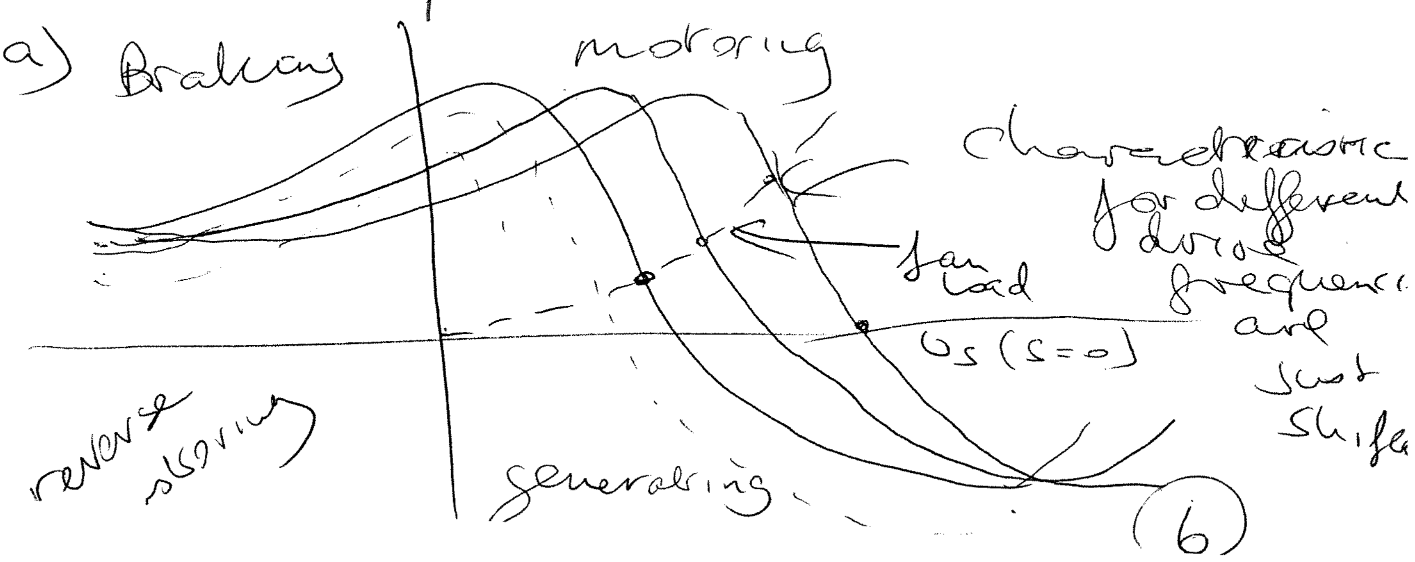
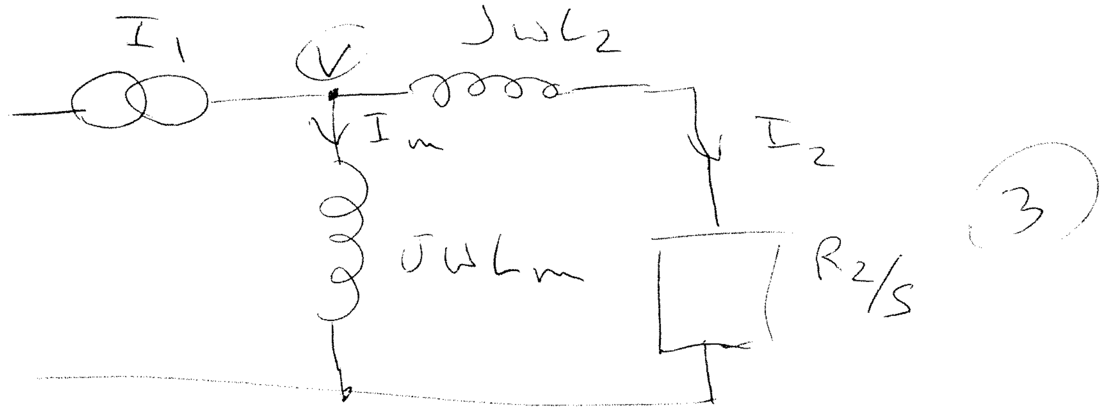
3B4 2003 exam Crib.

T. COOMBS

1 a)



b)



$$V = j\omega L_m I_m$$

$$I_2 = \frac{V}{(j\omega L_2 + R_2/s)} = \frac{j\omega L_m I_m}{(j\omega L_2 + R_2/s)}$$

$$I_1 = I_m + I_2 = I_m + \frac{j\omega L_m I_m}{(j\omega L_2 + R_2/s)}$$ (4)

$$I_1 = I_m \frac{(j\omega L_2 + R_2/s + j\omega L_m)}{j\omega L_2 + R_2/s} \Rightarrow I_1 = I_m \sqrt{\frac{(R_2/s)^2 + \omega^2 L_2 + L_m}{(R_2/s)^2 + (\omega L_2)^2}}$$

c) $I_{mag} = \dfrac{\frac{6.6\times10^3}{\sqrt{3}}}{60} = 63.5A.$

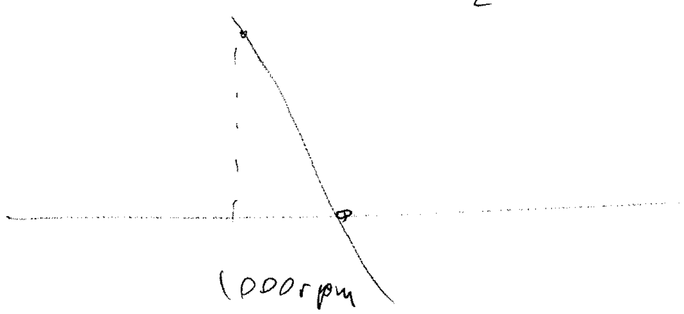
$$400 = I_{mag}\sqrt{\frac{0.1^2+\omega_2^2\left(\frac{62.4}{1000}\right)^2}{0.1^2+\omega_2^2\left(\frac{2.4}{1000}\right)^2}}$$

$$400 = 63.5\sqrt{\frac{0.1^2+\omega_2^2\left(\frac{62.4}{1000}\right)^2}{0.1^2+\omega_2^2\left(\frac{2.4}{1000}\right)^2}}$$

$\Rightarrow \omega_2 = 3.227$

Assume a straight line characteristic

solve for s
when $\omega_2 = s\omega$



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$(1-s)\omega = \dfrac{1000\times2\pi}{60}$

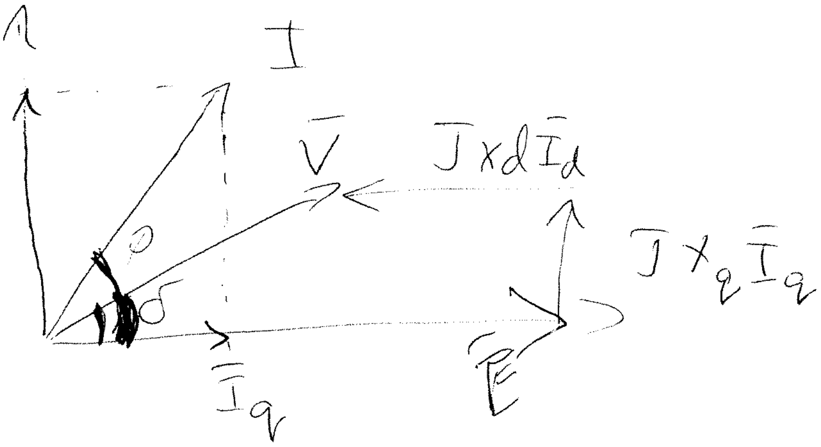
$s\omega = 3.23$

$\Rightarrow \omega = 107.9$

$f = 17.2Hz.$

2 a)

(4)



$I_q = I\cos(\phi+\delta)$

$I_d = I\sin(\phi+\delta)$

$\tan\delta = \frac{X_q I_q}{V\cos\delta} = \frac{X_q I\cos(\phi+\delta)}{V\cos\delta}$

$\tan\delta = \frac{X_q I}{V}\left(\cos\phi - \frac{\sin\phi\sin\delta}{\cos\delta}\right)$

(5)

$\Rightarrow \tan\delta\left(\frac{V}{X_q I}\right) + \cancel{\frac{A}{\cos\delta}}(\sin\phi) = \cos\phi$

$\Rightarrow \tan\delta = \left(\frac{I X_q\cos\phi}{V + I X_q\sin\phi}\right)$

b) i) $P = 3VI\cos\phi$

$= 3\times\frac{6.6\times10^3}{\sqrt{3}} I\times1 = 10\times10^6$

$\Rightarrow I = \cancel{4374A}$ 875 A

from a) $\delta = \tan^{-1}\left(\frac{X_q\times I_q}{V}\right) = 16.6^\circ$

(4)

$E = V\cos\delta + X_d I_d = 3651 + 1.8\times875\times\sin 16.6$
$= 4{,}101V$

2 contr.

b) ii) $P = 3(VI_q\cos\delta + VI_d\sin\delta)$

But: $X_qI_q = V\sin\delta$

and $X_dI_d = E - V\cos\delta$

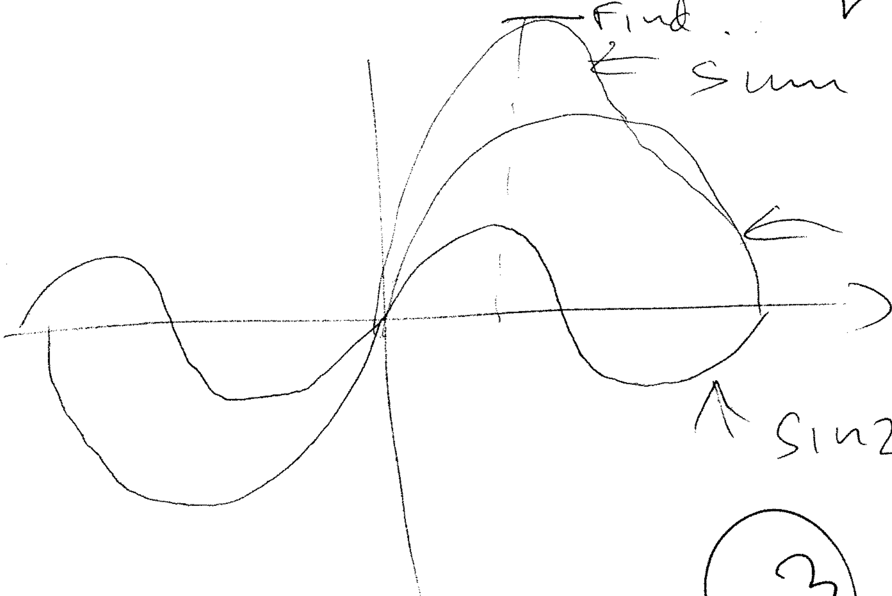
$$\Rightarrow P = 3V\left(\frac{V\sin\delta\cos\delta}{X_q} + \frac{(E - V\cos\delta)\sin\delta}{X_d}\right)$$

4

$$= \frac{3VE\sin\delta}{X_d} + 3V^2\left(\frac{\sin\delta\cos\delta}{X_q} - \frac{\sin\delta\cos\delta}{X_d}\right)$$

$$T\omega_s = \frac{3VE\sin\delta}{X_d} + \frac{3V^2}{2X_d\cancel{X_q}}(X_d - X_q)\sin 2\delta$$

iii)



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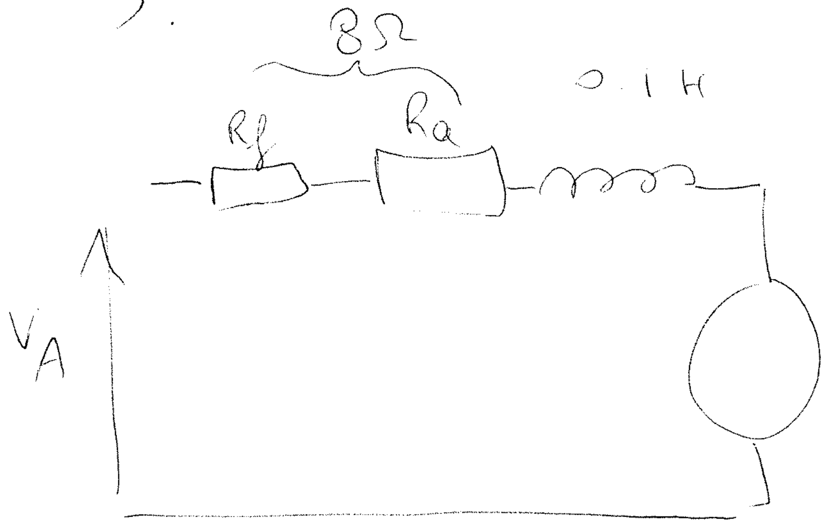
3. a)



$e_a = K' I_f \omega$

$= K' \times 2.8 \times \frac{\overbrace{4500 \times \pi \times 2}^{\omega}}{60}$

$e_a = 240 - 2.8 \times 8 = 217.6$

$\Rightarrow \quad K' = 0.165$

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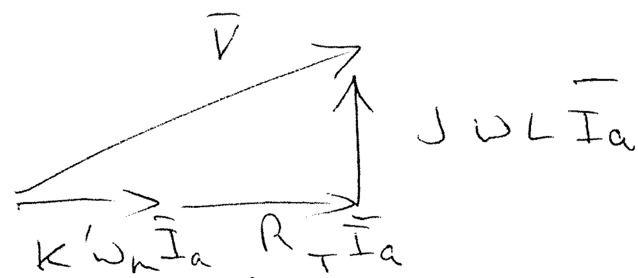
$P_{out} = e_a i_a = 609W = T\omega$

$\Rightarrow T = 1.3 Nm$

b) $\bar{V}_a = \bar{e}_a + j\omega L \bar{I}_a + (R_f + R_a)\bar{I}_a$

$= K' I_a \omega_{mech} + j\omega L_a \bar{I}_a + (R_f + R_a)\bar{I}_a$



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from the diagram.

$240^2 = ((100\pi \times 0.1) \times 2.8)^2 + (0.165\,\omega_{mech} \times 2.8 + 8 \times 2.8)^2$

i) $\Rightarrow \omega_{mech} = 435 \text{ rad s}^{-1} \approx 4151$ rpm (2)

ii) Torque is unchanged ie 1.3 Nm (1)

iii) $\cos\phi = \frac{(R_f + R_a)I_a + k'\omega_m I_a}{V}$

$= \frac{8 \times 2.8 \times 0.165 \times 435 \times 2.8}{240}$

$= 0.931$ lagging (2)

iv) $\text{Power}_m = \omega T = 566$

Power efficiency $= \frac{566}{566 + 2.8^2 \times 8} \times 100$ (1)

$= 90\%$

DC motor gives greater Torque because it has a lower series impedance. Hence current is greater for the same speed (ie the same back emf).

c) Power dissipated as heat $= 2.8^2 \times R$
$P_m = 63W$.

$C\frac{d\theta}{dt} = P_m - k(\theta - \theta_0)$

$-C\int_{40}^{70} \frac{d\theta}{-P_m + k(\theta - 18)} = 90$

$-\frac{C}{k}\left(\ln\left(-\frac{63}{k} + (\theta - 18)\right)\right)\Big|_{40}^{70} = 90$

$$-\frac{c}{k}\ln\left(\frac{70-63/k-18}{40-63/k-18}\right)=90$$

Also (when switched off)

$$-\frac{c}{k}\Big[\ln(\theta-18)\Big]_{70}^{40}=45$$

$$-\frac{c}{k}\left(\ln\frac{22}{52}\right)=45$$

$$\Rightarrow c/k=52.3$$

$$52-\frac{63}{k}=\left(22-\frac{63}{k}\right)\cancel{\;}\,e^{-(90/52.3)}$$

$$=\left(22-63/k\right)\times 0.179$$

$$\Rightarrow k=1.075$$

$$c=55.9$$

$$52=22e^{-(90/52.3)}+\frac{63}{k}\left(1-e^{-90/52.3}\right)$$

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(4)

a) $F(\theta, I) = \frac{2NI}{\pi} \cos(p\theta)$

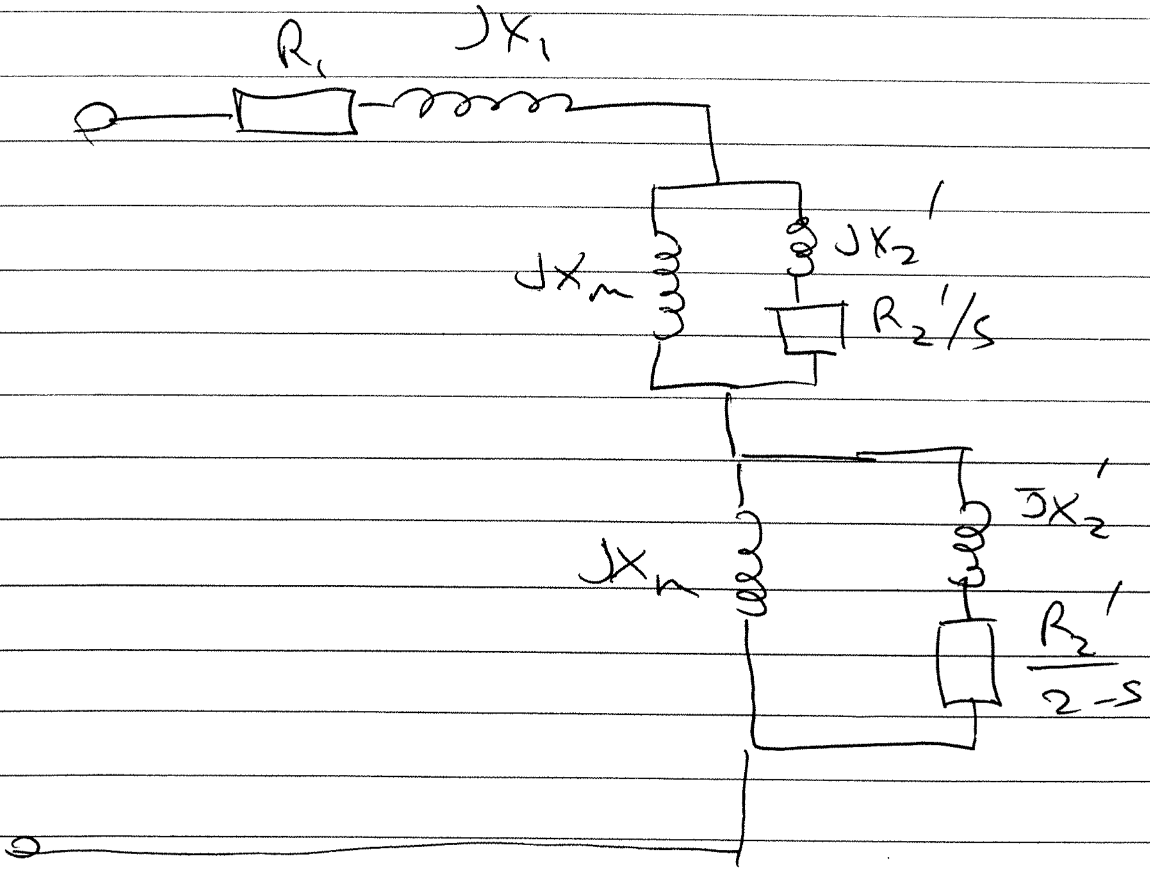
$I = \hat{I} \cos \omega t$.

$F = \frac{2N\hat{I}}{\pi} \cos(\omega t) \cos(p\theta)$

4

$\Rightarrow F = \frac{N\hat{I}}{\pi} \left(\underset{\uparrow \text{ forward}}{\cos(\omega t - p\theta)} + \underset{\uparrow \text{ backward}}{\cos(\omega t + p\theta)} \right)$

b)



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Forward $= R_2'/s$ ie for small s forward impedance is large backward is small

Backward $= R_2'/(2-s)$

When the motor is stationary the two are equal.

c) $\bar{Z}_f = \dfrac{jX_m(jX_2' + R_2/s)}{jX_m \cancel{\ell} + jX_2' + R_2/s}$

$= \cancel{(jX_m(jX_2' + R_2/s))(}$

$\left(j\dfrac{X_m R_2}{s} - X_m X_2'\right) \times \left(j(X_m + X_2') - R_2/s\right)$

$-\left((X_m + X_2')^2 + \left(\dfrac{R_2'}{s}\right)^2\right)$

$Re(\bar{Z}_f) = \dfrac{\dfrac{s^{\cancel{2}} X_m^2 R_2'}{\cancel{s}}}{s^2(X_m + X_2')^2 + \left(\dfrac{R_2'}{\cancel{s}}\right)^2}$ (2)

$Re(\bar{Z}_b) = \dfrac{(2-s) X_m^2 R_2'}{(2-s)^2(X_m + X_2')^2 + (R_2')^2}$

$\boxed{P = 3I^2 \left(Re(\bar{Z}_f) - Re(\bar{Z}_b)\right)}$ (1)

when $P = 0$; Torque $= 0$

$\Rightarrow \quad 0 = \dfrac{s}{s^2(X_m + X_2')^2 + R_2'^2} - \dfrac{(2-s)}{(2-s)^2(X_m + X_2')^2 + R_2'^2}$

use $A = (R_2')^2 \quad B = (X_m + X_2')^2$

$\Rightarrow \quad 0 = \dfrac{s}{s^2 B + A} - \dfrac{(2-s)}{(2-s)^2 B + A}$

(9)

$$\Rightarrow 0 = 4sB - 4Bs^2 + s^3B + As.$$

$$- 2Bs^2 + Bs^3 - 2A + sA$$

collecting terms we get.

$$0 = -2A + s(A + 4B) \cancel{+ - s^2(4B)} 6Bs^2 + 2Bs^3$$

we know that $(s-1) = 0$ is one of the solutions.

$$\Rightarrow 0 = (s-1)(s^2 + 2s + A/B) = 0.$$

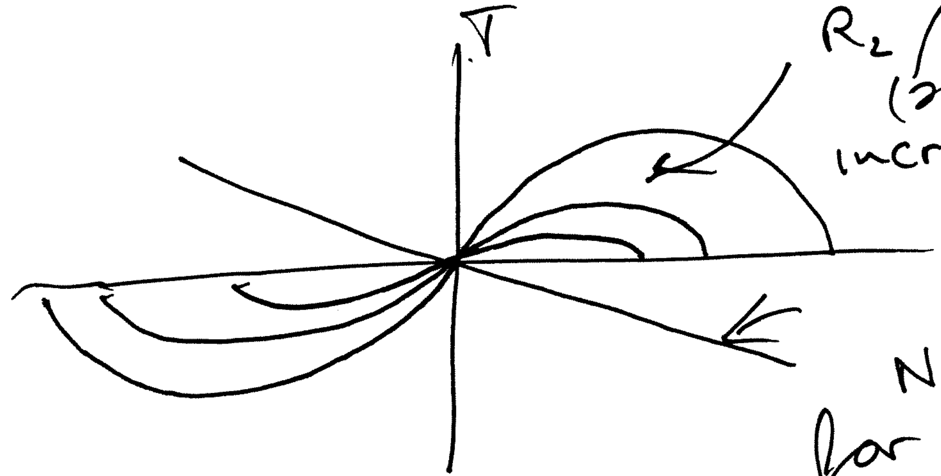
$$\Rightarrow s = +/- \sqrt{\frac{4 - 4A/B}{4}}$$

$$\Rightarrow s = 1 \pm \sqrt{1 - \left(\frac{R_2'}{(X_m + X_2')}\right)^2} \quad (3)$$

Due to the backward wave T is actually negative at synchronous speed

(1)

d)



No solution for $R_2/(x_2 + x_2') > 1$

(2)