3B4 Cmb 2009 - Dr P R Palmer

1/ a) Specific Magnetic Loading – Average flux density over one pole pitch. Other flux densities in the machine can be found from this.

Specific Electrical Loading – Total effective current averaged around the airgap. It is not current density. Current density is applied to give the final wire choice and the depth of the slots (and winding losses).

b/ Using Specific Magnetic Loading $\bar{B}$ and Specific Electrical Loading $\bar{J}$

$$S = 3 V_{ph} I_{ph} = \frac{\pi}{\sqrt{2}} Vol. \frac{\omega}{p} . \bar{B} . \bar{J}$$

Assume 80% efficiency, 0·8 power factor.

6000 rpm $\equiv 200\pi$ rads/s

$$\frac{50 kW}{0{\cdot}8 \times 0{\cdot}8} = \frac{\pi}{\sqrt{2}} Vol. 200\pi \times 0{\cdot}5 \times 30{,}000$$

$$Vol = 3{\cdot}73 \times 10^{-3} m^3 \ (3{\cdot}73 L)$$

Could be wheel shaped or bottle shaped!

1b cont./

A gearbox allows for a higher motor speed and motor volume can be reduced.

Higher motor speeds may increase iron losses. (or inverter losses, or cost of gearbox) (any one point)

2 pole motors have long end windings.

8 pole motors at 6000 rpm means 400Hz ac, which is OK with more expensive laminations, more complicated winding, more cost (any 2 points).

8 pole, distribute by 2 slots, 3 phases = 48 slots.

Single layer to keep costs (and maths!) low

Ignore R_1 & $j\omega L_1$ so,

$$V = E = l \frac{\omega}{p} . d \, N_{eff} \, B_{rms} \qquad B_{rms} = \frac{\bar{B}\pi}{2\sqrt{2}}$$

$$k_d = \frac{\sin(2\beta P/2)}{2\sin(\beta P/2)} \qquad \beta = \frac{360}{48} = 7.5^\circ \quad k_d = 0.866$$

Δ connected (thinner wire, more turns) or star.

$$200 = \frac{3.73\times10^{-3}}{\pi . 0.12^2} \times 200\pi \times 0.240 \times N \times 0.866 \times 0.5 \times \frac{\pi}{2\sqrt{2}}$$

$N = 33.6$ (Not integer ×16)

Choose 32 Turns

1b cont.

This is only ~~4~~2 turns per slot. The current is high, so parallel paths maybe necessary. (Δ winding)

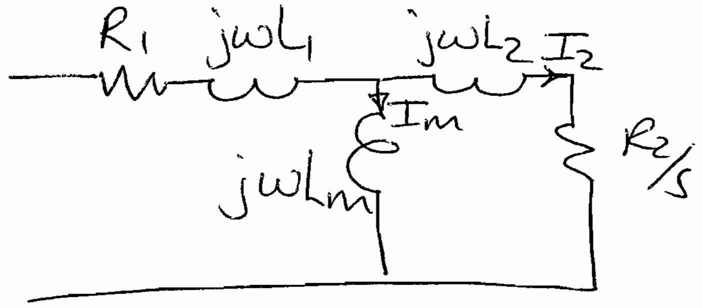
$$I_{ph} = \frac{50k}{0.8 \times 0.8} \cdot \frac{1}{3 \times 200} = 130A$$

$5A/mm^2 \Rightarrow 26mm^2 = \pi\left(\frac{d}{2}\right)^2 \Rightarrow d = 5.7mm$

2 paths $\Rightarrow 13mm^2 \Rightarrow d = 4mm$. Better.

Some optimisation needed!

2 a/



At speed $T\omega_s = 3 I_2^2 R_2/s$.

Neglect R_1 & $j\omega L_1$

$$\omega_s = \frac{\omega}{p}.$$

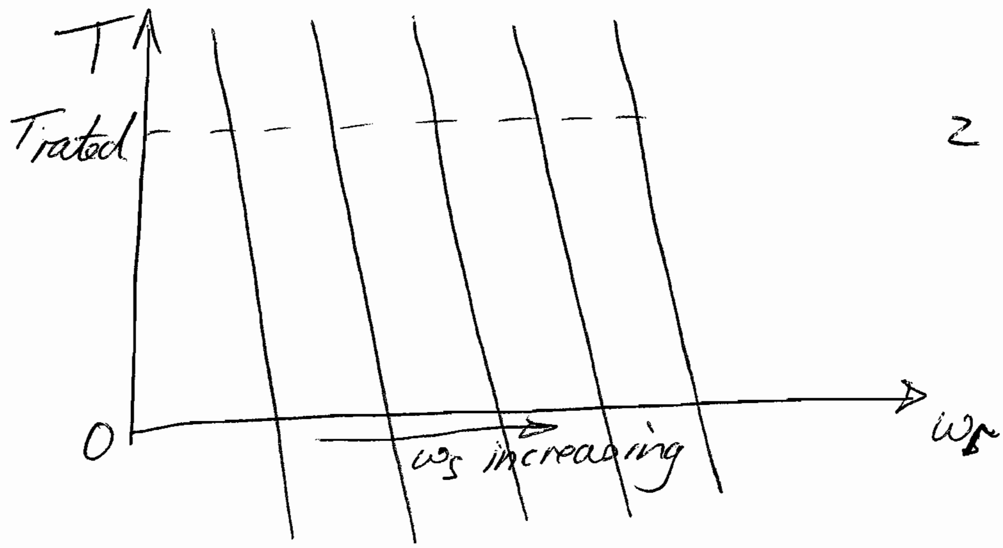
$$T = \frac{3}{\omega_s} \cdot \frac{V^2 R_2/s}{(R_2/s)^2 + (\omega L_2)^2}.$$

$$= 3p\left(\frac{V^2}{\omega^2}\right) \cdot \frac{R_2 s\omega}{R_2^2 + (s\omega L_2)^2} \qquad 4$$

If we keep $\frac{V}{\omega}$ constant T is independent of ω_s.

At standstill, $s = 1$ so $s\omega = \omega$ so a small ω_s provides the full torque. 2

Sketched



2

2(b) Neglect $s\omega L_2$ $\qquad \omega_s = \frac{\omega}{p}$.

$$T = 3p\frac{V^2}{\omega^2} \cdot \frac{s\omega}{R_2} \qquad k = \frac{V}{\omega_s}$$

A constant value keeps I_m constant (flux constant)

$$= 3pk^2 \frac{s\omega}{R_2} = 3pK_M^2 s\omega.$$

2

$$P_{IN} - P_{out} = T\omega_s - T\omega_r. \qquad s\omega_s = \omega_s - \omega_r.$$

$$= Ts\omega_s = \frac{Ts\omega}{p} \quad — (1)$$

$$= 3K_m^2 (s\omega_s)^2.$$

$$\sqrt{P_{IN} - P_{out}} = \sqrt{3}\, K_m s\omega_s.$$ Oops!

Substitute for $s\omega$ in (1)

$$P_{IN} - P_{out} = \frac{T^2}{3pK_m^2}$$

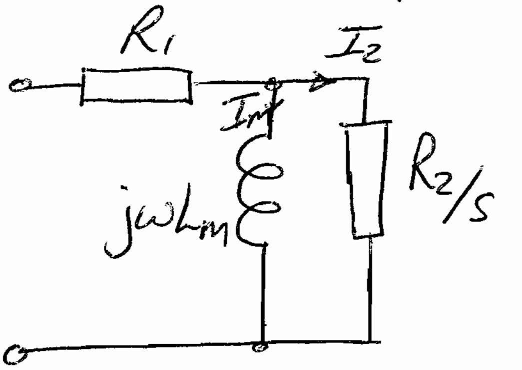
2

$$K_m^2 = \frac{T^2/p^2}{3(P_{IN} - P_{out})} \qquad K_m = \frac{T/p}{\sqrt{3(P_{IN} - P_{out})}}$$

This neglects R_1 & $j\omega L_1$ and assumes full flux in the machine.

2

2/c) Equivalent cct for standstill, rated flux



2 pole, 3000rpm.

$S_{rated} = \frac{60}{3000} = 0{\cdot}02$

@ 50Hz

$$T = 3k^2 \frac{s\omega}{R_2} = \frac{3700}{2\pi 50 \times 0{\cdot}98} = \frac{3 \times 415^2}{(2\pi 50)^2} \cdot \frac{0{\cdot}02 \times 2\pi 50}{R_2}.$$

$$R_2 = \frac{3 \cdot 415^2 \cdot 0{\cdot}02 \times 0{\cdot}98}{3700} = 2{\cdot}74\Omega$$

$$I_2 = \frac{415}{2{\cdot}74/0{\cdot}02} = 3{\cdot}03\,A \qquad p.f. = 0{\cdot}8 \ (3\text{-}4\text{-}5 \text{ triangle})$$

$$\Rightarrow I_m = \frac{3{\cdot}03 \times 3}{4} = 2{\cdot}27$$

Need to estimate V_{boost} at standstill.

I_2 & I_m remain the same.

$s = 1$ BUT $s\omega$ is the same as above.

$$\Rightarrow s\omega = 0{\cdot}02 \times 2\pi 50$$
$$= 2\pi \text{ rads/s } (1Hz)$$

$\therefore$ V with no boost is $\frac{415 \times 2\pi}{2\pi 50} = 8{\cdot}3V.$

We don't know R_1. If we did we could be precise, but usually V_{boost} is commissioned in a simple manner. And $R_1 \simeq R_2$ (referred)

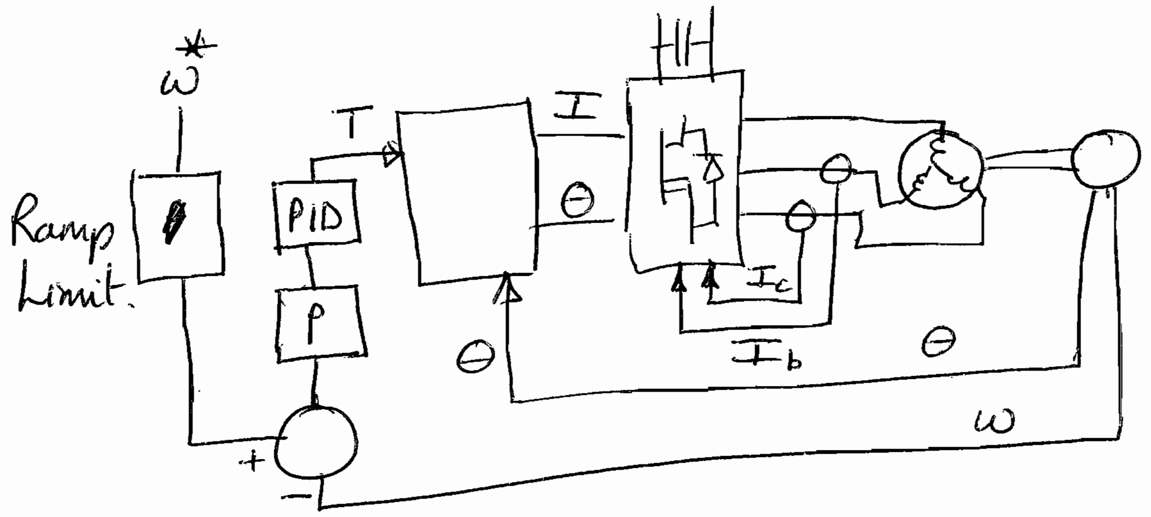
Say 16.6V, 1Hz.

i.e. Choose something sensible

8.3V, 1Hz has no boost

3 a/ Must have θ & ω feedback. 2

Also needs current feedback



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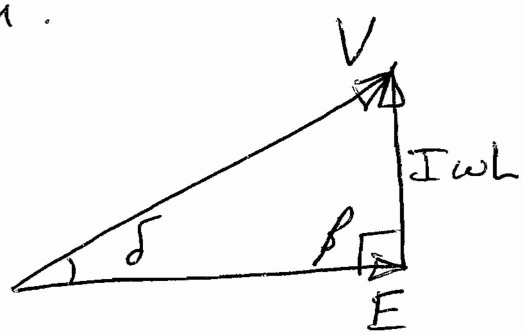
Phasor diagram.



2

this is the same as for a synchrous motor except the controller maintains the Torque angle β at 90°. Everything is sinusoidal.

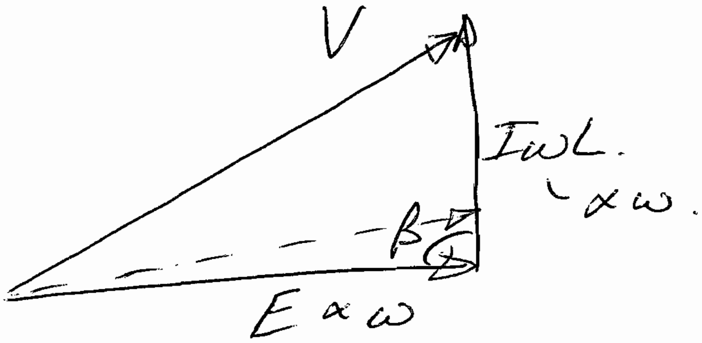
At speed R can be neglected. 2

$E \propto k\phi\omega$.

$T\omega = VI\cos\phi = VI\cos\delta = IV\cos\delta = IE$

Cogging is a reluctance torque, which would mean the torque has a ripple, which becomes a ripple in the finished work. 2

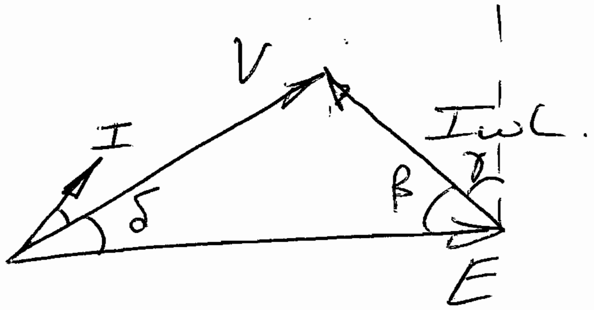
3/b) As speed increases:



Power = EI E inc. I decreases.

Until the $E \simeq V$ then its stuck.

the only alternative to to allow β to change.



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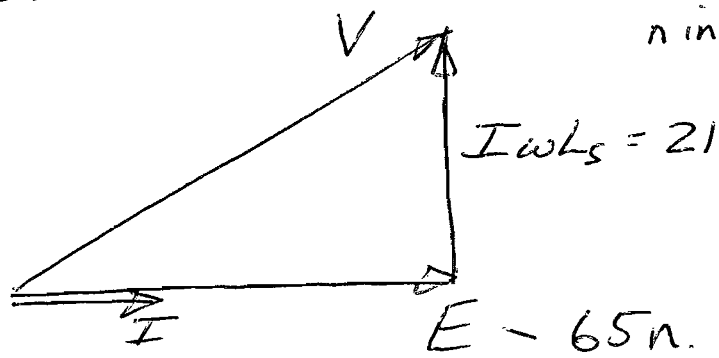
"Phase advance" is angle γ. This is just the same as for an overexcited synchronous motor.

3/ b.) cont.



n in 1000's rpm

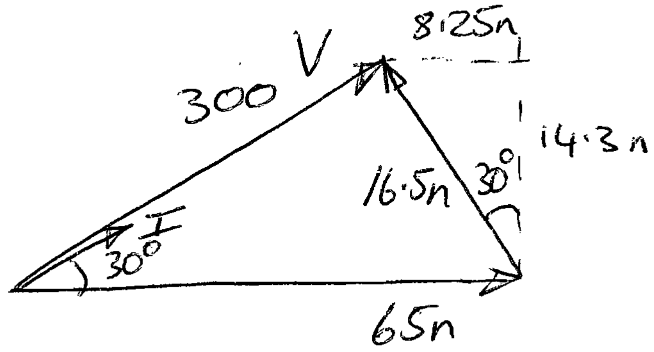
$$I\omega L_s = 21 \times \frac{n\,1000}{60} \cdot 2\pi \times 3 \times 2.5\,\text{mH}$$

p to get right ω

$$300^2 = 65^2 n^2 + 16.5^2 n^2$$

$n = 4.474$ <u>4474 rpm</u>

30° advance.



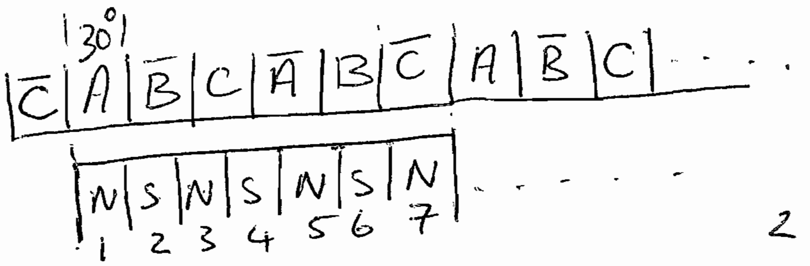
$$300^2 = 56.75^2 n^2 + 14.3^2 n^2$$

$n = 5.126$ <u>5126 rpm</u>

4 a/ Microstepping is based on exciting the windings of a 2 phase motor at the same time, with fractional current to get a step position between two steps. 2 This has two main uses. Firstly it can be used to move between major steps without exciting oscillations and it can provide more accurate positioning. 2

The half an full step modes are symmetrical and magnetic saturation doesnt matter. 2 An asymmetrical or inbetween mode has problems with saturation of the corners of the teeth etc. so the position is not likely to be as accurate. In all cases the load affects the position, so with a known load the resultant position can be repeated accurately even using microstepping. 2

4 b/ 12:14



12 stator poles.
14 rotor poles.

2

With A on in the right sense, pole 1 will align (and $\bar{A}$ misalign with 4&5).

When $\bar{B}$ comes on next, pole 2 will align (and B misalgn with 5&6)

When C comes on next, pole 3 will align. (and $\bar{C}$ misalign with 6&7).

2

And so on. (The misalignment is important with a "salient" or concentrated stator winding on simple poles. If it were 6:6 stator to rotor the cogging or reluctance torque would be massive. Clear detent positions arise here, but no great detent torque)

Step angle. Flux move 30° but rotor moves?

(In brushless dc it is half stepping.) $\frac{180^\circ}{7} = 25.7^\circ$
$A\bar{B}$, $\bar{B}C$, $C\bar{A}$ ...

4.3° 2

4(c) 100kW, 3000rpm.

	DC	Induction	BLDC	SR	
Eff.	4	4	6	5	
Maturity	6	6	5	4	
Low Cost	4	6	3	6	
Noise	6	5	4	0	4
	20	21	18	15	

The induction motor has few drawbacks and can be made to be quite efficient. At these powers water cooling is probably a good idea, lessening the drawback of efficiency. 2

In a different application a heavy weighting may be applied.