Modelling of machines – section 3

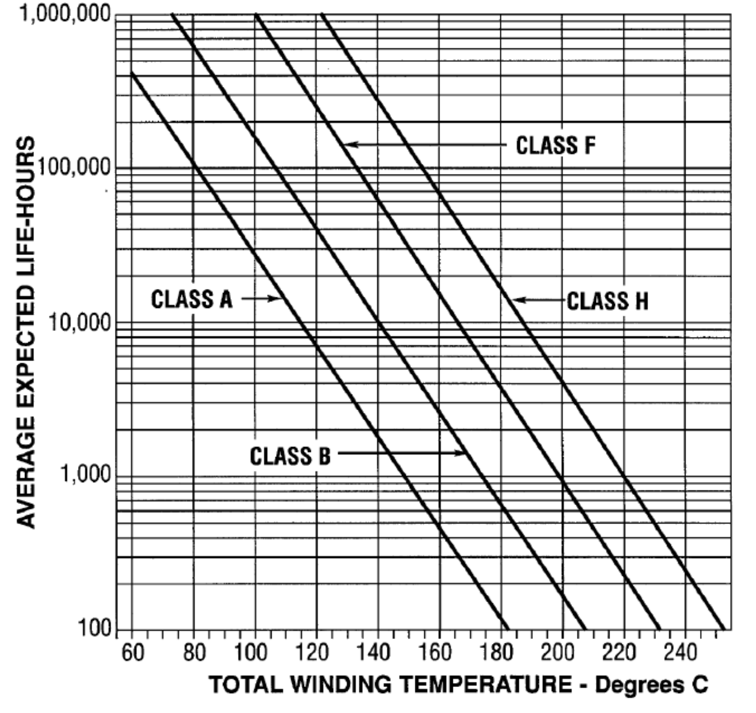
Design features

The overall size of an SR machine that is capable of meeting a given torque and/or speed specification is usually limited by thermal considerations, i.e. the stator winding temperature rise must remain within the limits specified by the wire manufacturer for the particular class of insulation being used

It is always possible to trade lifetime for maximum temperature rise, but the rate of decrease is very punitive (halving of lifetime per 10^{o}C over-temperature)

The cooling of the machine can be improved by using:

- Forced air cooling (e.g. separate fan ducted into casing)
- Liquid jacket (fluid circulated within closed ducts in the machine casing – usually water/glycol mix or oil)
- Direct liquid cooling of windings

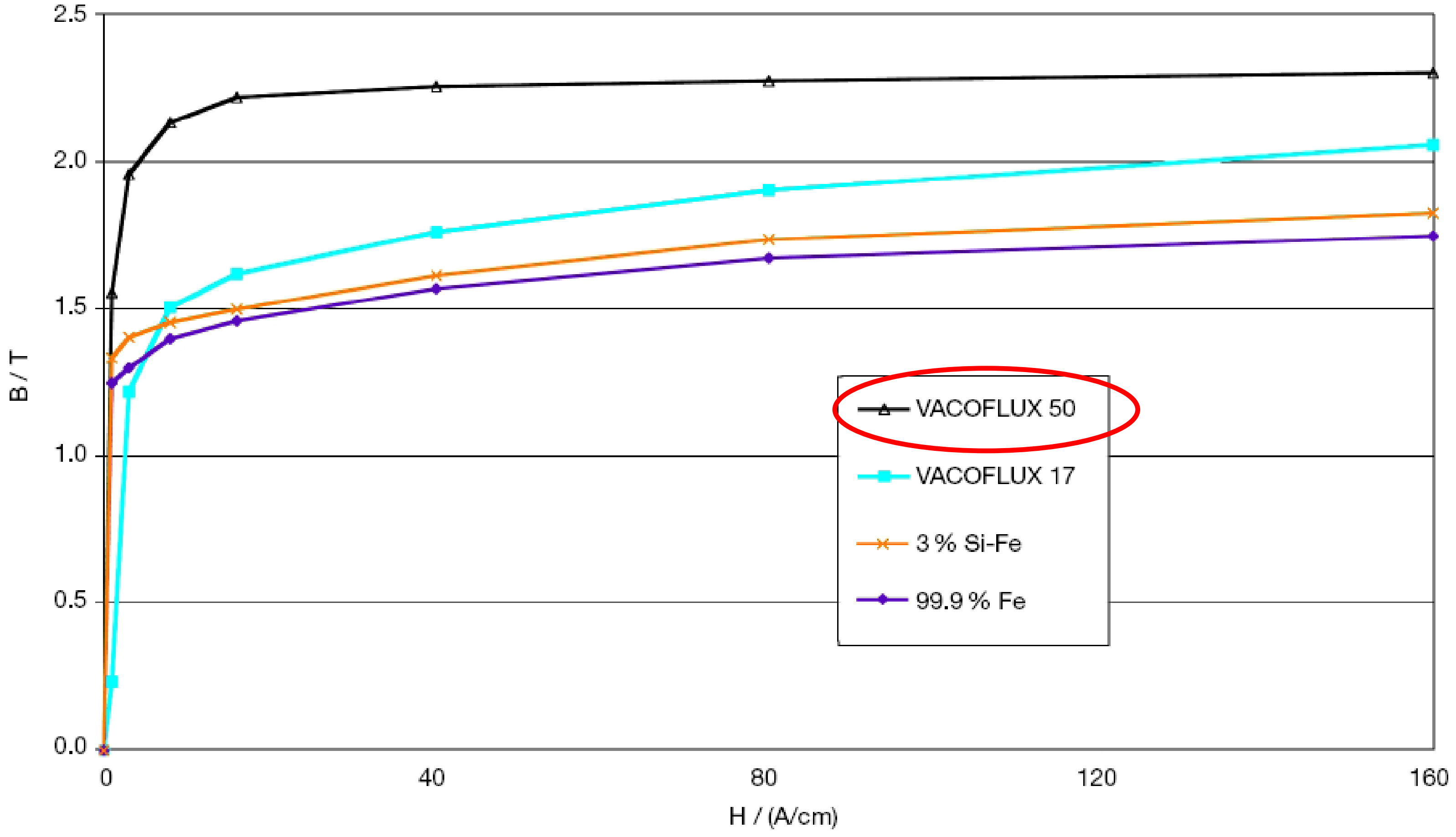


For equal cooling, and hence the same overall losses, there are two design features which can improve torque density

Replacement material for stator and rotor core

- Virtually all SR machines (and indeed other medium to high performance machines) are manufactured using Silicon Iron rotor and stator cores
- Silicon Iron (which contains ~3% Silicon) is a relatively low cost material (approx £1-£2 per kg depending on grade and lamination thickness)
- Provides a reasonable compromise between high electrical resistivity (useful for reducing eddy current losses) and saturation flux density (~2.03T according to ‘physics’ definition)
- However, the shape of a typical ψ-I curve suggests that an increase in torque could be achieved if a material with a high saturation flux density was used
- One candidate is Cobalt Iron, specifically the grades with ~49% Cobalt content (saturation flux density of ~2.35T)
- Very expensive (order of £100 per kg depending on quantity and grade)
- Use in electrical machines is usually limited to aerospace and motor-sport where the very substantial cost premium can be tolerated (80-100 times the cost for ~15% higher performance!)

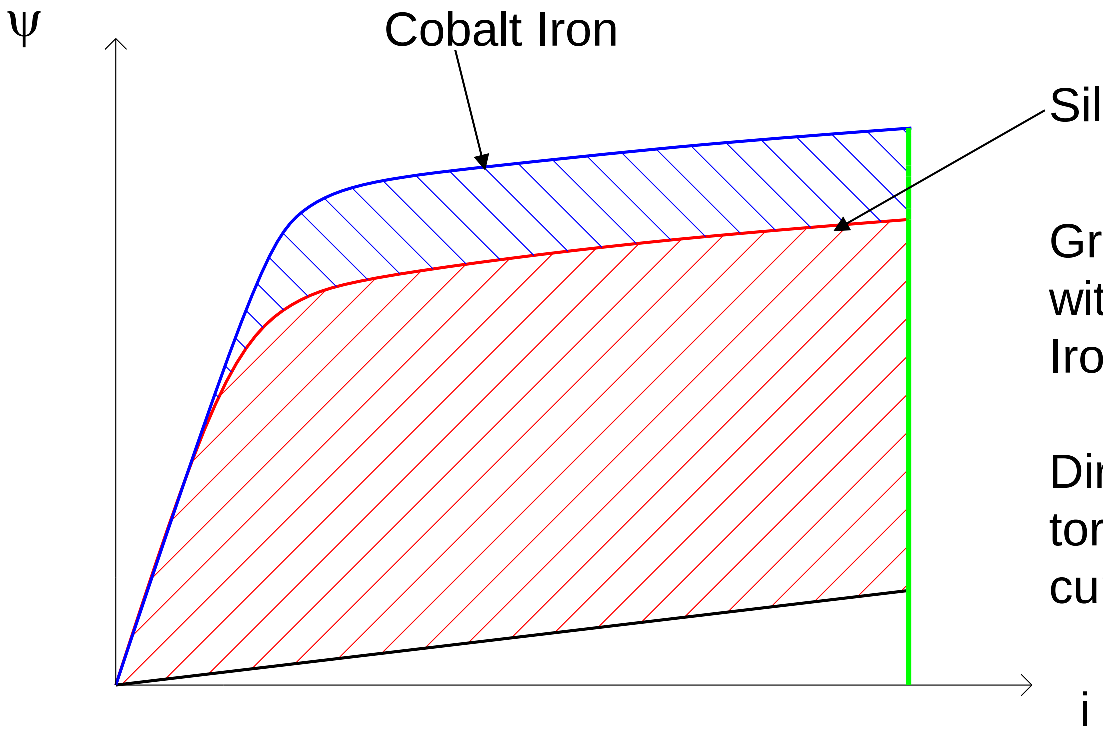
Comparison of typical Cobalt Iron magnetisation curve with Silicon Iron



Further details on materials at

http://www.vacuumschmelze.de/dynamic/docroot/medialib/documents/broschueren/htbrosch/Pht-004_e.pdf

Effect of replacing Silicon Iron with Cobalt Iron on ψ-I characteristic



Greater co-energy change with Cobalt Iron once Silicon Iron is saturated

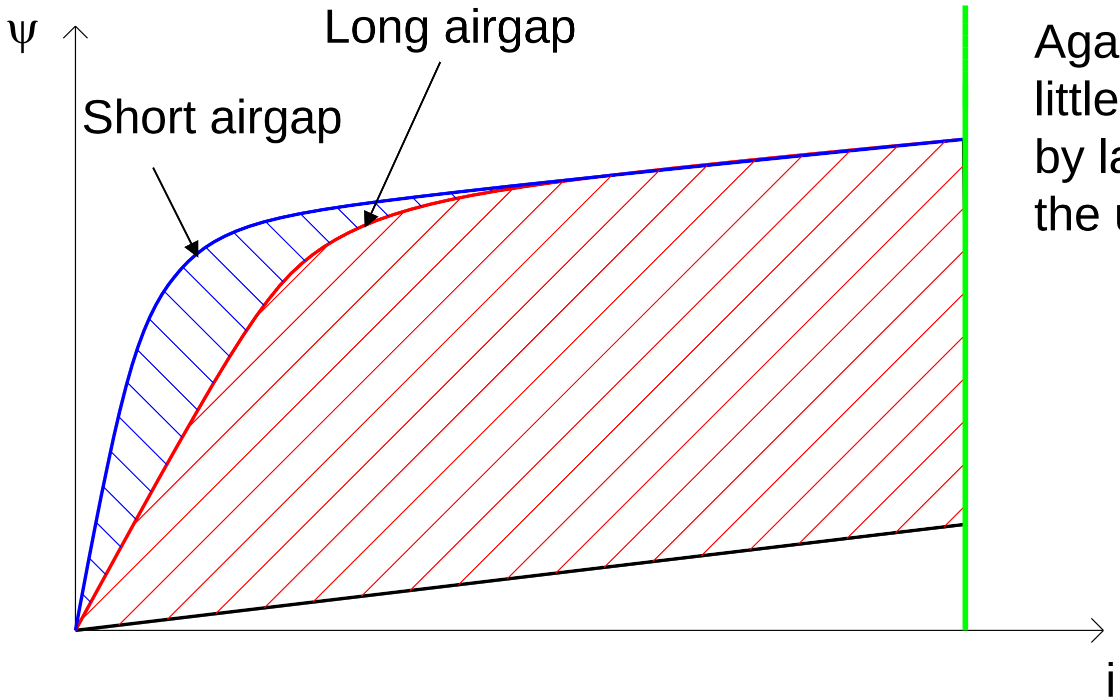
Directly translates to higher torque (but only at higher currents)

Both characteristics in the un-aligned position will be essentially identical
-No real saturation at play and reluctance dominated by various air paths

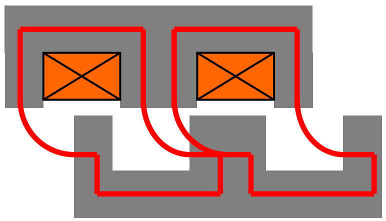
-Slope of both aligned curves are equal – slope dominated by influence of airgap

Reduce airgap in aligned position

Effect on ψ-i characteristic

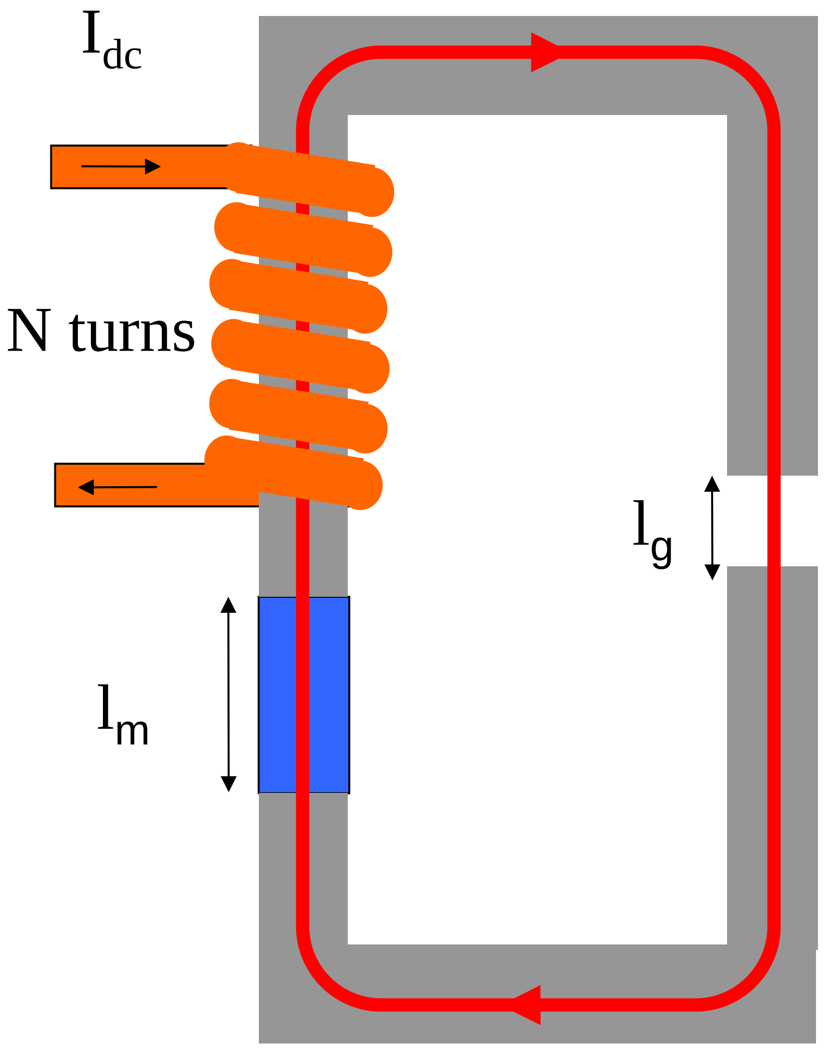


Again un-aligned curve shows little or no effect – dominated by larger effective airgaps in the unaligned position



Slope steeper with reduced airgap but saturation effects similar in both cases
Achieve slightly higher torque but more difficult to manufacature

ψ-I modelling of permanent magnet polarised devices

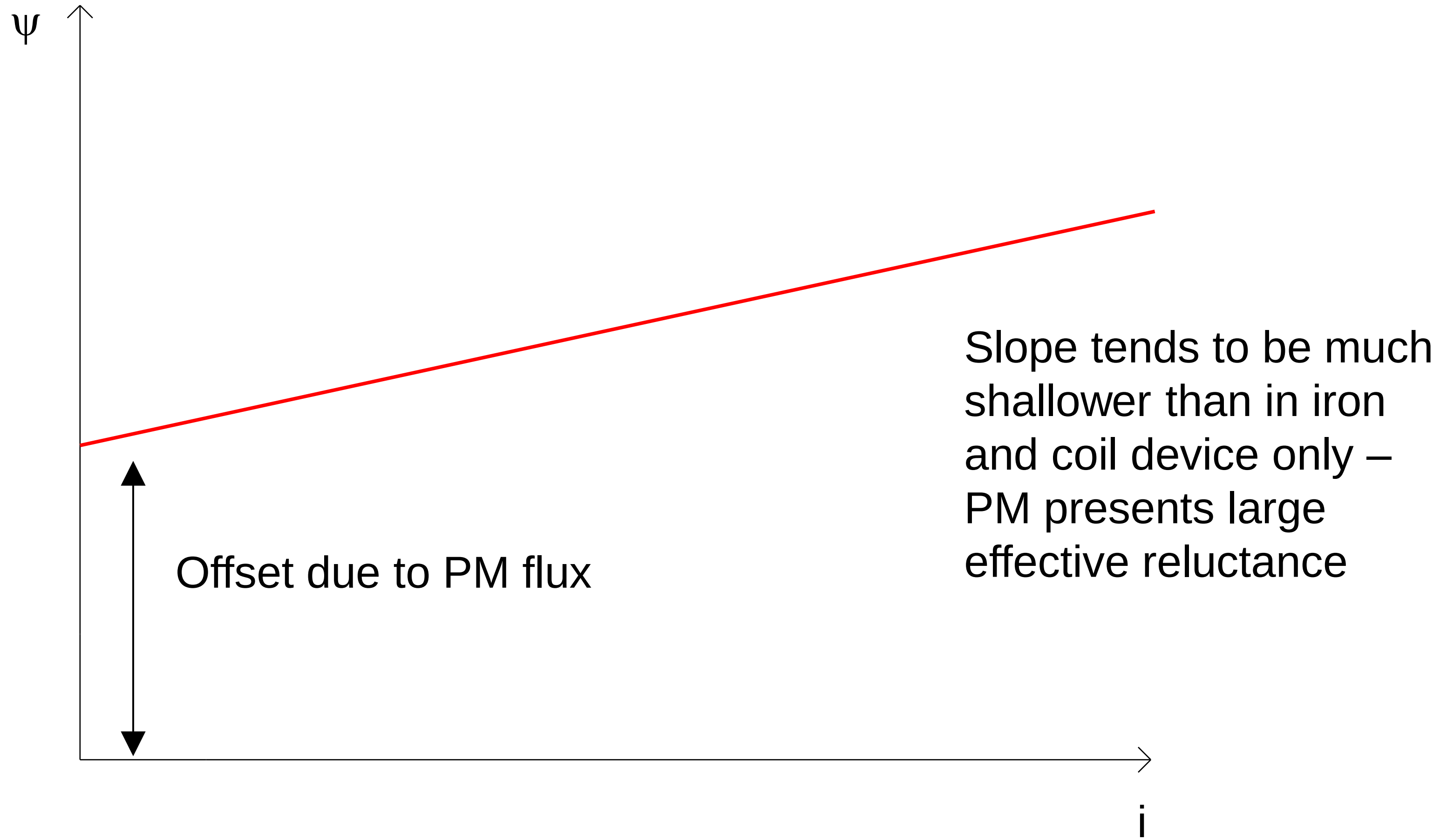


In the absence of current in the coils, then there is fixed, non-zero, flux density in the airgap which is produced by the permanent magnet

$$B_g = \frac{B_r}{1 + \mu_r \dfrac{l_g}{l_m}}$$

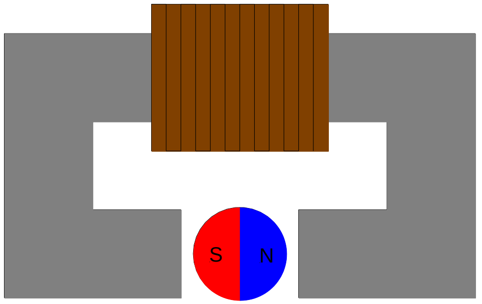
B_g – airgap flux density
B_r – magnet remanence (material property)
μ_r – relative recoil permeability of magnet (dimensionless – typically 1.05 for a permanent magnet)

Typical ψ-I characteristic for a magnetic circuit with PM excitation



All usual effects associated with saturation of cores are still possible – however less prevalent than in SR machines

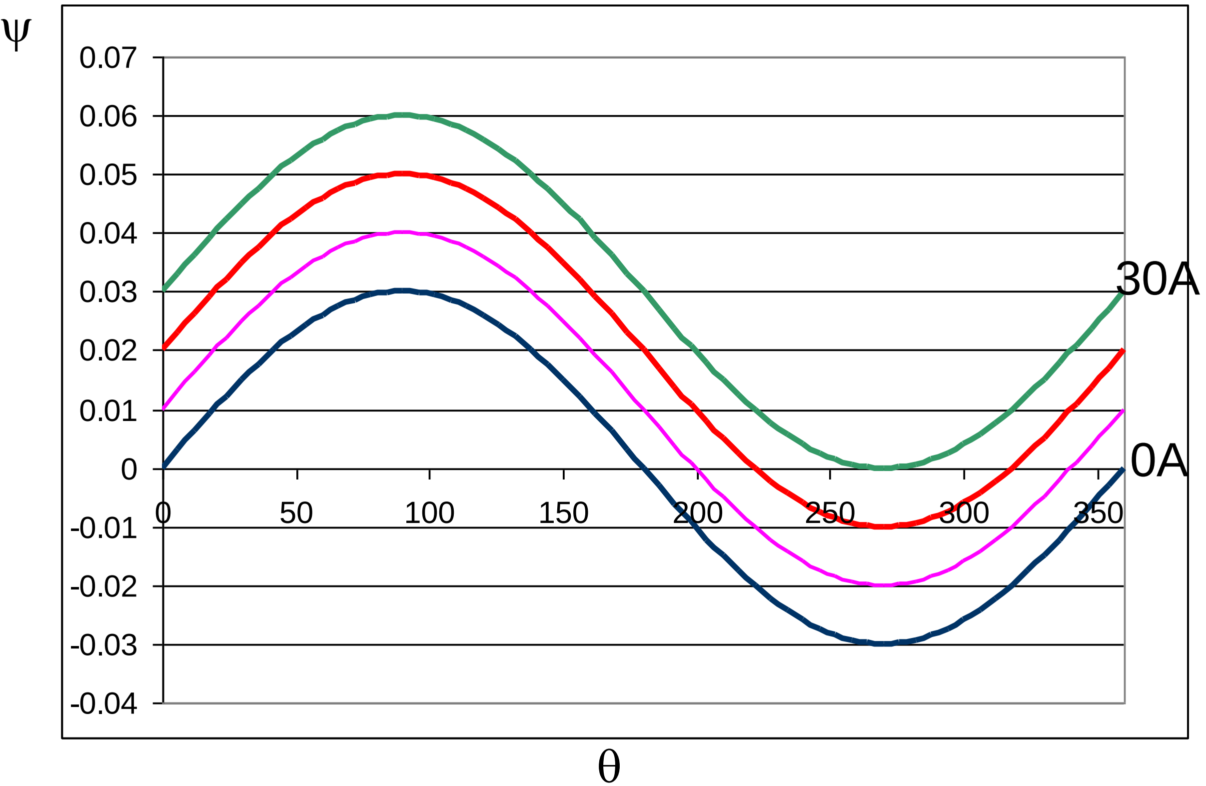
Application to rotating PM machines



Consider a single-phase synchronous motor which produces a sinusoidal flux linkage variation with rotor angular displacement

N.B Flux linkage present even with i=0

More intuitive to start with ψ- θ characteristics



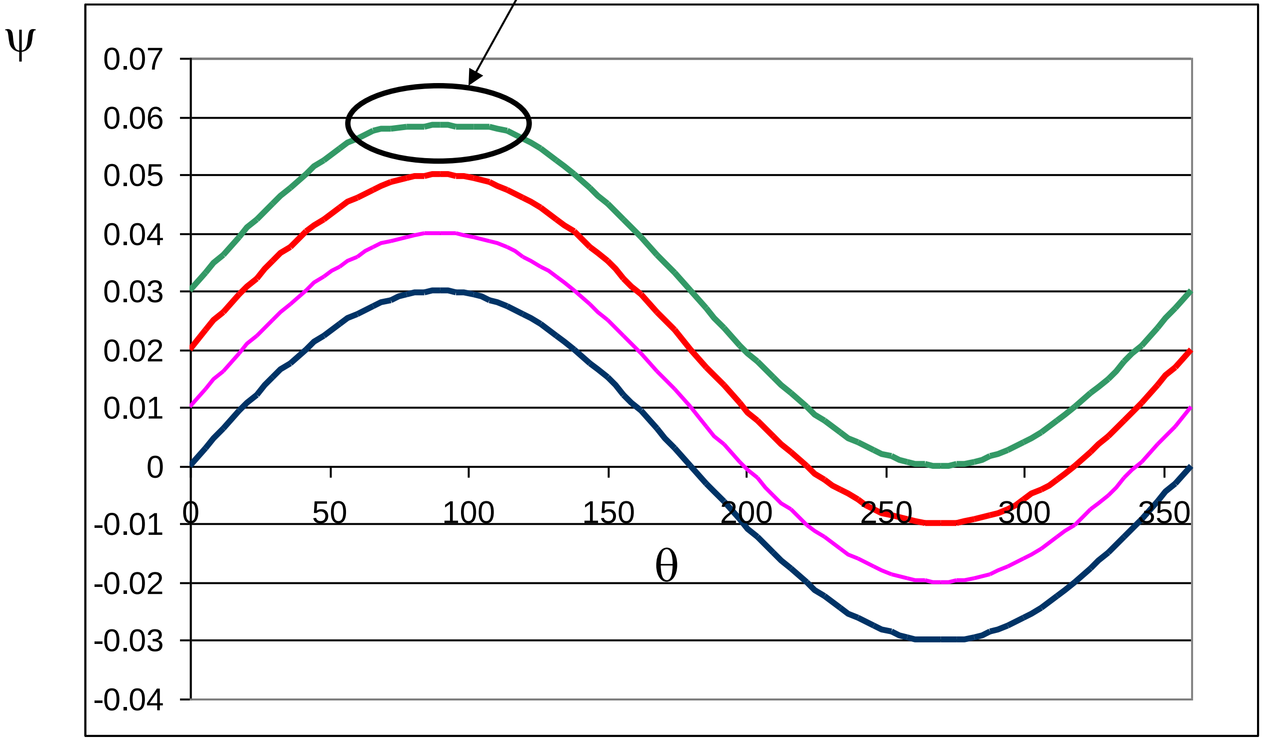
Increasing DC bias as current increased

No change in shape (and hence no change in $d\psi/d\theta$) with increasing current if no saturation encountered

Influence of magnetic saturation

- Tends to suppress flux linkage values at higher values (note: asymmetric nature of characteristics because current either pro-magnetises or de-magnetises the magnet)

Onset of magnetic saturation



Lose torque capability at high currents

But saturation is a function of rotor position (which determines magnet flux) and current