3B4 2006 CRIB

PART IIA 2006
3B4: Electric drive systems
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Datasheet: None

1/(a) Specific Magnetic Loading.

Average Flux Density over one pole pitch.

Related to the peak fundamental airgap flux and magnetising current and/or iron losses.

Specific Electrical Loading.

Total electrical current per unit length averaged around the airgap. ~ relates to the resistive losses on load.

(Clearly not the current density, although related, nor a true mmf)

(b) $$S = \frac{\pi}{\sqrt{2}} \cdot \pi \left(\frac{d}{2}\right)^2 L \, \frac{\omega}{p} \times \bar{B} \times \bar{J}$$

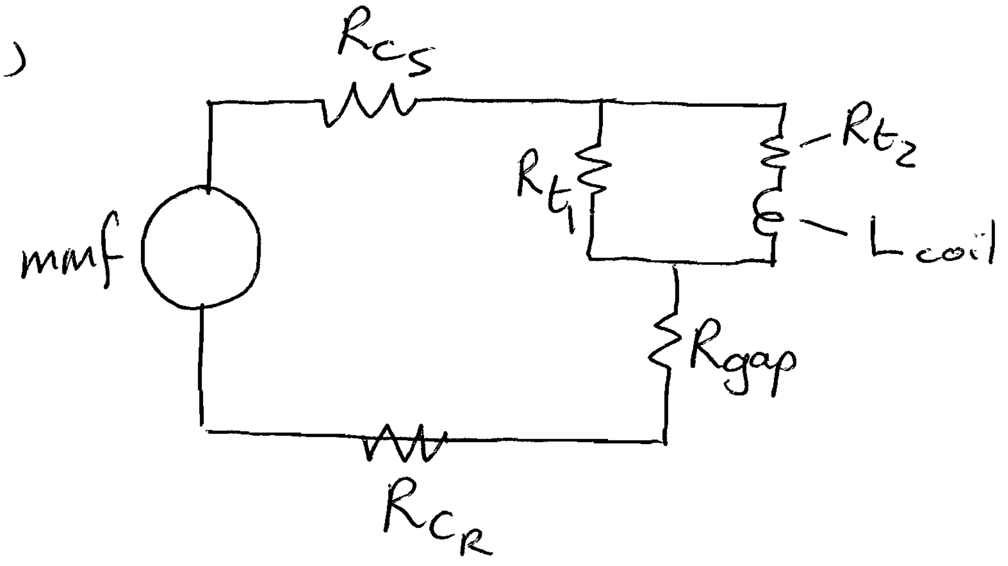
$$= \frac{\pi^2}{\sqrt{2}} \, \frac{0.03^2}{4} \cdot 0.035 \times 2\pi \times 50 \times \underset{\text{usual}}{0.5} \times \underset{\text{usual}}{30{,}000}.$$

$$= 259 \text{ VA}.$$

efficiency × powerfactor = 0.5×0.7 ? low for small motors!

$P_{out} = 90\text{W}$.

1 (c)



The copper coil means we get two flux components, one lagging the other. This resolves into a good rotating flux vector for good induction motor operation.

(d) 90 W is quite large, so simple PM motor drives with single ended coils would be very inefficent and not good for modern goods. Thus a full bridge is needed. 3 phases is efficient.

Ferrite is cheap, but $\bar{B}$ is low, so the motor would be large. NeFeB is much more expensive but allows for a small machine. Maybe cost effective eventually.

2 (a) Neglect R_1 and ωL_1 and assume that $\omega L_2 << R_2/s$, i.e. that the slip is small.

$$T\omega_s = 3 I_2^2 \frac{R_2}{s}$$

$$I_2 = \frac{V}{R_2/s}$$

$$\text{so} \quad T = \frac{3}{\omega_s} V^2 \frac{R_2}{s} \frac{1}{(R_2/s)^2}$$

$$= \frac{3V^2}{\omega_s} \cdot \frac{s}{R_2}$$

But $s = \dfrac{\omega_s - \omega_r}{\omega_s}$

$$\text{so} \quad T = \frac{3V^2}{\omega_s^2 R_2} \cdot (\omega_s - \omega_r)$$

Note that ω_s is the synchronous angular speed and not supply frequency so p, the number of pole-pairs, does not appear.

(b) Rated torque implies operation fully fluxed and that needs V/f control.

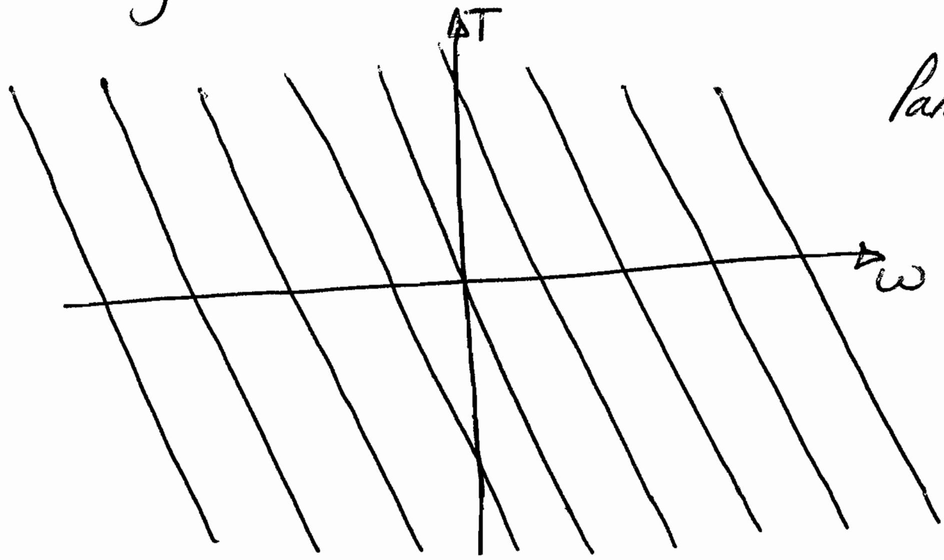
Voltage boosting made be necessary at low frequencies with V/f control.

(The phase pattern must be reversible; this is done in the modulation)

2(b) cont.

Torque - Speed in 4 quadrants:

Only want stable part of the characteristic!



Parallel lines with $\frac{V}{F}$ = const.

(c) Rated Torque is

$$\frac{4000}{314} = 12.7\,Nm$$ assuming $s \approx 0$ (R_2 referred < R_1) both small

No comment so <u>Delta</u>

(i) $1.5 \times 12.7\,Nm$. (Best found using similar triangles in the $T-\omega$ curves above)

ω_s at 33 Hz $2\pi . 33 = 207.3$ rads/sec

$$T = 3\left(\frac{V}{\omega}\right)^2 \frac{(\omega_s - \omega_r)}{R_2}$$ <u>Neglect</u> $R_1, \omega L_2, \omega L_m$

$$19.1 = 3\left(\frac{415}{100\pi}\right)^2 \frac{(207.3 - \omega_r)}{2.14}$$ $\omega_r = 199.5$ rads/s = <u>1905 rpm</u>

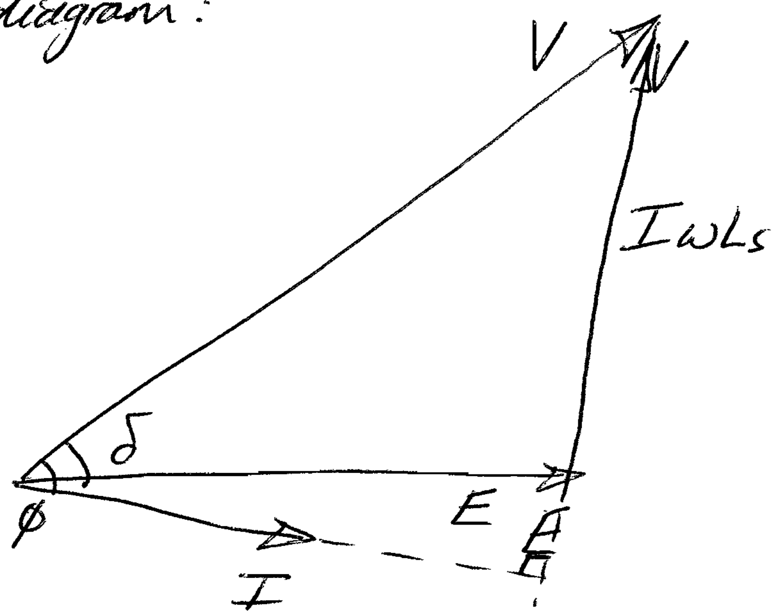
(ii) 67 Hz > 50 Hz So field weaken (not similar triangles)

$$12.7 = 3\left(\frac{415}{134\pi}\right)^2 \frac{(134\pi - \omega_r)}{2.14}$$ $\omega_r = 411.7$ rads/s

= <u>3931 rpm</u>

3 (a) The currents need to be sinusoidal too!
Thus sinusoidal references are needed for the current control loops. They must also be scalable to allow torque control. The θ feedback maybe used to 'clock' through a sine function stored in memory, and scaled using floating point maths functions.

Phasor diagram:



$$P = 3IV\cos\phi = 3IE\sin(180-\beta)$$
$$= 3IE\sin\beta$$

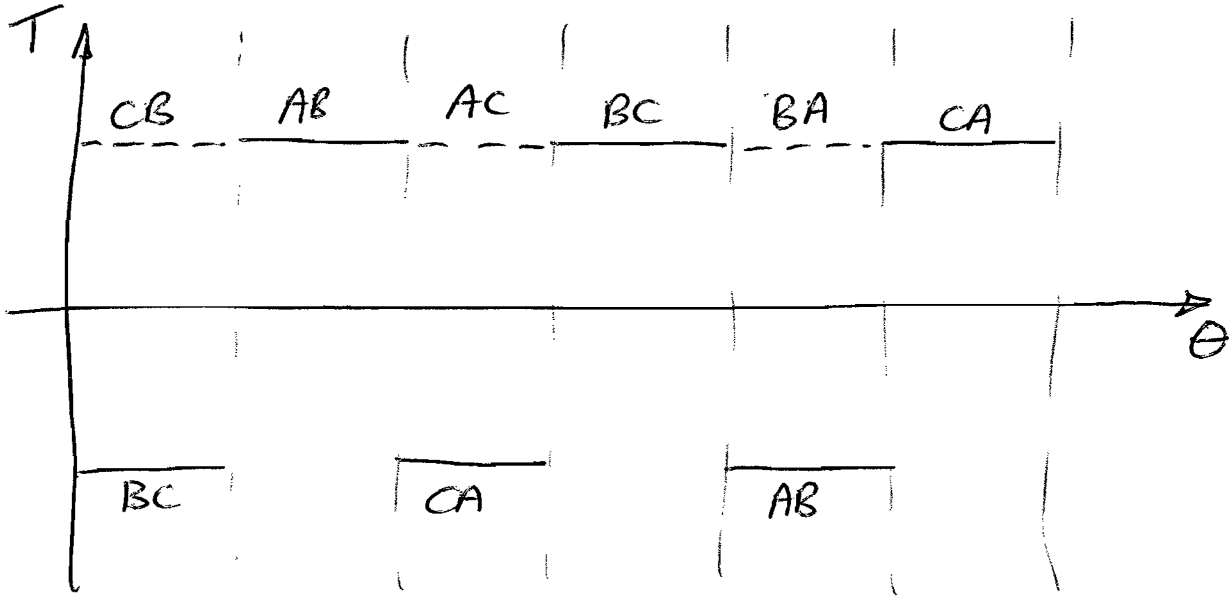
$T = \dfrac{3IE}{\omega_s}\sin\beta$ For max torque per amp $\sin\beta = 1$
ie. $\beta = 90°$

$E \propto \omega_s$ due to the permanent magnets.

$T = KI$ like DC motors.

3 (a) cont. $T = J\frac{d^2\theta}{dt}$ which is a second order response. With a position control loop and no mechanical friction an undamped second order system will be formed. Noting that $T = KI$, it will be unstable. A PID controller can be added and the system may be stabilised. As $\omega = \frac{d\theta}{dt}$, the 'D' function necessary for damping is performed by the encoder. A 'D' function in the foward path is unattractive as the demand will be differentiated, possibly saturating the drive. Also differentiating a modern encoder signal in a microcontroller is not easy. A purpose built encoder with θ and ω outputs is therefore very practical.

3 (b) Star connected, for a current flowing in two phases produces the profile of Fig 3. With three phases, two on at any one time and switching between the flat sections, a constant torque can be formed:



Note that the flat part of the torque $-\theta$ characteristic must be $\geq 60°$

The difficulty is in eliminating the torque ripple at the switching instants. In a sinusoidal drive the torque ripple is small and a function of the current ripple. In trapezoidal drives there is a controlled current level, so current ripple and the finite di/dt at the switching θ's above.

4/(a) 3 Stack VR stepper:

3 Stator stacks mounted co-axially

A rotor common to the stator stacks

The rotor and stator have the same number of teeth.

Each stack has a single phase winding on all the stator poles.

Each stack of the stator is offset from the others by β where $\beta = \dfrac{360^\circ}{3N_s}$

(b) $T_A = \dfrac{1}{2} I_A^2 \dfrac{dL_A}{d\theta}$ assuming no saturation.

$L_A = L_o + L\cos m\theta$

$$\Rightarrow T_A = -\frac{m}{2} i_A^2 L \sin(m\theta)$$

θ is taken as a displacement in tests, with a restoring torque. When working as a motor the torque is in the direction of θ

$$T_A = \frac{m}{2} i_A^2 L \sin(m\theta)$$

$50mH - 70mH \Rightarrow 2L = 20mH,\ L_o = 60mH$

$$\hat{T}_A = \frac{m}{2} i_a^2 L = \frac{8}{2} . 5^2 . 10m = \underline{1Nm}$$

4 (c) $T_A = -\frac{m}{2} i_A^2 L \sin m\theta$

$T_B = -\frac{m}{2} i_B^2 L \sin m(\theta - \beta)$

$i_A = i_B \qquad T_{A+B} = -\frac{m}{2} i_A^2 L \left[\sin m\theta + \sin m(\theta - \beta) \right]$

$= -m i_A^2 L \cos\left(\frac{m\beta}{2}\right) \sin m\left(\theta - \frac{\beta}{2}\right)$

For equilibrium $T_{A+B} = 0 \Rightarrow \theta = \beta/2$

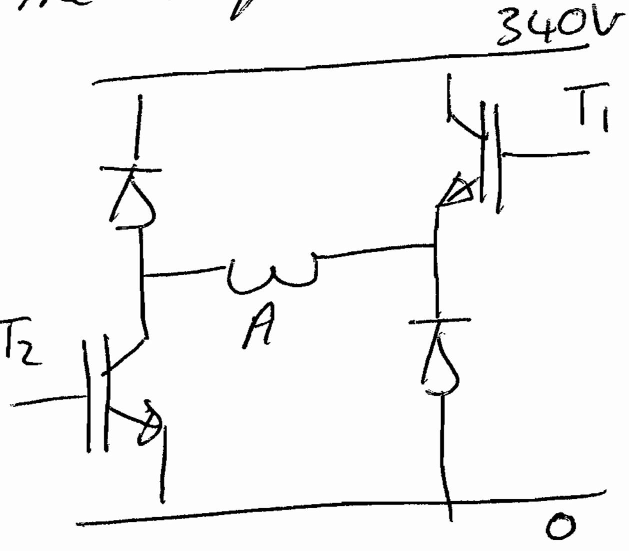
The half step position.

$$\frac{|\hat{T}_{A+B}|}{|T_A|} = \frac{m i_A^2 L \cos\left(\frac{m\beta}{2}\right)}{\frac{m}{2} i_A^2 L} = 2\cos\left(\frac{m\beta}{2}\right)$$

$\beta = \frac{360°}{3m}$

$= 2 \times \frac{1}{2} = \underline{\underline{1}}$

4 (d) The phase current need only be in one direction. However the power is high so current chopping is needed to control the torque.



chopping by turning T_1, T_2 off and on together causes rapid changes in the current. This results in acoustic noise as a high pitched ~~torque~~ ripple is created. Keeping T_1 on and chopping with T_2 reduces the current ripple (and switching losses). Thus lowers the acoustic noise, important in a domestic appliance. (Used in some washing machines now.)
Cheaper to manufacture. Simple electronics.