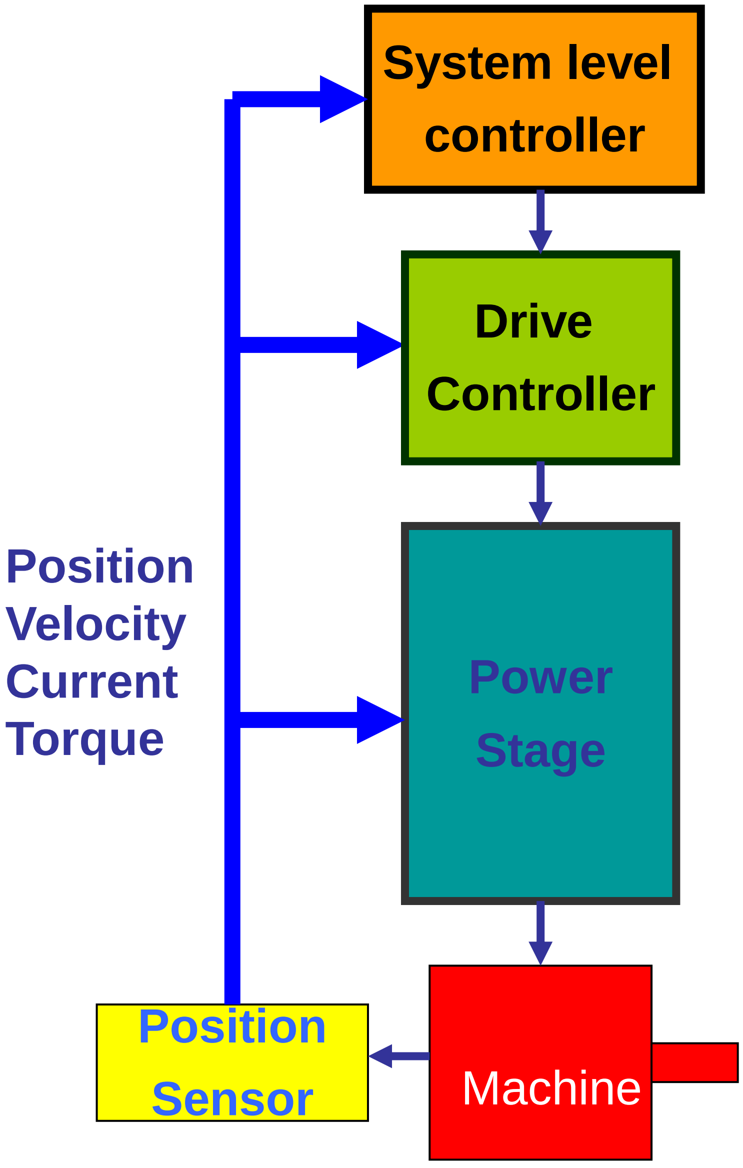
Modelling of machines – section 4

Multi-phase PM machines

- Previous slides in section 3 related to a single phase machine. Although this is a useful starting point in terms of understanding the basic principles, it is of limited practical use since 1-phase PM machines are seldom used in applications requiring anything other than very low powers (up to 20W or so), e.g. mains electric shavers and mains driven clocks or very cost sensitive applications.
- Multi-phase, and in particular 3-phase, machines are far more common for powers of greater than a few tens of Watts
- Although brushed PM machines are still used in some applications, the vast majority of high power PM machines are so-called ‘brushless’ machines in which the stator current are switched in sequence by a power electronic converter rather than a mechanical commutator
- Brushless machines are broadly divided into two classes, viz. brushless DC and brushless AC.
- Since distinction is not clear cut in terms of the motor itself, but relates instead to the way is it controlled. Indeed a given PM machine can usually be operated as either a brushless DC machine or an AC machine (the phrases AC and DC are not particularly helpful either!)

Brushless AC and DC operation

- In simple terms, a brushless DC machine is fed with so-called six-step 120° square wave currents and a brushless AC machine with sinusoidal currents
- Both involve imposing current pattern in the stator which are functions of rotor position (not time per se)
    - Brushless DC requires simpler position detector
- Both require a converter of very similar connection – principal different is control

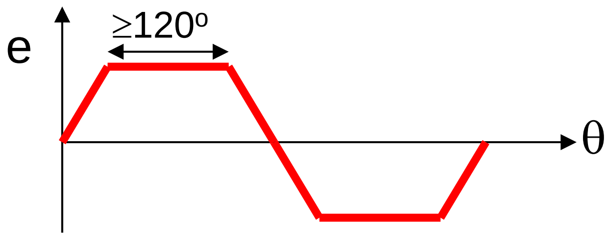


Brushless DC

120° square wave current operation

Idealised flux-linkage variations

Idealised emf – in practice tend to be more trapezoidal

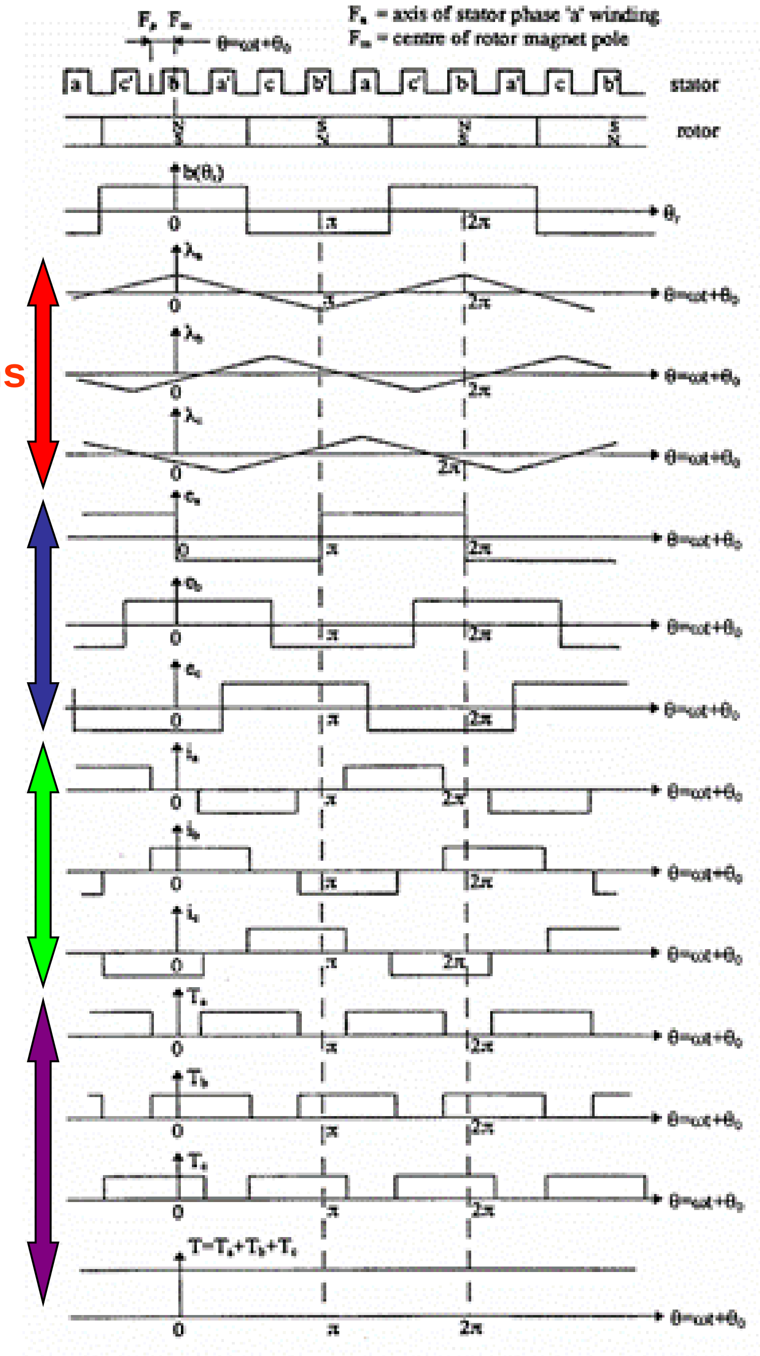


Generally aim to design the machine such that the width of the flat-top is ≥120°

120° wide square wave currents – usually aligned to coincide with flat-op of emf

Individual phase torques and net torque

Ideally produce constant torque

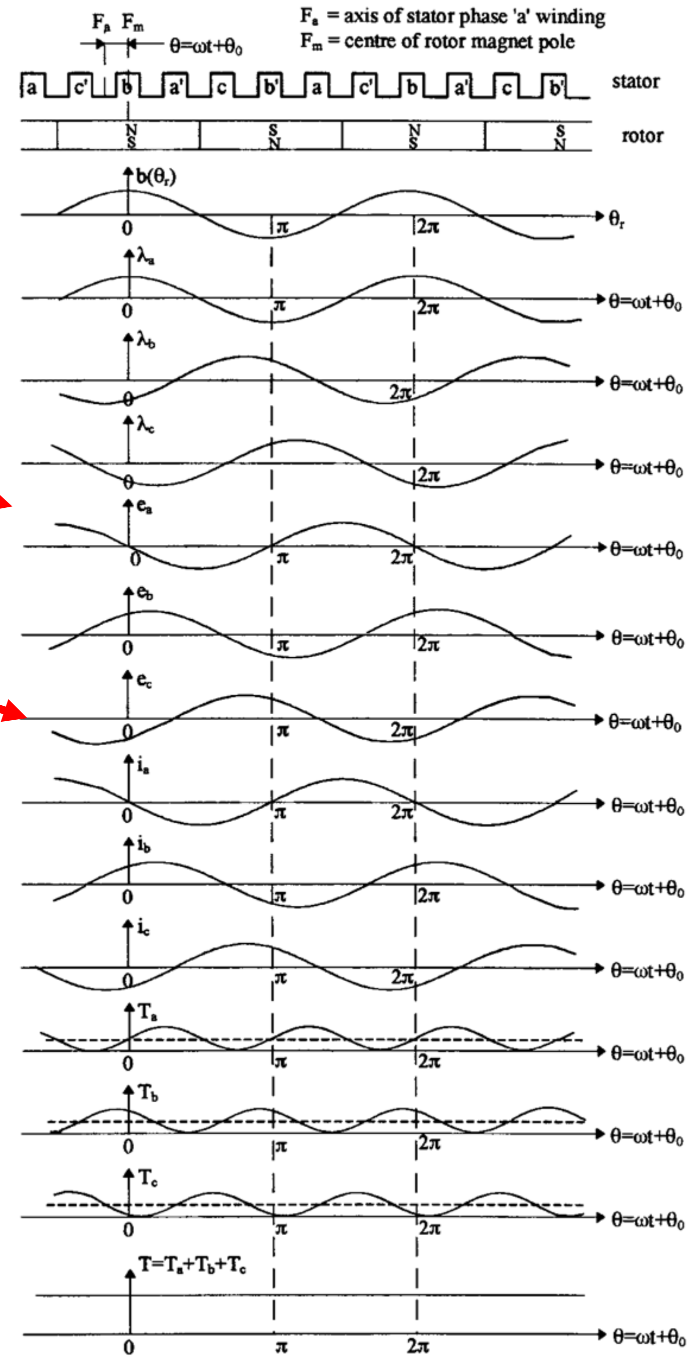


Brushless AC operation

Similar principles, except the machine is designed to produce a sinusoidal emf (usually with minimal harmonic current)

The machine is fed with position synchronised sinusoidal current waveforms

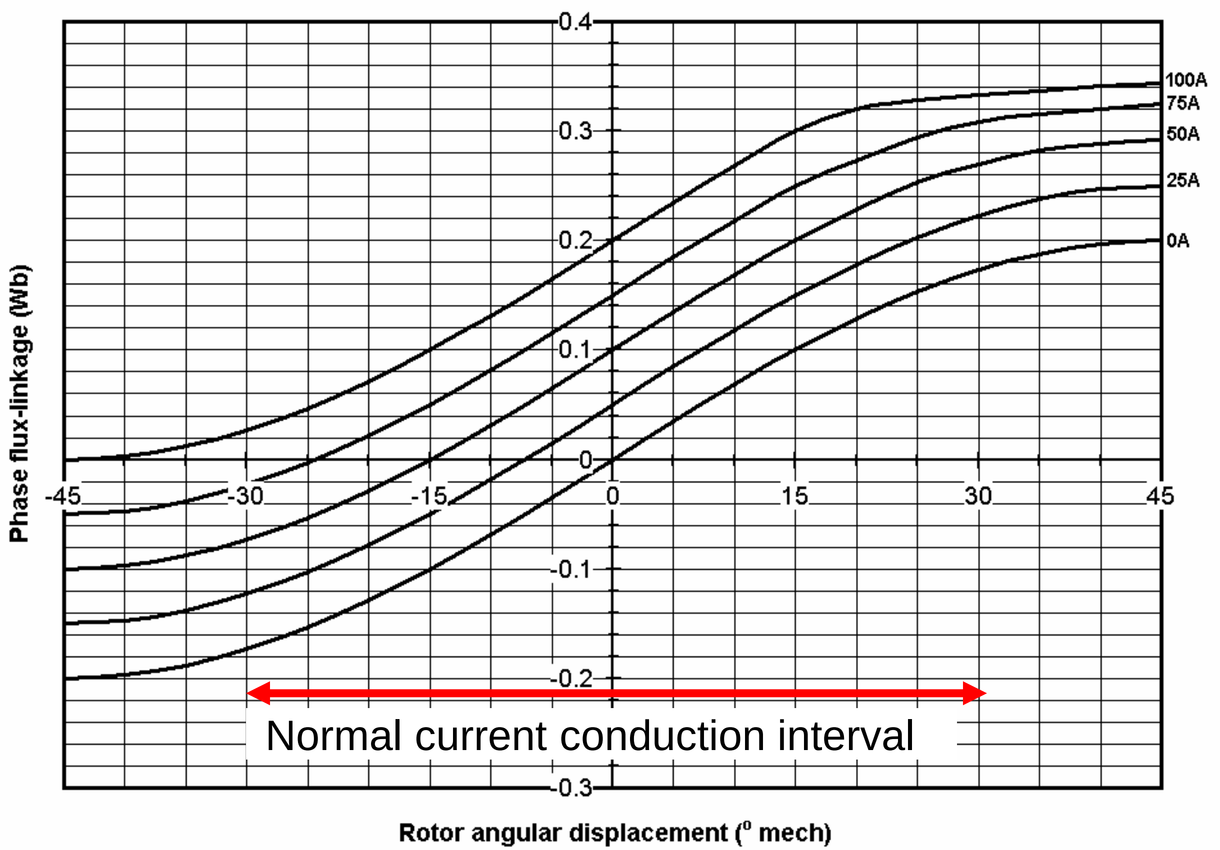
Produce a 2×frequency pulsating torque in each phase which sum to a smooth torque



Summary of brushless DC and AC operation

- Either control mode can be applied to most machines, e.g. brushless DC applied to sinusoidal emf machines or vice versa
- But best suited (in terms of efficient and minimising torque pulsations) if applied to machines with emfs which meet the nominal requirements
- In this course we will focus on brushless DC operation, specifically the injection of a constant current over a prescribed angular interval (principles equally applicable to sinusoidal currents but manual calculation with non-linear saturation is more time consuming for brushless AC excitation with sinusoidal currents)

Example of ψ-θ characteristic for one phase of a brushless PM machine – ***DC current present for all angles***



Notes:

You can determine that this is a 4-pole machine (half an electrical cycle corresponds to 90° mech)

Effect of magnetic saturation at 100A is clear (tapering off after 15-20°)

As with ψ-θ characteristics for SR machines, the phase emf at any speed and rotor angular displacement can be calculated using:

$$e = \frac{d\Psi}{dt} = \frac{d\Psi}{d\theta} \times \frac{d\theta}{dt}$$

$\frac{d\Psi}{d\theta}$ Obtained from approximating slope of curve

Inductance in PM machines

- As well the general definition of flux-linkage produced per unit current, there are many different definitions of inductance:
- Absolute inductance: $$L_{abs} = \frac{\Psi}{I}$$

  Note: the flux-linkage ψ in the above equation is only the flux contributed by the coil and not that by the PM.

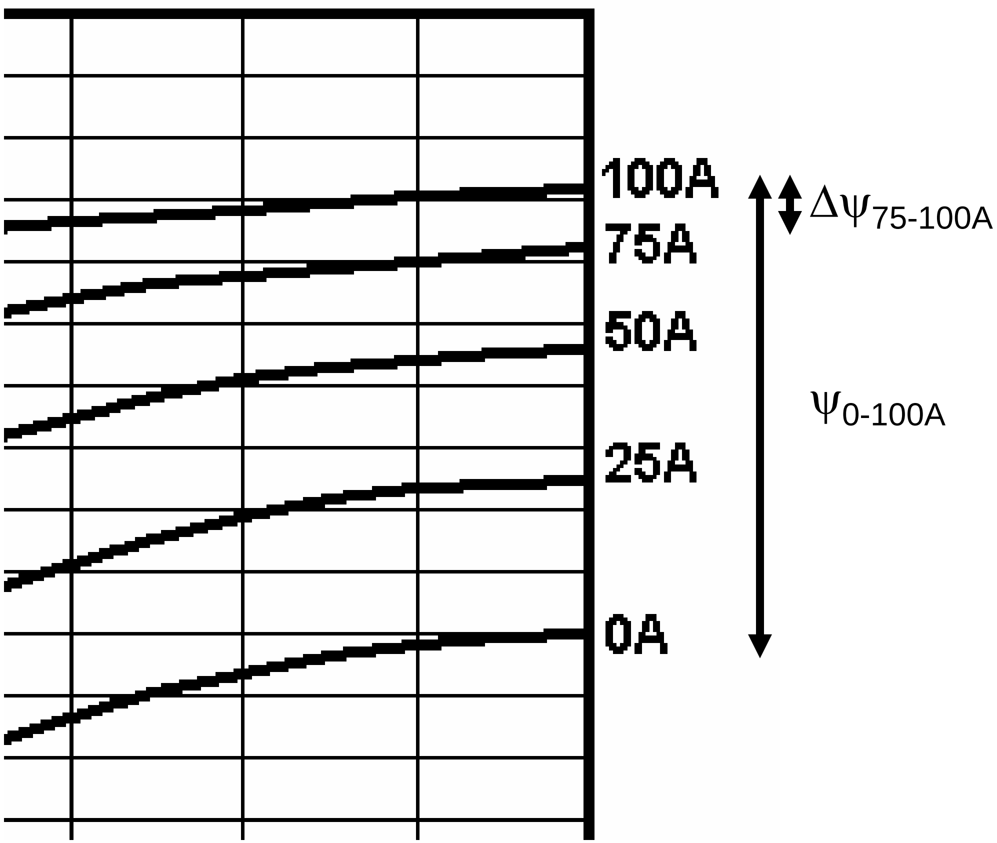
- Incremental inductance: $$L_{inc} = \frac{\Delta\psi}{\Delta I}$$

Inductance may vary with angle due to magnetic saliency – e.g. non-cylindrical rotor iron and with current due to magnetic saturation

Inductance calculation

Zoom in on top right hand side of previously shown ψ-θ characteristics

Supposing we are interested in the inductance at an angle of 45º (mech)



$$L_{abs0-100A} = \frac{\Delta\psi_{0-100A}}{100}$$

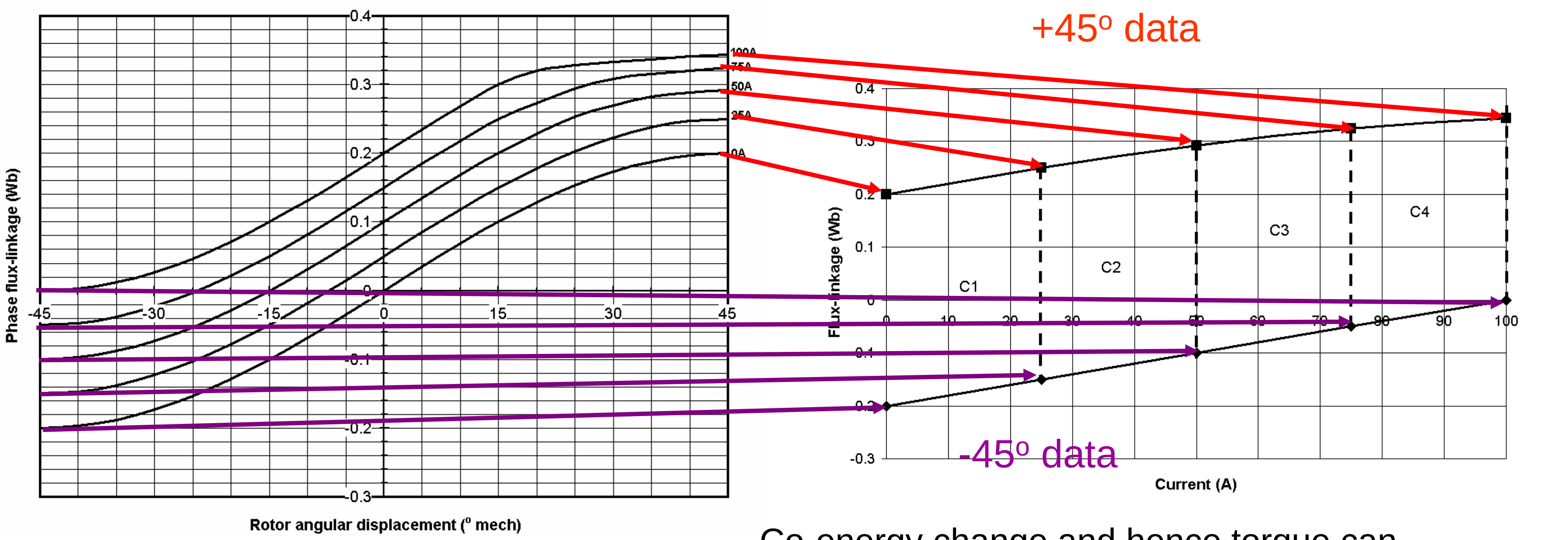
$$L_{ins75-100} = \frac{\Delta\psi_{75-100A}}{25}$$

N.B L_{inc} and L_{abs} only start to become a function of current when magnetic saturation occurs

Torque calculation

- It is common to see PM machine data in the form of ψ-θ curves – these can however be readily translated to ψ-i for torque calculation

e.g. calculation of torque produced if a DC current of 100A is passed through phase A over the full -45º to +45º excursion



Co-energy change and hence torque can be calculated in the same way as SR machines

Notes on torque calculation

- Ensure that radians (mechanical) are used in the calculation of $\Delta\theta$
- If (as is usual) the ψ-θ curve is for one-phase, then the total torque produced in 3$\times$phase torque (not $\sqrt{3}$ of 3/2)
- Although it is normal practice to only put current in over 120° (electrical), sometime questions can ask for the full 180 $^\circ$ (electrical) – answer the question !
- Many examples available in previous exam papers