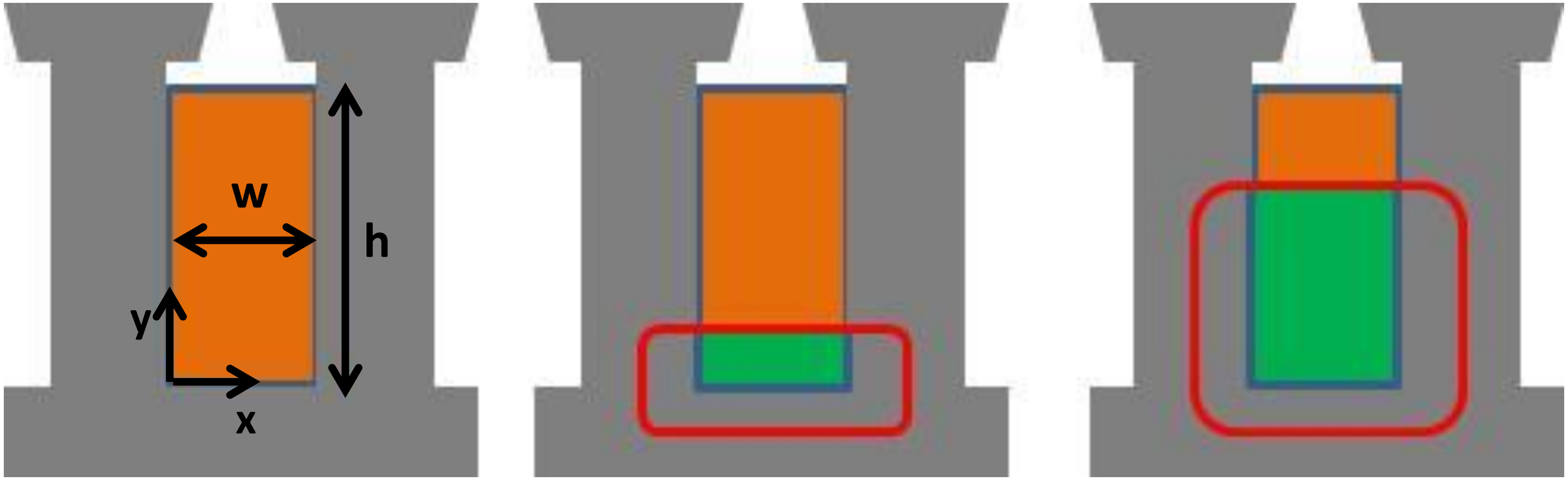
Cross-slot leakage



Application of Ampere's Law (i.e. the integral of H around a closed path equals the current enclosed by that path) clearly demonstrates that the cross-slot leakage flux increases towards the front of the slot, i.e. the region of the slot nearest the airgap

Assuming that the stator core is infinitely permeable then the x-component of magnetic field strength in the rectangular section of the slot is given by:

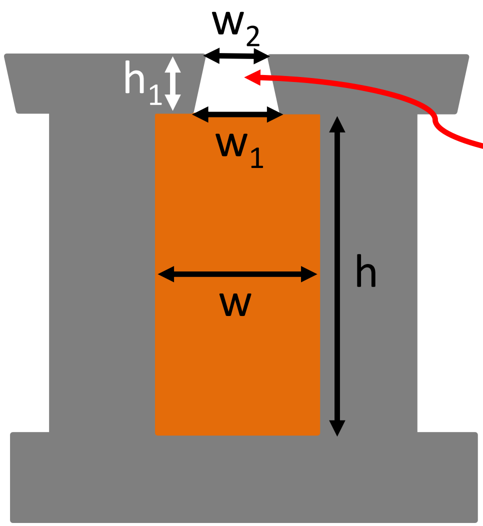
$$H_x(y) = \frac{Jwy}{w} = Jy$$

Hence, the flux density is given by: $B_x(y) = \mu_0 Jy$

If the axial length of the machine is Lax, then the total flux across the region of the slot which is occupied by the coil is given by:

$$\emptyset_{cs1} = \int_0^h B_x L_{ax} dy = \mu_0 L_{ax} \int_0^h Jy\, dy = \mu_0 L_{ax} J \left[\frac{y^2}{2}\right]_0^h = \frac{\mu_0 L_{ax} J h^2}{2}$$

The cross-slot leakage in regions outside the stator coil can similarly be calculated, recognising that the integration path encompasses the full current.

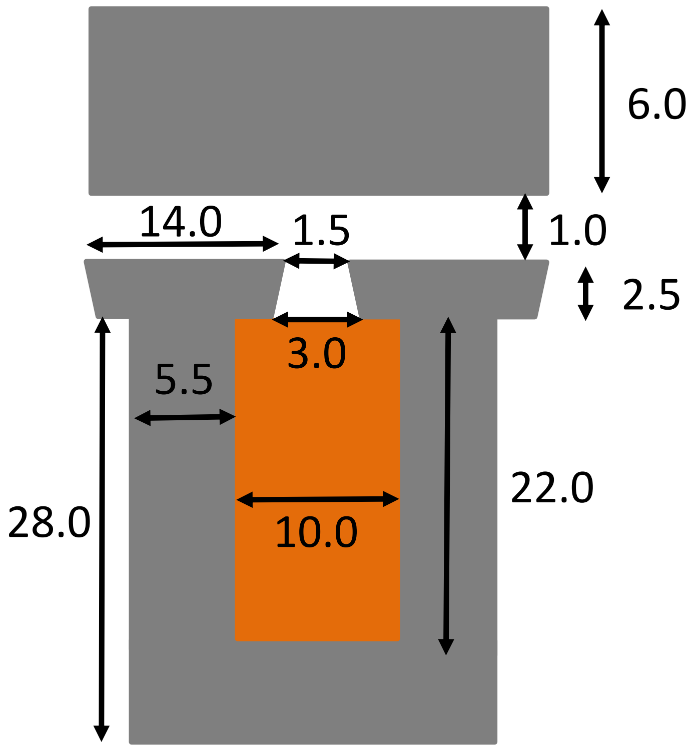


$$Cross\ sectional\ area = h_1 L_{ax}$$

$$Mean\ path\ length = \frac{w_1 + w_2}{2}$$

$$\emptyset_{cs2} = \frac{whJ\, \mu_0 L_{ax}\, h_1}{\frac{w_1 + w_2}{2}}$$

Example – simplified single slot



Slot packing factor = 0.45
Current density in conductor = 5A/mm^2
Axial length = 50mm

Effective current density across slot 0.45×5 = 2.25A/mm^2

Flux through main airgap

$$\varnothing_{gap} = \frac{Jwhw_p L_{ax}\mu_0}{2l_g}$$

$$= \frac{2.25 \times 10^6 \times 0.01 \times 0.022 \times 0.014 \times 0.05 \times 4\pi \times 10^{-7}}{0.002}$$

$$= 2.18 \times 10^{-4} Wb$$

$$\varnothing_{cs1} = \frac{\mu_0\, L_{ax}\, Jh^2}{2} = \frac{4\pi \times 10^{-7} \times 0.05 \times 2.25 \times 10^6 \times 0.022^2}{2} = 3.42 \times 10^{-5} Wb$$

$$\varnothing_{cs2} = \frac{whJ\, \mu_0\, L_{ax}\, h_1}{\frac{w_1 + w_2}{2}} = \frac{0.01 \times 0.022 \times 2.25 \times 10^6 \times 4\pi \times 10^{-7} \times 0.05 \times 0.0025}{0.00225}$$

$$= 3.46 \times 10^{-5} Wb$$

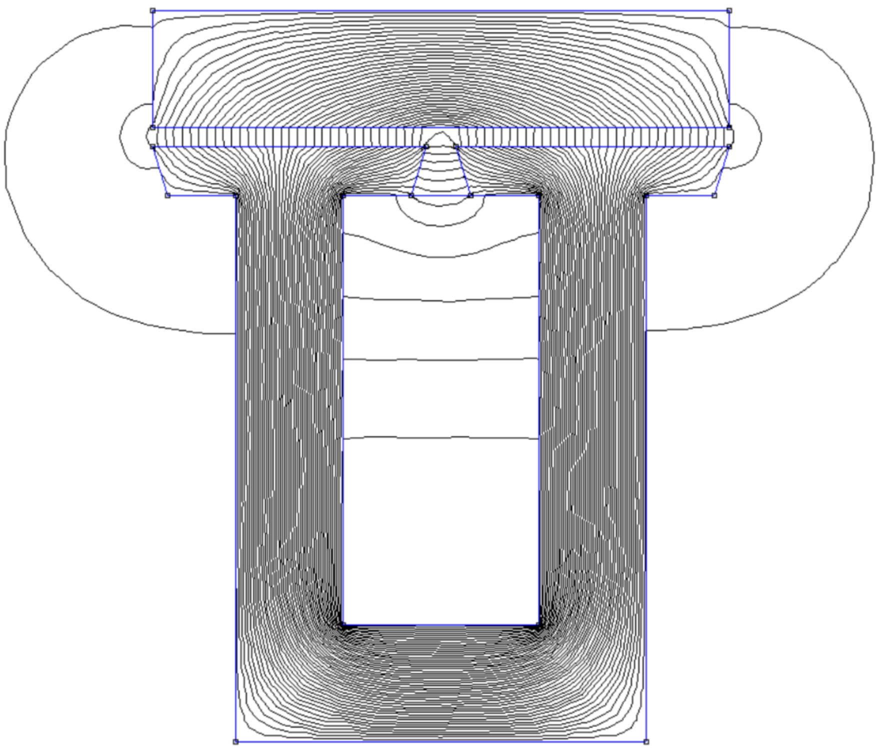
Total flux is hence given by:

$$\emptyset_{total} = \emptyset_{gap} + \emptyset_{cs1} + \emptyset_{cs2} = 2.18 \times 10^{-4} + 3.42 \times 10^{-5} + 3.46 \times 10^{-5} = 2.86 \times 10^{-4} Wb$$

Inductance for **1 turn** is given by: $L = \dfrac{\emptyset_{total}}{Jwh} = \dfrac{2.86 \times 10^{-4}}{0.01 \times 0.022 \times 2.25 \times 10^{6}} = 0.578 \mu H$

This can be scaled by the square of the number of turns to obtain the actual inductance

Comparison with finite element modelling:



Finite element predicted coil flux linkage for 50mm deep model = 3.15×10^{-4}Wb (c.f. 2.86×10^{-4}Wb) from analytical model

50 Equipotential contours shows
– also referred to as ‘flux lines’
Equal flux between each pair of contours
Approx. 12% of flux crosses coil region
Approx. 14% of flux cross between tooth tips
Approx. 70% of flux crosses main gap
Approx 4% of flux leaks outside slot region modelled analytically