\mathrm{Cos}\theta\,\mathrm{Cos}\omega$$

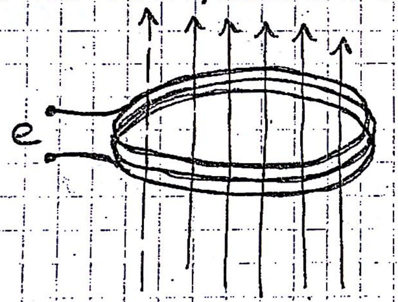
$$\phi = BA\mathrm{Cos}\theta$$

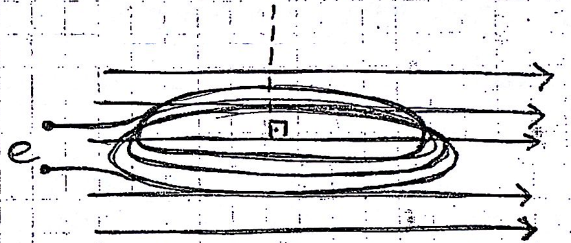
$$e = -100\frac{d\,BA\mathrm{Cos}\theta}{dt} = -100A\mathrm{Cos}\theta\frac{dB}{dt} = -100A\mathrm{Cos}\theta\frac{d}{dt}$$

$$e = -20000\pi A\mathrm{Cos}\theta\,\mathrm{Cos}\omega t$$

#2 ⇒ $B = 2\,\mathrm{Tesla}$ coil is stationary find $e = ?$

$$\left.\begin{array}{l} A = r^2\pi \\ \phi = AB\mathrm{Cos}\theta \end{array}\right\} \quad e = -100\frac{d\phi}{dt}$$





$\theta = 90°$

$\phi_{min} = 0$

ϕ_{max}

$\theta = 0°$

$$e = -N\frac{d\,BA\mathrm{Cos}\theta}{dt} \Rightarrow -NBA\frac{d\mathrm{Cos}\theta}{dt} = 0$$

(B, A, θ ⇒ constant variable)

#3 ⇒ $B = 2\,\mathrm{Tesla}$, the coil rotates with 3000 rpm

$$\theta = \omega t \longrightarrow \theta = \frac{3000}{60} \times 2\pi t = 100\pi t$$

$$e = -100\frac{d\,BA\mathrm{Cos}\theta}{dt} = -100AB\left(100\pi \cancel{t}\right)\mathrm{Sin}\theta$$

(B, A ⇒ constant) $e = 20000\pi A\ \mathrm{Sin}\,100\pi t$

#4 ⇒ B = 2 Tesla, The magnetic field rotates clockwise with speed of 3000 rpm and the coil rotates counterclockwise with the same speed, find e?

$\theta = \omega t \longrightarrow \theta = \left[\frac{3000}{60} \times 2\pi t\right] + \left[\frac{3000}{60} \times 2\pi t\right]$

$$\theta = 200\pi t$$

$$e = -100 \frac{dBA\cos\theta}{dt} = 100(2)(A)(200\pi)[\sin 200\pi t]$$

$$e = 40000\pi A (\sin 200\pi t)$$

#5 ⇒ B = 2 Tesla, the magnetic field and the coil rotates at the same direction with speed of 2000 rpm

$$e = -N\frac{d\phi}{dt} = -N\frac{dBA\cos\theta}{dt} = -\underbrace{NBA}_{}\frac{d\cos\theta}{dt} = 0$$

B, A, θ ⇒ Constant variable...

#6 ⇒ B = 2 Sinωt, coil and field rotates at the same direction with speed of 4000 rpm.

$$e = -N\frac{d\phi}{dt} = -N\frac{dBA\cos\theta}{dt} = -NA\cos\theta\frac{dB}{dt}$$

$$e = -NA\cos\theta\left(\frac{d\,2\sin\omega t}{dt}\right)$$

$$e = -NA\cos\theta\left[2\omega\cos\omega t\right]$$

#7 ⇒ $B = 2\sin\omega t$, the magnetic field rotates with speed of n_1 (clockwise) and the coil rotates with speed of n_2 (counter-clockwise), find e?

$$e = -N\frac{d\phi}{dt} \Rightarrow e = -N\frac{dBA\cos\theta}{dt} = -NA\frac{dB\cos\theta}{dt}$$

$$e = -NA\left[(\cos\theta)\frac{dB}{dt} + B\frac{d\cos\theta}{dt}\right]$$

$$\underbrace{\theta = \left[\frac{n_1}{60} \times 2\pi t\right] + \left[\frac{n_2}{60} \times 2\pi t\right]}$$

$$\theta = \frac{(n_1+n_2)}{60} \times 2\pi t$$

sec

$$e = -NA\left\{\left(\cos\frac{n_1+n_2}{60}2\pi t\right)\left[2\omega\cos\omega t\right] + (2\sin\omega t)\left(\frac{n_1+n_2}{60}2\pi\right)\sin\frac{n_1+n_2}{60}2\right.$$

$$e = -NA\left\{\left[\cos\left(\frac{n_1+n_2}{60}2\pi t\right)\right]\left[2\omega\cos\omega t\right] + \left[2\sin\omega t\right]\left[\frac{n_1+n_2}{60}2\pi\right]\sin\frac{n_1+n}{60}\right.$$

4/5 Soru Vize için
1- [illegible]
2- DC Machine (1 yada 2 soru)
3- Tanım
4- Trafo

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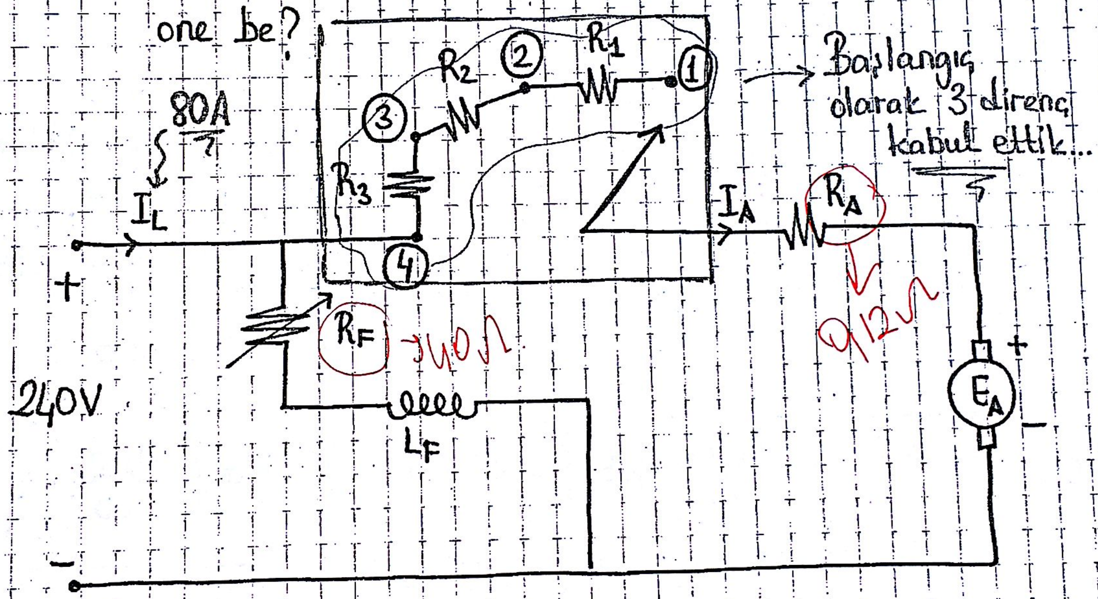
Example: An automatic starter circuit is to be designed for a shunt motor at 20hp, 240V and 80A. The armature resistance of the motor is 0.12Ω and the shunt field resistance is 40Ω. The motor is to start with no more than 250 percent of its rated armature current, and as soon as the current falls to rated value, a starting resistor stage is be cut out. How many stages of starting resistance are needed and how big should each one be?



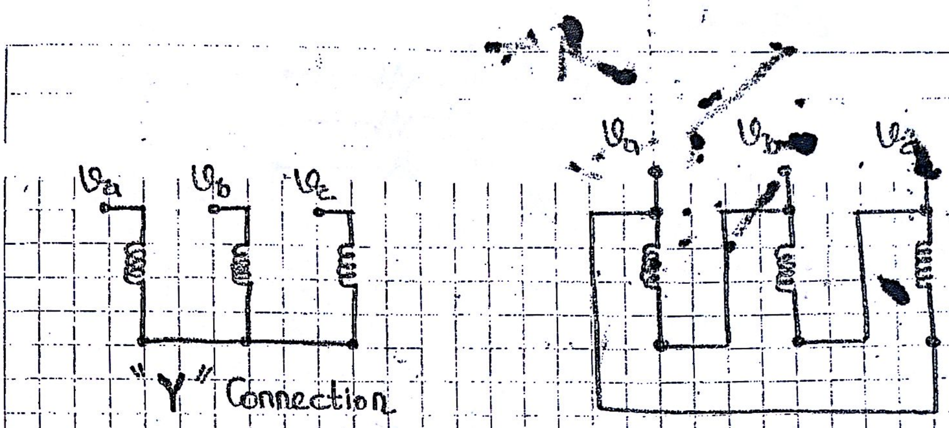
$R_A = 0.12\Omega$

$R_F = 40\Omega$

$$V_T = E_A + I_A R_A$$

$$V_T = K\phi\omega + I_A R_A$$

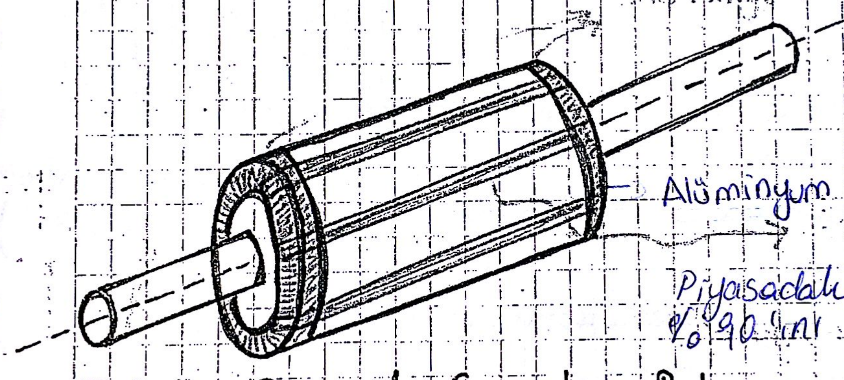
$$I_A = \frac{V_T - K\phi\omega}{R_A}$$



"Y" Connection

"Δ" Connection

Rotor
- a- Squirrel- Cage type
- b- Wound- Rotor type



Alüminyum yada bakır ile doldurulur (bir kafes gibi)

Piyasadaki endüksiyon motorlarının %90'ını böyledir.

Squirrel- Cage type Rotor → tel kullanılmaz, döküm olarak üretilir
(Sincap Kafes)

⊛ The squirrel-cage rotor consists of conducting bars placed in the slots and short circuited at both ends.

⊛ The wound rotor consists of a distributed windings, similar to that of stator.

The terminals of windings are brought out to slip-rings for external connection.

$$\cos(\theta+\omega t)+\cos(\omega t+\theta-240^\circ)+\cos(\omega t+\theta-480^\circ)=$$

$$\cos(\theta+\omega t)+\cos(\omega t+\theta-240^\circ)+\cos(\omega t+\theta-120^\circ)=0$$

$$F(\theta,t)=\frac{3}{2}F_{max}\cos(\omega t-\theta) \longrightarrow \text{Rotating Magnetic Field}$$

⊛ The rotating magnetic field rotates with a constant speed in the induction machine

⊛ The speed of this magnetic field is called as "synchronous speed", n_s.

⇒ n_s: the speed of "rotating magnetic field" (synchronous speed)

$$\boxed{n_s=\frac{120f}{P}} \rightarrow \text{rpm}$$

f: frequency of applied voltage or current
p: numbers of poles (even number)

$$\boxed{n_s=\frac{2f}{P}} \rightarrow \text{rps}$$

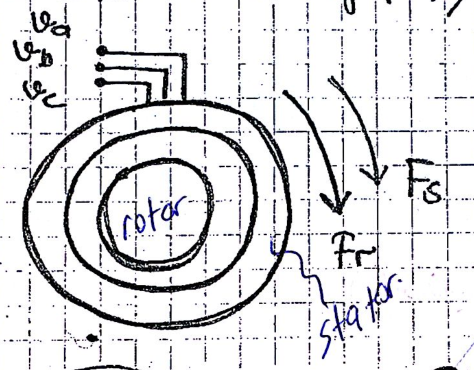
* 3 magnetic fields are produced inside the machine.
  ($H_{a^+a^-}$), ($H_{b^+b^-}$), ($H_{c^+c^-}$)
* A rotating ~~fie~~ magnetic fields is produced by these 3 magnetic fields.
* The speed of this magnetic field (rotating magnetic field) is constant and is equal to $\frac{120f}{P}$

$E_0 = \Phi, n, \quad \Phi I$

Operational Principles

- When the stator is excited with 3-phase balanced ac currents, a rotating mmf (F_s) is created in the air-gap.

- The rotating mmf (F_s) generated by stator will induce voltages and currents in the rotor windings which will create the rotor mmf (F_r)



r_1: resistance of stator windings
X_1: leakage reactance of stator winding.
r_2: rotor resistance
X_2: leakage reactance of rotor.

$$S = \frac{n_s - n_r}{n_s}$$

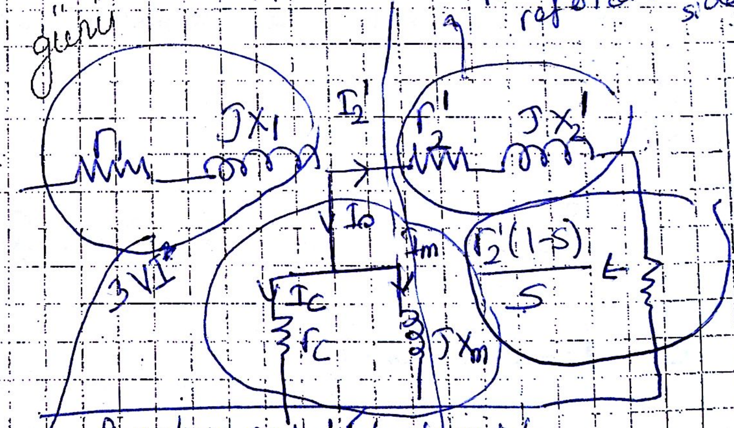
Slip

n_s: speed of rotating magnet field
n_r: the speed of rotor

$$n_r = (1-S)\,n_s$$

haftaya Perşembe günü Quiz 28 Nisan

equivalent circuit of rotor winding referred to stator side.



$$r_2' = \left(\frac{n_s}{n_r}\right)^2 r_2$$

$$X_2' = \left(\frac{n_s}{n_r}\right)^2 X_2$$

for phase equivalent circuit.

stator winding equivalent circuit

equivalent circuit of core

P_g (rotora geçen güç)

3 fazlı için $P = \sqrt{3}\, V_L I_L \cos\phi$

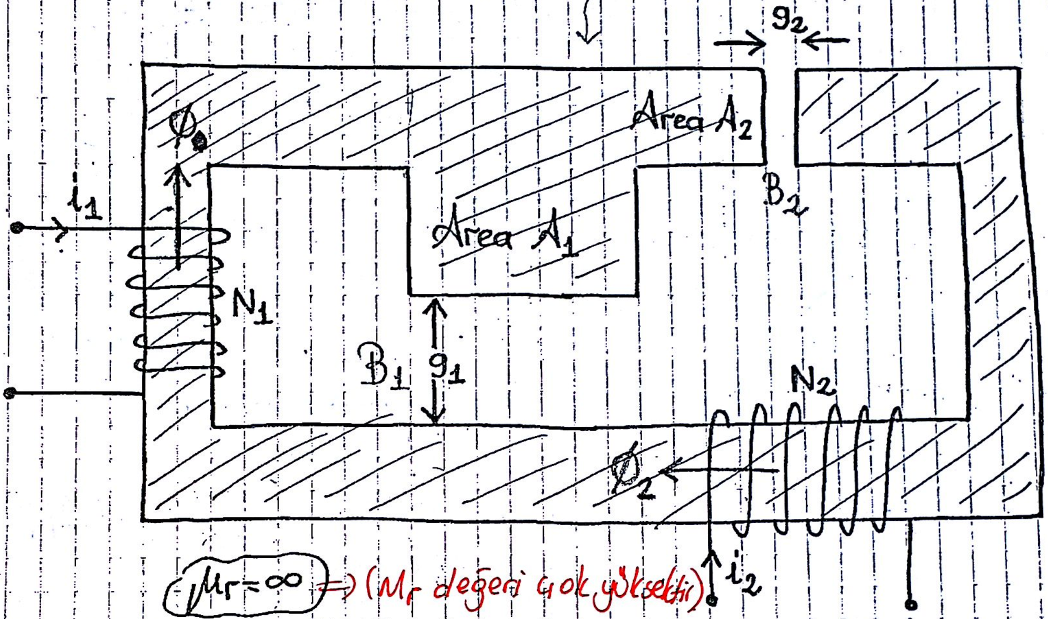
44-a

Midterm

Permability $\mu = \infty \Rightarrow$ nüve direnci $(R=0)$

Question # 1:

Sadece gap dirençleri hesaplanır...



$\mu_r = \infty \Rightarrow$ (μ_r değeri çok yüksektir)

a) $i_1 = I_1$, $i_2 = 0$

- Determine the magnetic flux of winding 1 ϕ_0
- Determine the magnetic flux of winding 2 ϕ_2
- Determine the magnetic flux densities of airgaps 1 and 2 B_1, B_2

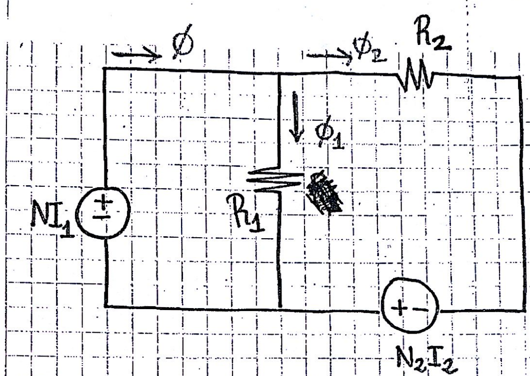
b) $i_1 = 0$; $i_2 = I_2$

Repeat the questions of part a

c) $i_1 = I_1$, $i_2 = I_2$

Repeat the questions of part a

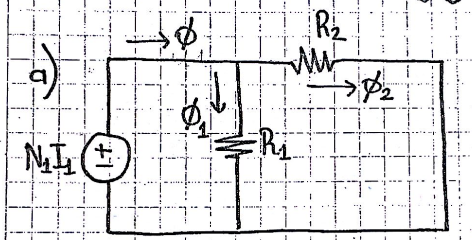
$\mu_0 = 4\pi \times 10^{-7}$



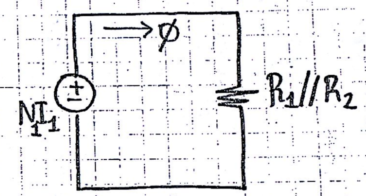
$$R_1 = \frac{g_1}{\mu_0 A_1}$$

$$R_2 = \frac{g_2}{\mu_0 A_2}$$

a)



$\Rightarrow$



$$R_1 // R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

$$N_1 I_1 = \phi (R_1 // R_2) = \phi \frac{R_1 R_2}{R_1 + R_2}$$

$$\phi = \frac{N_1 I_1 \left(\frac{g_1}{\mu_0 A_1} + \frac{g_2}{\mu_0 A_2} \right)}{\frac{g_1 g_2}{\mu_0^2 A_1 A_2}} = \frac{\mu_0 N_1 I_1 (g_1 A_2 + g_2 A_1)}{g_1 g_2}$$

Sargıdan geçen manyetik akı

$$\phi = \frac{N_1 I_1}{\frac{R_1 R_2}{R_1 + R_2}} = \frac{N_1 I_1 (R_1 + R_2)}{R_1 R_2}$$

$$\phi = \frac{N_1 I_1}{R_{g2}} \qquad \phi_1 = \frac{N_1 I_1}{R_{g1}}$$

$$\phi = \phi_1 + \phi_2$$

c) $\phi_1 = ?$

$\phi_2 = ?$

$B_1, B_2 = ?$

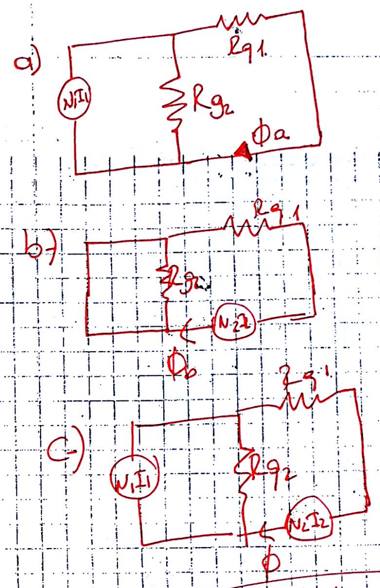
Devre Teorisi

$\phi_c = \phi_a + \phi_b$

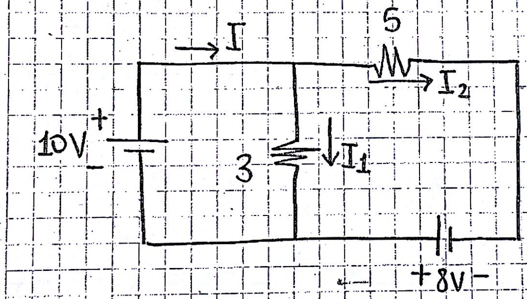
$\phi_{2c} = \phi_{2a} + \phi_{2b}$

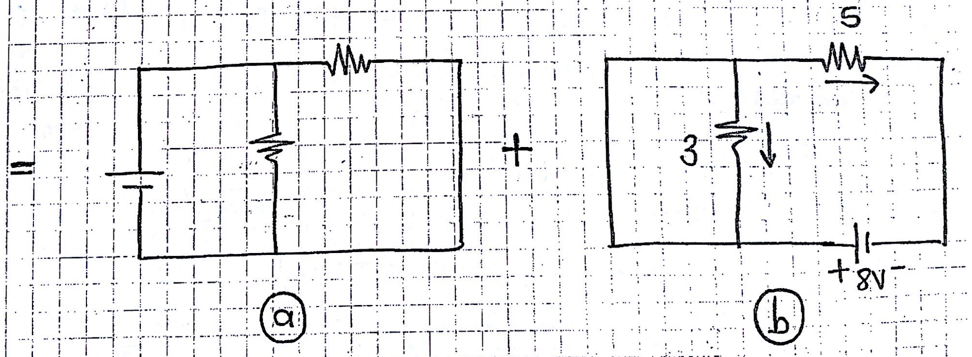
$B_{1c} = B_{1a} + B_{1b}$

$B_{2c} = B_{2a} + B_{2b}$

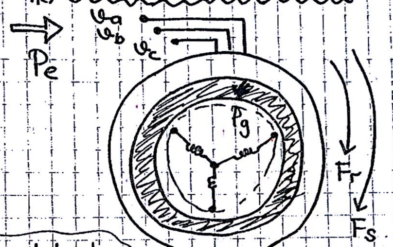


$\boxed{\phi = \phi_a + \phi_b}$





** Induction Machines:

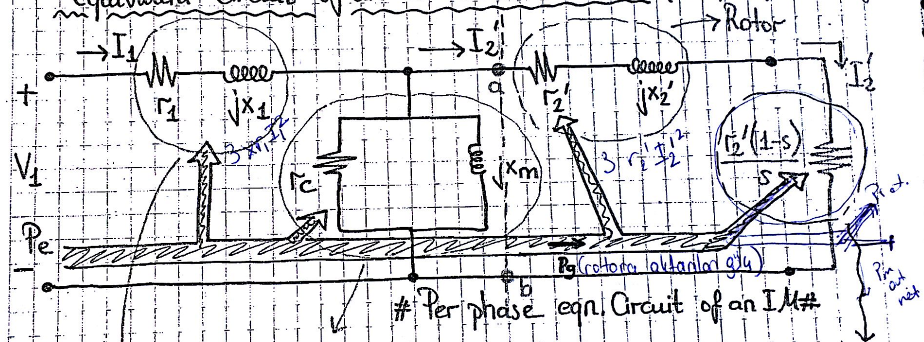


P_g: statordan rotora aktarılan güç

$$* n_s = \frac{120f}{P} \text{ (rpm)}$$

$$* n_s = \frac{2f}{P} \text{ (rps)}$$

Equivalent Circuit of an Induction Machine (IM)



Per phase eqn. Circuit of an IM

Equivalent Circuit of Stator Winding

Equivalent Circuit of Core $\frac{3V_C^2}{X_C}$

$P_e = \sqrt{3} V_1 I_1 \cos\phi$

Mekaniksel Güç

→ Elektriksel güç, mekaniksel güce dönüştürülür

$$P_{intm} = \frac{r_2'(1-s)}{s} * I_2'^2$$

internal mechanical power

For a 3_Phase IM

$$\boxed{P_{int.m} = 3 \times \frac{r_2'(1-s)}{s} I_2'^2}$$

Torque - Speed Characteristic of an IM

$$\boxed{P_m = \tau \omega_r}$$

P_m: Power (W) (mekaniksel güç)

τ: Torque (N.m)

ω_r: Angular Velocity of rotor (rad/sec)

$$\underbrace{3 \times \frac{r_2'(1-s)}{s} I_2'^2 = P = \tau \omega_r}$$

$$\boxed{\tau = \frac{3r_2'(1-s)}{s\omega_r} I_2'^2}$$

$$\boxed{s = \frac{n_s - n_r}{n_s} = \frac{\omega_s - \omega_r}{\omega_s}}$$

$n_r = (1-s)n_s$

$\omega_r = (1-s)\omega_s$

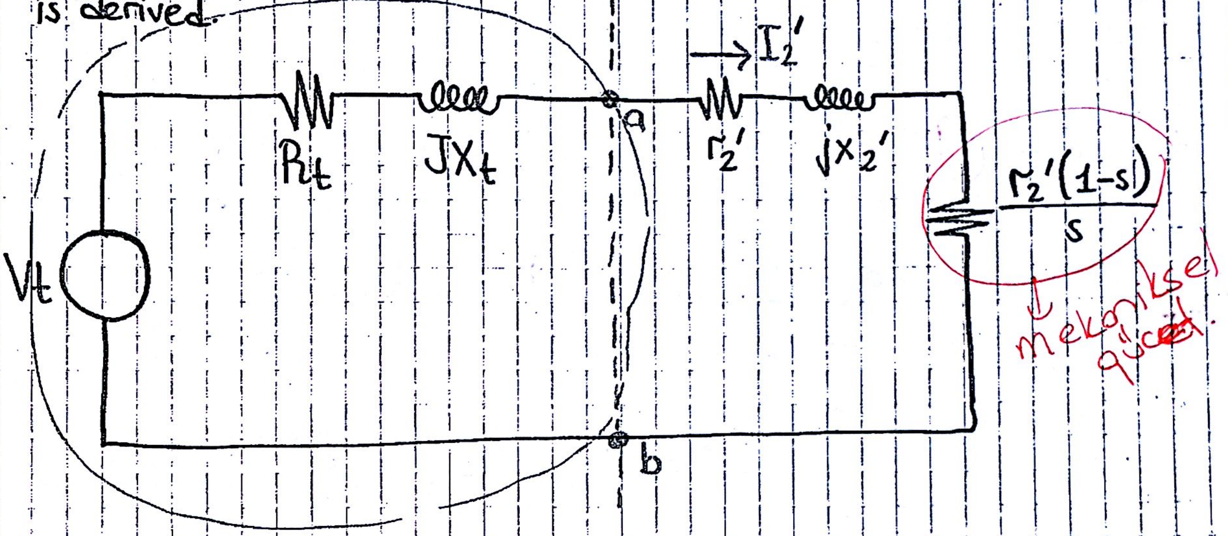
$$\boxed{\omega_r = (1-s)\omega_s} \checkmark$$

$$\Rightarrow \tau = \frac{3 \times r_2'(1-s)}{s(1-s)\omega_s} * I_2'^2 = \boxed{\frac{3r_2'}{s\omega_s} I_2'^2}$$

$$** \quad \boxed{\tau = \frac{3r_2'}{s\omega_s} I_2'^2}$$

MOTORUN PERFORMANS ANALİZİ

⇒ Using the Thevenin's Law the equivalent circuit between a and b is derived.



$$V_t = \frac{|(R_c // jX_m)|}{|(r_c // jX_m) + r_1 + jx_1|} * V_1$$

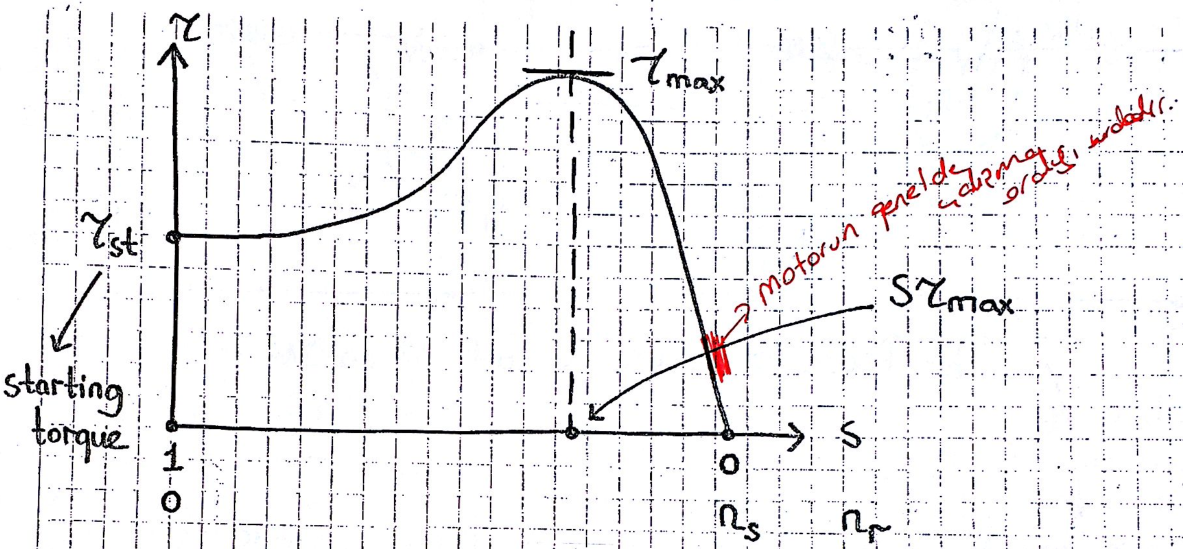
$$R_t + jX_t = (r_1 + jx_1) // r_c // jx_m$$

$$I_2' = \frac{V_t}{\sqrt{\left(R_t + \frac{r_2'}{s}\right)^2 + \left(X_t + X_2'\right)^2}}$$

$$P = \tau \cdot \omega_r \rightarrow \frac{rad}{s}$$

$$\tau = \frac{3r_2'}{s\omega_s} * \frac{V_t^2}{\left(R_t + \frac{r_2'}{s}\right)^2 + \left(X_t + X_2'\right)^2}$$

ASENKRON MOTORUN MOMENT – HIZ KARAKTERİSTİĞİ



τ–ω characteristic of an IM

S	n_r	n_s
0	n_{r_1}	n_{s_1}
0.1	n_{r_2}	n_{s_2}
0.2	n_{r_3}	n_{s_3}
|	|	|
|	n_r	n_s

$\tau(n=n_s)=0$

motor senkron hızda kuvvet oluşturamaz. Buna asenkron motor (induction motor) denir.

50-a

ω_r or ω_m → rotor → $\frac{n_r}{60} 2\pi$ (rpm)

ω_s → senkron hız → $\frac{n_s}{60} 2\pi$ (rpm)

60 → dakika

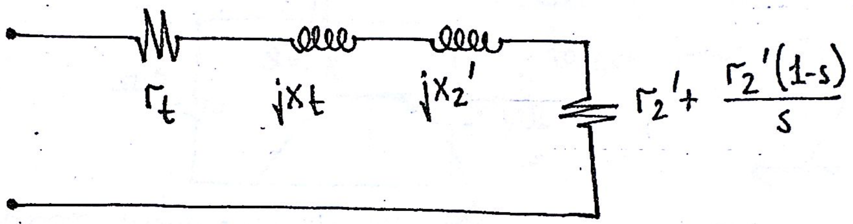
$$P_g = \tau \omega_s$$

→ senkron hız (sabit) $\left(\frac{120f}{P} = n_s\right)$

↳ şebeke frekansına bağlı (sbt)

⇒ τ is maximum if ($P_g = max$)

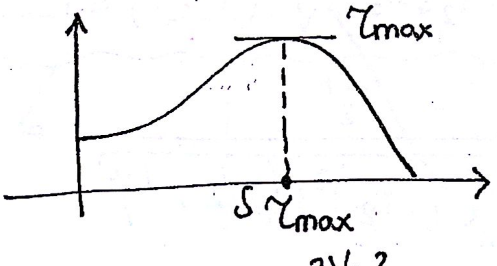
$$r_2' + \frac{r_2'(1-s)}{s} = \sqrt{r_t^2 + (x_t + x_2')^2}$$



$$\frac{r_2'}{s} = \sqrt{------}$$

$$s = \frac{r_2'}{\sqrt{r_t^2 + (x_t + x_2')^2}} = s_{\tau max}$$

→ max torque ⇒ ✱



II. yol → $$\tau = \frac{1}{\omega_s} * \frac{3V_t^2}{\left(r_t + \frac{r_2'}{s}\right)^2 + (x_t + x_2')^2} * \frac{r_2'}{s}$$ $y = f(x)$

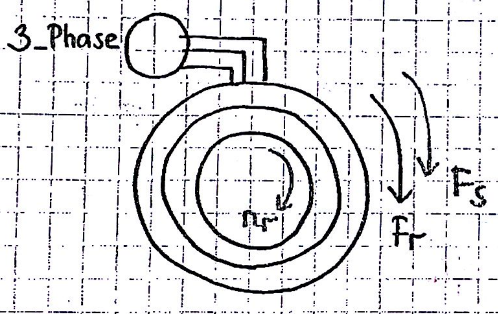
$$\left(\frac{d\tau}{ds} = 0\right) \longrightarrow s_{\tau max} \Rightarrow \tau_{max} ✓$$

3-phase AC system
line-to-line

28 Nisan 2011

Example: A 208 volt, 10Hp, 60Hz 4pole Y-connected induction motor has a full load slip of 5% $\longrightarrow$ $s = 5\%$

a) what is the synchronous speed of this motor?
b) what is the rotor speed of this motor at the rated load?
c) what is the rotor frequency of this motor at the rated loa
d) what is the shaft torque of this motor at the rated load



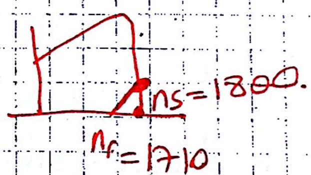
$F_s \Rightarrow$ Rotating magnetic field (stator)

$F_r \Rightarrow$ Rotating magnetic field (rotor)

n_s = synchronous speed (the speed of rotating magnetic field)

$$n_s = \frac{120f}{P} \longrightarrow$$ f: frequency of 3-phase ac system
P: # of poles

a) $n_s = \dfrac{120 \times 60}{4} = \underline{1800 \text{ rpm}}$

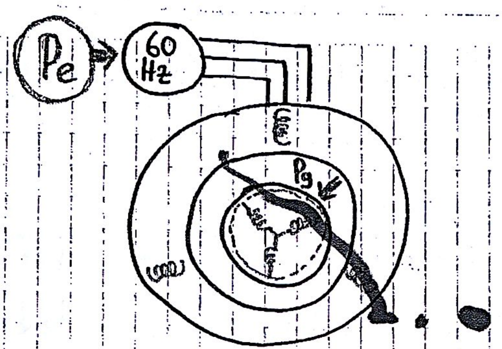


b) n_r = rotor speed = ?

$$s = \frac{n_s - n_r}{n_s} \Rightarrow \frac{5}{100} = \frac{1800 - n_r}{1800}$$

$$n_r = (1 - 0.05) \times 1800 = 1710 \text{rpm}$$

stator frekansı şebekeye bağlıdır.



c) fr: frequency of current or voltage of rotor windings

$f_r = s f_s$

$f_r = (0.05) \times (60\text{Hz}) = 3\text{Hz}$

d) $\tau_{rated} = ?$

$P = \tau \omega_r \longrightarrow P = 10 \times 746 = 7460\text{Watt}$

$7460 = \tau \times \frac{1710}{60} \times 2\pi$ nr

$\tau = 41{,}7\ (\text{N.m})$

Pout, net
(çıkış gücü)
motordan alınabilecek faydalı güç

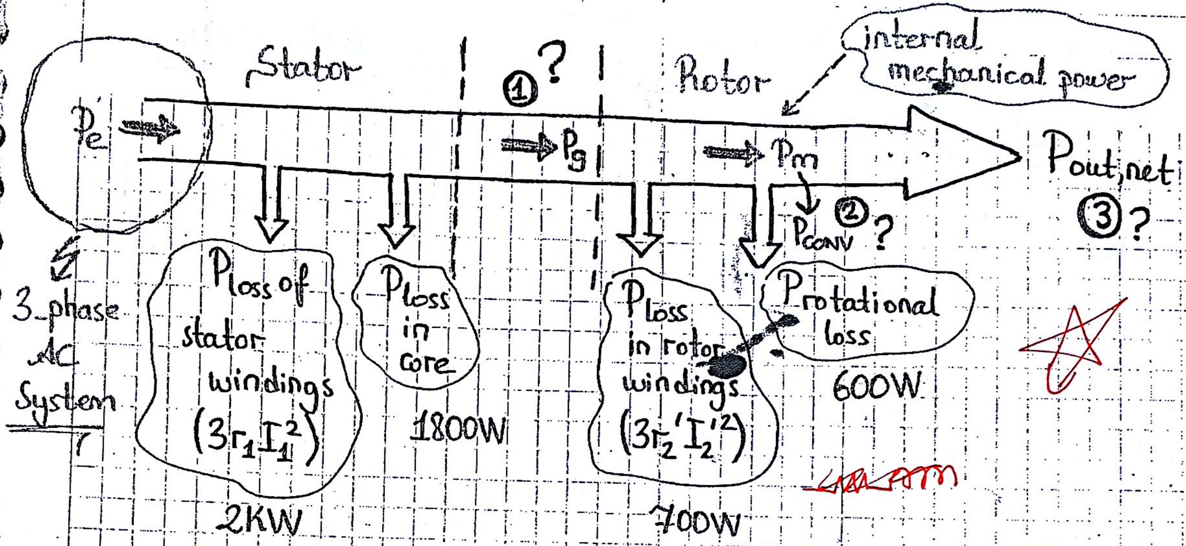
1hp = 746 Watt

Example: A 480-V, 60Hz, 50 HP 3-phase induction motor is drawing 60 A at 0.85 PF lagging.

The stator copper losses are 2KW, and the rotor copper losses are 700W.

The friction and windage losses are 600W, the core losses are 1800W and the stray losses are neglected. Find;

a) the air-gap power, $P_g = ?$
b) the power converted?
c) power converted.
d) the efficiency of the motor?



Solution:

$$P_{in} = \sqrt{3}\, V_{LL}\, I_L \cos\phi$$

$$P = \sqrt{3}(480)(60)(0.85)$$

$$P_e \Rightarrow P = 42400\,W$$ → motorun elektrik şebekesinden çektiği güç $= P_e$

a) $P_g = P_e - 2K - 1800$

$$P_g = 42400 - 2000 - 1800 = 38600\,W$$

2Kw copper, core loss

b) $P_{conv} = P_m$

$$P_m = P_g - 700 \Rightarrow P_{conv} = 38600 - 700$$

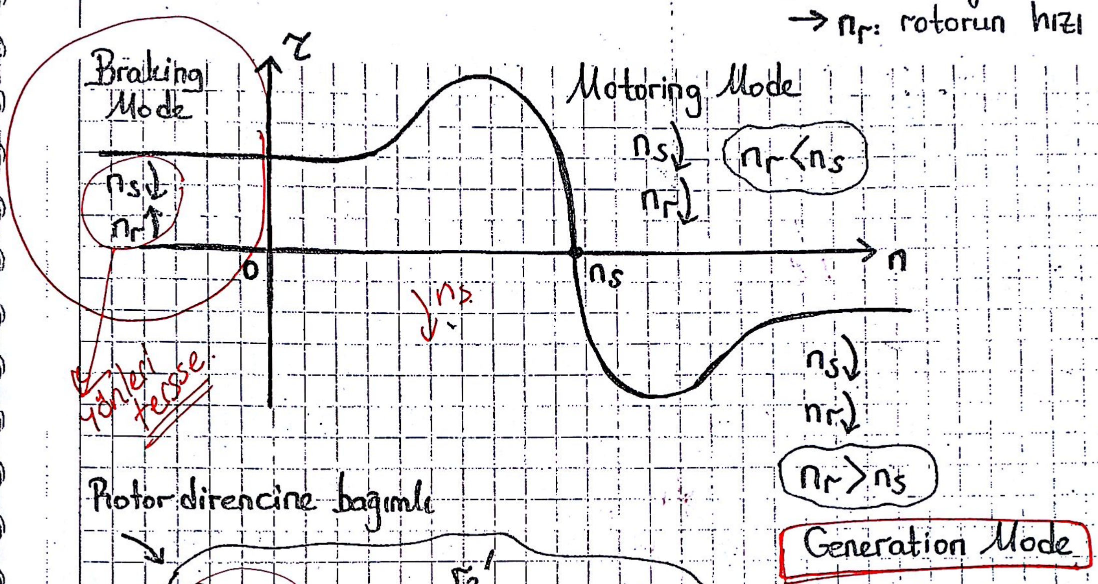
P_{cur}

$$P_{conv} = 37900\,W$$

c) $P_{out,net} = 37900 - 600 = 37300\,W$

d) $\eta = \frac{37300}{42400} \times 100 = 88\% = \frac{P_{out}}{P_{in}} \times 100$

(senkron hızı)
→ n_s: dönen manyetik alanın hızı
→ n_r: rotorun hızı



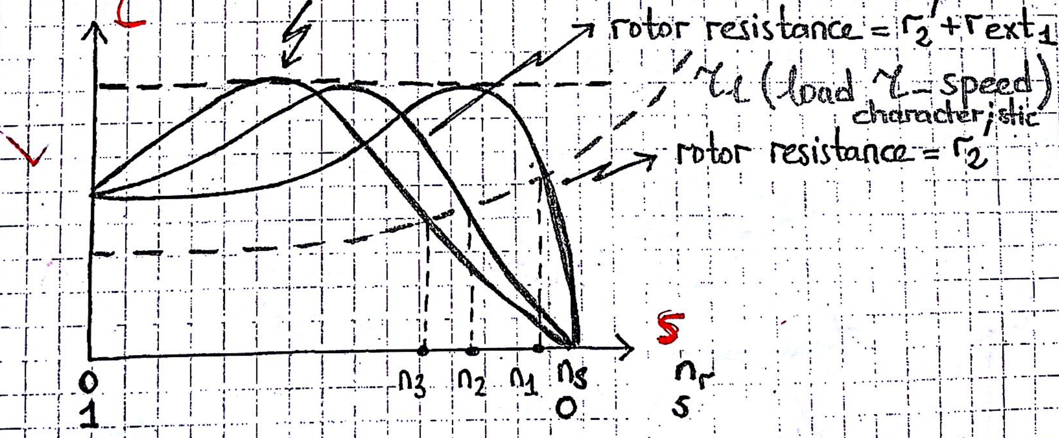
Rotor direncine bağımlı

$$S_{\tau max} = \frac{r_2'}{\sqrt{r_t^2 + (x_t + x_2')^2}}$$

$$\tau_{max} = \frac{\left(\frac{1}{2} \times 3V_t^2\right)}{(\omega_s) \times \left(r_t + \sqrt{r_t^2 + (x_t + x_2')^2}\right)}$$

Rotor direncinden bağımsız

rotor resistance $= r_2' + r_{ext_2}$



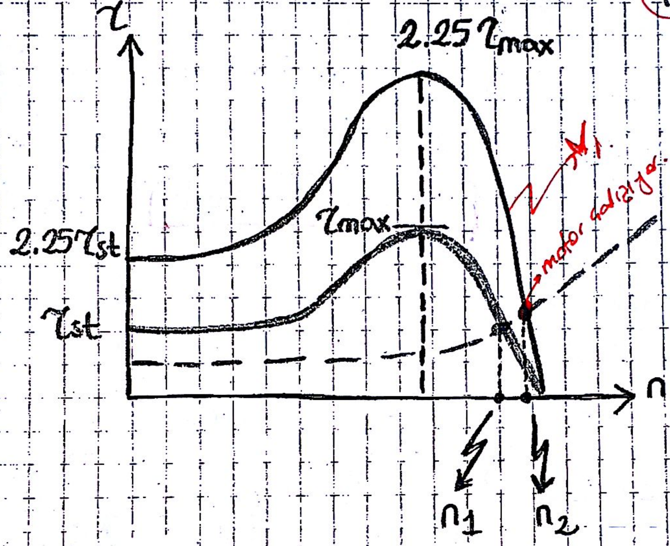
$r_{ext_2} > r_{ext_1}$ → τ_{max} does not depend on the rotor resistance, but $S_{\tau max}$ depends.

$$\tau = \frac{1}{\omega_s} \times \frac{3 \times \frac{1}{2} V_t^2}{\left(r_t + \frac{r_2'}{s}\right)^2 + \left(x_t + x_2'\right)^2} \times \frac{r_2'}{s}$$

$\tau \propto V_t^2$

(i) * Speed control of an IM by varying the applied voltage

* The generated torque is proportional with V_t^2



$V_{t_1} = 1.5V_t$

$n_2 > n_1$

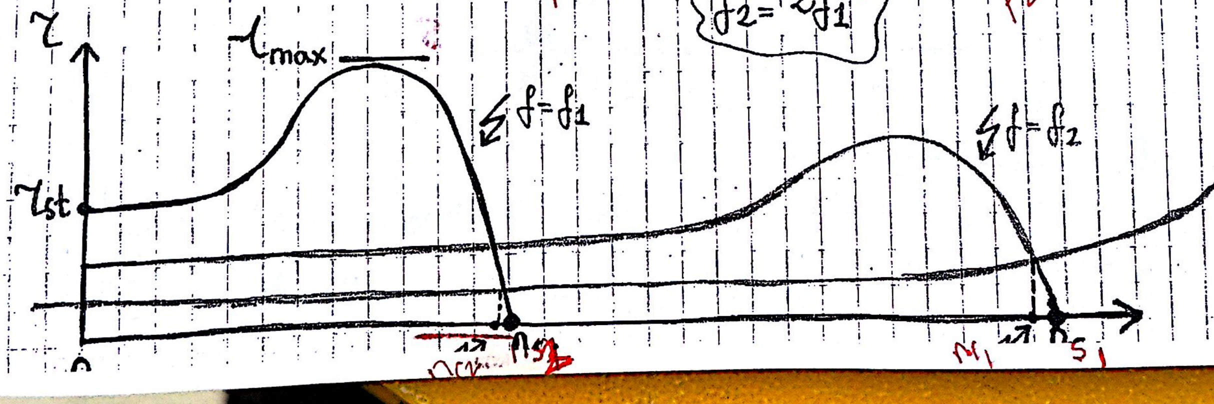
(ii) * The speed of motor can be adjusted by varying the rotor resistance

(iii) * The speed control by varying synchronous speed, n_s.

$n_s = \frac{120f}{P}$ → pole

$f_2 = 2f_1$

$P_2 = 2P_1$



54-a

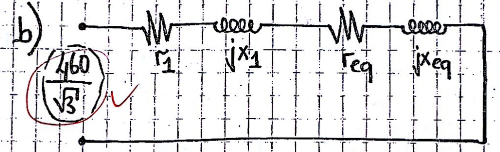
$n_s = \frac{2f}{P}$ } devir dakika

$n_s = \frac{2\times 60\times f}{P} = \frac{120f}{P}$ } devir saniye

a) $s = \frac{n_s - n_r}{n_s}$, $n_s = \frac{120f}{P}$ $\Rightarrow$ $n_s = \frac{120\times 60}{4} = \underline{\underline{1800\ rpm}}$

$\frac{2.2}{100} = \frac{1800 - n_r}{1800}$ $\Rightarrow$ $\underline{\underline{n_r = 1760\ rpm}}$

b)



$r_{eq} + jx_{eq} = (jx_m) \| \left[\frac{0.332}{0.022} + j0.464 \right] = \underline{\underline{12.94 \angle 31.1\ \Omega}}$

$0.332 + \frac{0.332(1-s)}{s} = \frac{0.332}{s}$

$r_{eq} = 12.94\ \cos(31.1°)$

$x_{eq} = 12.94\ \sin(31.1°)$

Voltaj

$I_1 = \frac{\frac{460}{\sqrt{3}} \angle 0° = 266 \angle 0°}{0.641 + j1.106 + 12.94\cos(31.1) + j12.94\sin(31.1)} = \underline{\underline{18.88 \angle -33.6°\ A}}$

Akım

endüktif devre.

c) $PF = \cos\phi \angle \frac{I}{V}$

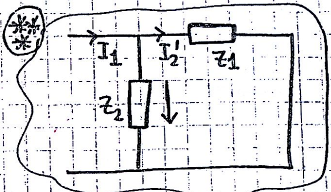
ϕ (between V and I) $= 33.6°$ (Akım geride) (lagging)

$PF = \cos(33.6°) = \underline{\underline{0.833}}$

d) $P_{m,int}$ OR $P_{conv} = 3 \times \frac{r_2'(1-s)}{s}(I_2')^2$

$r_2' = 0.332$

$s = 0.022$



$\Rightarrow \frac{Z_2}{Z_1+Z_2}$

$\underbrace{}_{I_2'}$

$$I_2' = \frac{jX_m}{jX_m + \frac{r_2'}{s} + jX_2'} I_1$$

$$I_2' = \frac{j26.3}{j26.3 + \frac{0.332}{0.022} + j0.464} * 18.88\angle -33.6°$$

Haftaya Çarşamba Quiz

11 Mayıs 2011

$P_{m,int}$ OR $P_{conv} = 11585W$

$P_{out} = (P_{m,int} \text{ OR } P_{conv}) - P_{rotational}$

$= 11585 - 1100 \Rightarrow \underline{P_{out} = 10485W}$

e) $P = \tau \omega_r$

$n_r = 1760 \text{ rpm} \rightarrow \omega_r = \frac{1760}{60} 2\pi$

$P_{m,int} = \tau_{m,int} \omega_r$

$11585 = \tau_{m,int}\left(\frac{1760}{60} 2\pi\right)$

$\tau_{m,int} = 62.8 \text{ N.m}$

$$\tau_{out} = \tau_{load} = \frac{P_{out}}{\omega_r} = \frac{10485}{\left(\frac{1760}{60} \times 2\pi\right)} = 56.9 \text{ N.m}$$

f) $\text{efficiency} = \eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{10485}{P_{in}} \times 100 = 83.7\%$

$P_{in} = \sqrt{3}\, V_{line\ to\ line}\, I_L \cos\phi$

$P_{in} = \sqrt{3} \times 460 \times 18.88 \cos(33.6) = 12530W$