3B4 2010

2010 PART IIA 3B4 ELECTRIC DRIVE SYSTEMS
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1 a/ $VA = S = \frac{\pi}{\sqrt{2}} \cdot \frac{\pi d^2 l}{2} \cdot \frac{\omega}{p} \bar{B} \bar{J}$

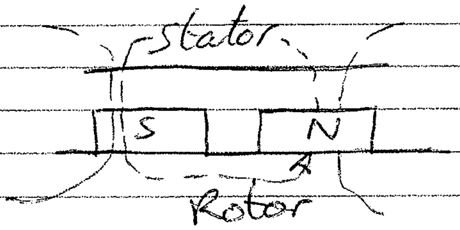
Volume speed 3

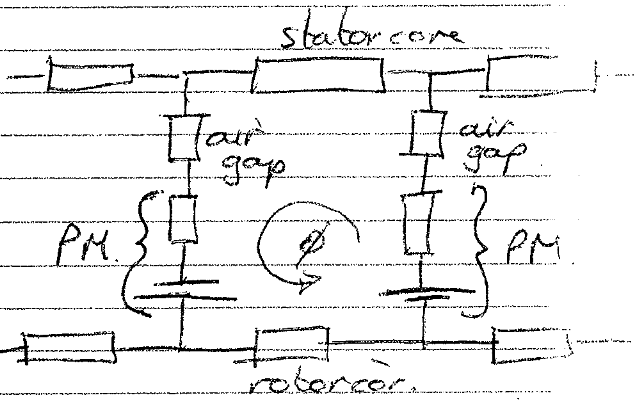
$\therefore$ volume $\propto 1/\text{speed}$ 3

By Faraday $V \propto \bar{B} \frac{\omega}{p}$ $\bar{B}$ average flux over one pole
Current $\propto \bar{J}$

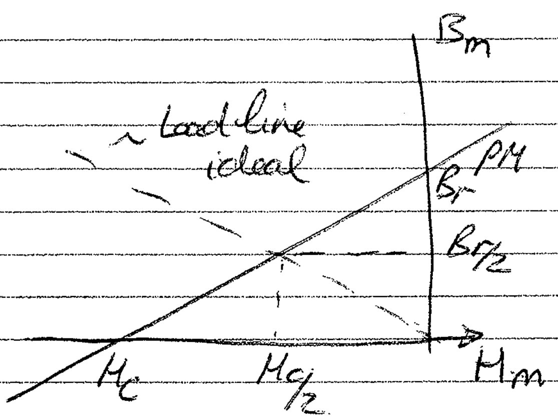
The number of poles pairs is p. For a speed and volume a higher p means a higher ... not used
Limitation is iron losses and switching/skin effect

(b)





4



Neglect iron

$H_m l_m + H_g l_g = 0$ ①

$B_g A_g = B_m A_m$ ~~say~~

(full pitch PM $A_g = A_m$)

$B_g = \mu_0 H_g$

Subs. into ①

$B_m = -\mu_0 \frac{H_m l_m}{A_m} \cdot \frac{A_g}{l_g}$ load line

For a PM $B_m = \mu_m H_m + B_r$

$$B_m - B_r = \frac{B_m}{(\ )} \Rightarrow (B_m - B_r) \cdot -\frac{\mu_0}{\mu_m} \frac{l_m A_g}{A_m l_g} = B_m$$

So $A_g = A_m$ and $\mu_0 = \mu_m$

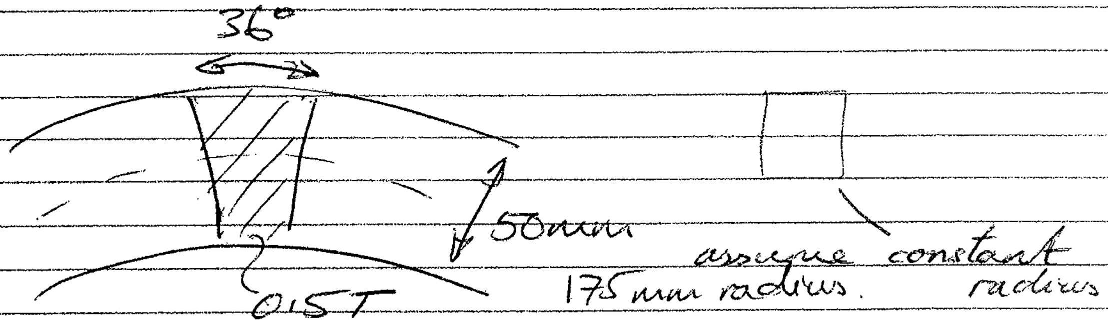
So for $B_m = \frac{B_r}{2}$ set $l_m = l_g$. 3

OR Look at the circuit. $R_{gap} = R_m$

for max energy in the gap!

An induction motor needs a small gap as its an electromagnet and the current for magnetising needs to be small for good efficiency. 1

4.



Try 18 poles on the winding, to make it easy

Each wire gives a voltage

360 rpm $\Rightarrow$ ~~6~~ 18 rps. Flux cutting: $B_g \times$ length $\times$ velocity

1080 rpm

$V = 0.175 \times 2\pi \times \frac{\cancel{6}}{18}$ $\quad E_{turn} = 0.5 \times 0.05 \times 0.175 \times 2\pi \times 6$

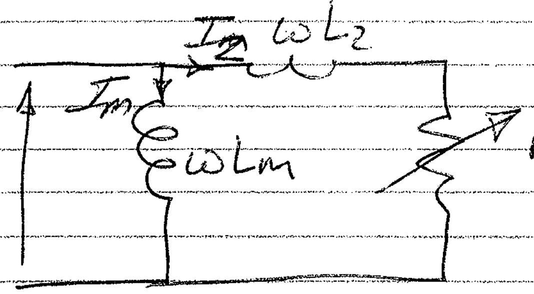
$= 0.165\ V \times 3$ $\quad$ 4 32V 64.6

$\Rightarrow$ ~~194~~ ~~turns~~ coil sides

3 phase $\Rightarrow$ 4 poles at a time

$\frac{64.6}{4}$ ~~194/4~~ = ~~24.25~~ ~~48.5~~ 16.16 per pole So use ~~25~~ ~~48~~ turns. 16 turns 2

2 a/

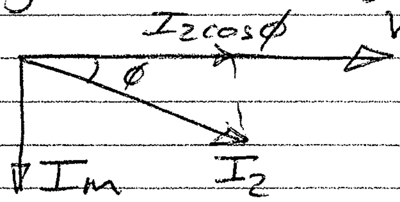


neglect R_1 & ωL_1

The only 'power' component is R_2/s

$T\omega_s = I_2^2 R_2/s$ (for 1 phase) 2

But by phasor diagram.



2

$I_2 \cos\phi$ is the component producing power: $T\omega_s = VI_2\cos\phi$

So $T\omega_s = I_m j\omega L_m \times I_2 \cos\phi$

$T \propto L_m I_m I_2 \sin(90-\phi)$

$\hookrightarrow$ flux $= I_m L_m$. 3

b) Neglect ωL_2 ' $\quad T\omega_s = \dfrac{V^2}{R_2/s} = i_2^2 R_2/s$

$\dfrac{T}{p} = i_2^2 \dfrac{R_2}{s\omega}$

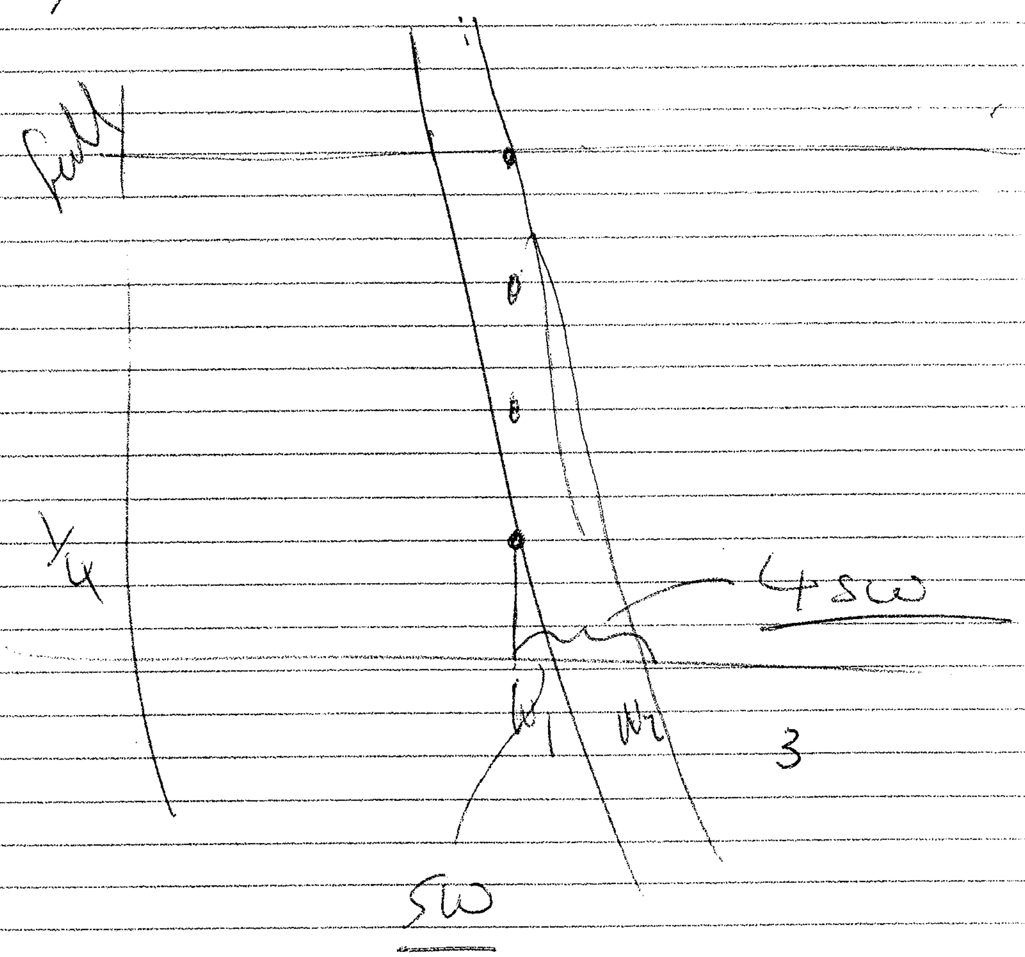
$= \dfrac{V^2}{\omega^2} \cdot \dfrac{s\omega}{R_2}$

But $i_2 = \dfrac{i_m \omega L_m}{R_2/s}$ 2

$\dfrac{i_2}{i_m} \dfrac{R_2}{L_m} = s\omega = \dfrac{i_2}{i_m} \dfrac{1}{T}$ 1

Also neglects R_1 & X_1 2

2c Explain briefly why full torque is obtained using full flux and how this may be achieved ~~over the~~ while varying the frequency at which the motor operates.



$$T = \frac{3V^2}{\omega^2} \frac{s\omega}{R_2}$$

$\omega_1 = 1500 + s\omega$

$\omega_2 = 1500 + 4s\omega$

$\Delta\omega = 3s\omega$

Full flux $\Rightarrow T \propto s\omega$

or $\Delta\omega = \frac{3}{4} s\omega_{max}$

@ 50Hz; $\frac{3.7kW}{3} = \frac{V^2}{R_2/s}$ $\quad s = 1.88\%$

$\Rightarrow s\omega_{max} = \frac{1.88 \times 50}{100}$ Hz

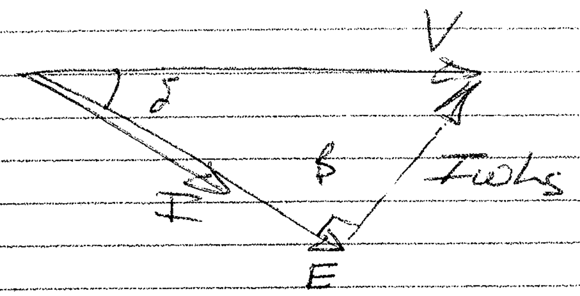
$= 0.94$ Hz 2

$\Delta\omega = \frac{3}{4} \times 0.94$ Hz

$= 0.70$ Hz 2

(should keep phasor same)

3(b)



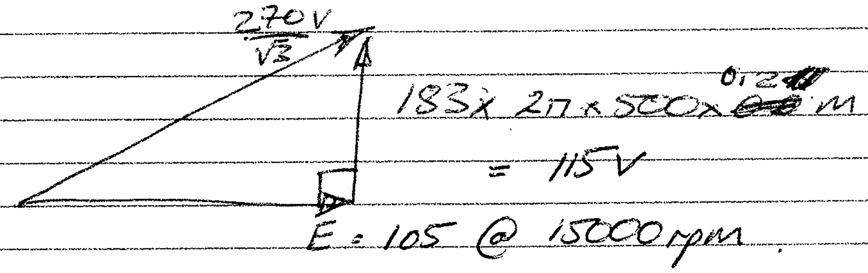
2

β is maintained at 90° and torque is controlled using a current controller or a feedforward voltage controller (And speed feedback) 2

The warning is needed as it is not 50Hz mains and not trapezoidal. 2

i) 12000 rpm @ 60kW

We need E first. Neglect R.



@ 12000 rpm $E = 84$.

$3EI = 60kW \therefore I = 238A.$

$$V = \Big[\,84^2 + \underbrace{\left(238 \times 2\pi \times \tfrac{12}{15} \times 500 \times 0.2m\right)^2}_{120^2}\Big]^{1/2}$$

$= 146V \times \sqrt{3} = 253V$ 4

IGBTs $\simeq 2V \times 2$

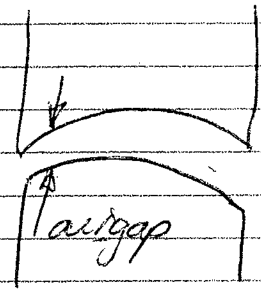
4V in 200 − 330

ii @ 18000 rpm $E = 126$.

$3EI = 60kW \therefore I = 159A.$ $\frac{3I^2R}{60kW} = \frac{1.5kW}{60kW}$ 2

Efficiency is good. 2

4 a/ A single phase winding produces a pulsating flux not rotating. So there is nothing for the rotor to follow. However, if the magnets stop somewhere misaligned, the the pulse will bring them into line and inertia can carry it through the pole position. Shaping the magnets makes them stop at a misaligned position. (same for airgap) 2

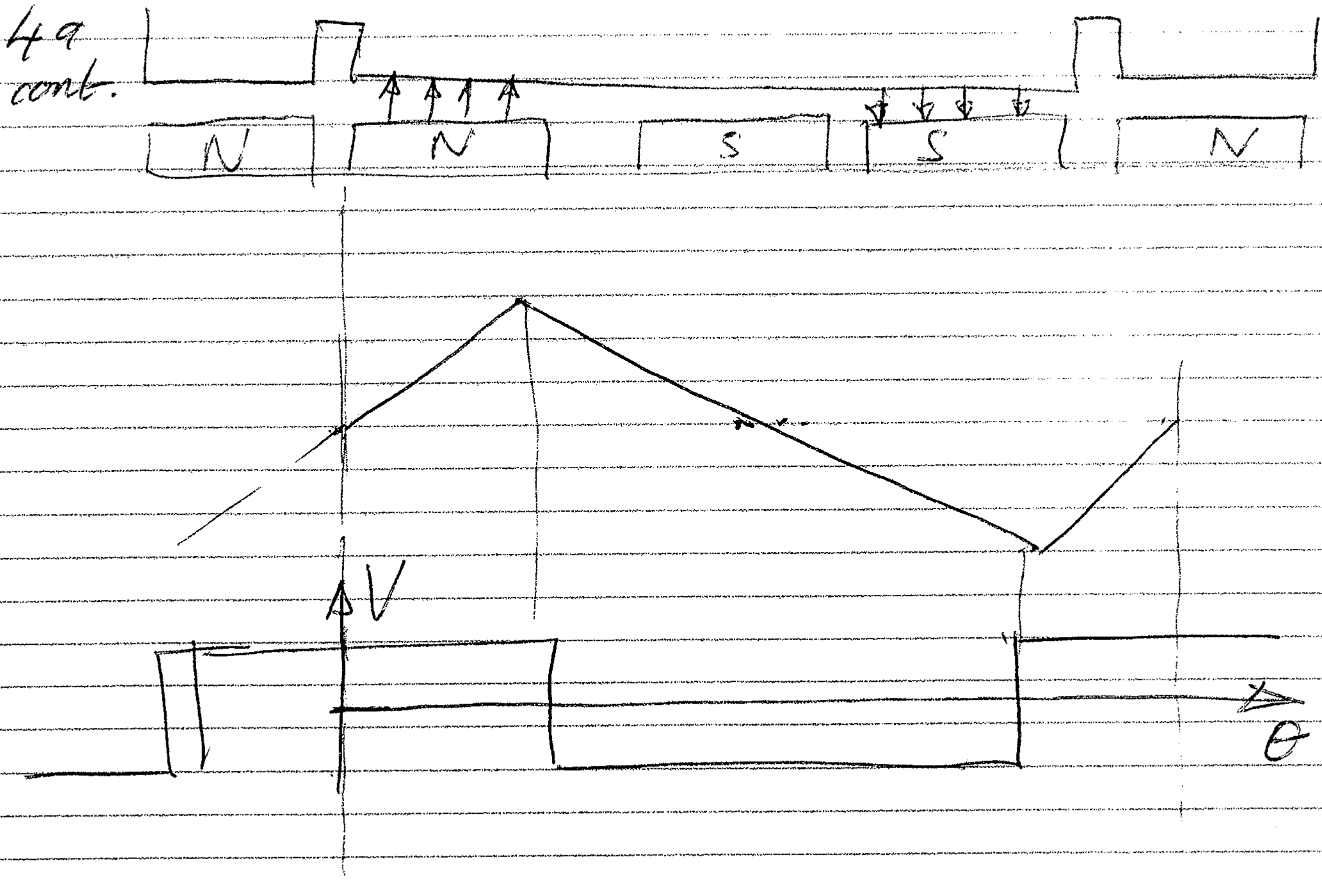


the airgap is wider to the right. So the rotor prefers to stop at an angle to the left. 2

Sketch Several positions, but always poles against the main poles. to a maximum of two. (zero flux)

Limited pole arc saves magnet material, ~~and~~ as it matches the smaller pole and the maximum alignment torque is lower than if the magnets were wider arcs. (lower reluctance torque)

4a cont.



Pretty ideal squarewave. 4

Rectified it is dc — so put squarewave current in. ("Brushless dc") 2

4(b) $T = -\hat{T} \sin N_s \theta$

$T_e = J\ddot{\theta}$ (ignore friction ~ often low)

Equate noting θ is for small displacements

$-\hat{T} N_s \theta = J\ddot{\theta}$

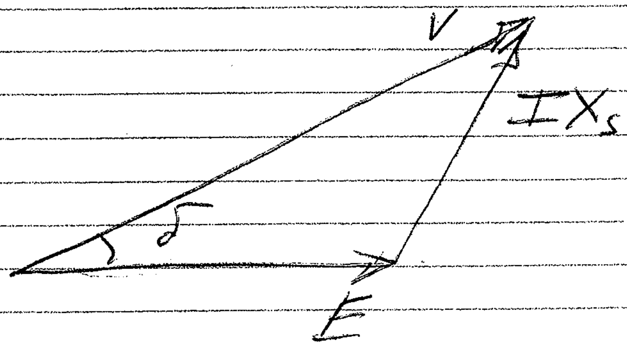
This is SHM with a natural frequency of

$$\sqrt{\frac{\hat{T} N_s}{J}}.$$ 4

Clearly this natural resonance can be excited if there is no friction, and distinct steps are perfect for exciting systems if some ~~multiple~~ fraction of ω!

4 b continued.

Microstepping applies a stepped waveform to phases A and B in the fashion of sinewaves if enough micro steps are used. (Microsteps as this is all within 1 step). Thus the resonance is less likely to be excited. Then it can be seen as a synchronous motor with a huge number of poles. 2



This same behaviour can be achieved if the motor accelerates or decelerates at such a rate to keep the angle δ positive (or negative) avoiding it oscillating around a step position ~~and~~ at ω_1 and then stepping at ω. This is known as "accelerating" through and is done at commissioning. 2