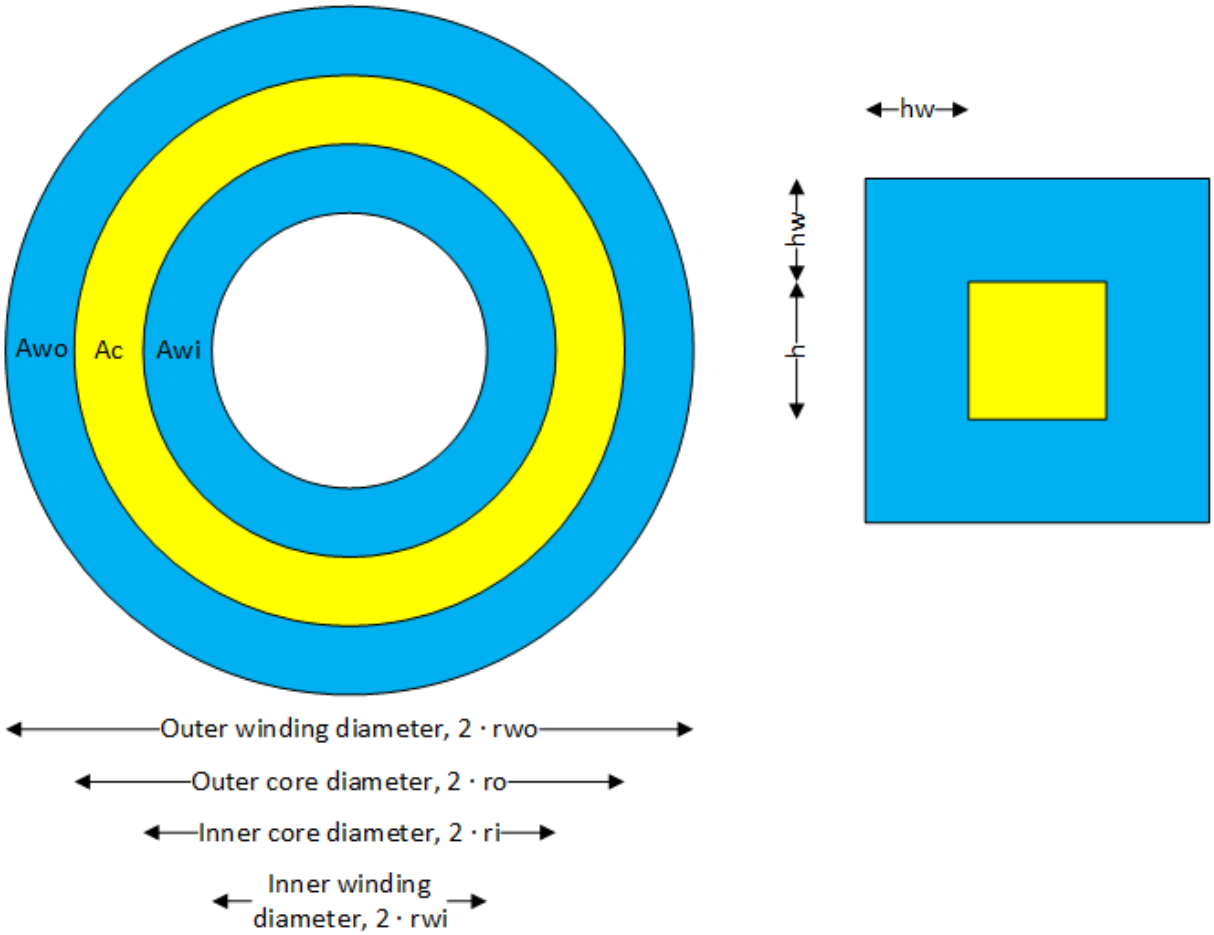
Surface Area Calculations: Temperature Rise of a Ring Core

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For an R 41.8/26.8/12.5 ring core.

Core dimensions

$r_o := \frac{41.8\ mm}{2} = 20.9\ mm$ $r_i := \frac{26.2\ mm}{2} = 13.1\ mm$ $h := 12.5\ mm$

Presumed shuttle radius required (start with assumption that half the inner radius is needed for the shuttle unless your build-to-print house tells you they can wind on more turns).

$r_s := \frac{r_i}{2} = 6.55\ mm$

Area of a torus

$A_{tor} = \left(R_o^{\ 2} - R_i^{\ 2}\right) \cdot \pi$

Ator - Area of the torus
Ro - outer radius
Ri - inner radius

The inner wound area

$$A_{wi} := \pi \cdot \left({r_i}^2 - {r_s}^2 \right) = 4.043 \ cm^2$$

The inner wound diameter (should be same as the minimum shuttle requirement)

$$r_{wi} := \sqrt{{r_i}^2 - \frac{A_{wi}}{\pi}} = 6.55 \ mm$$

The winding height

$$h_w := r_i - r_{wi} = 6.55 \ mm$$

The core + winding height (total height)

$$h_{tot} := h + 2 \cdot h_w = 25.6 \ mm$$

Awi = Awo - same amount of copper and at the same fill factor. Same amount of Kapton tape and former material etc. etc.

$$A_{wo} := A_{wi}$$

$$r_{wo} := \sqrt{\frac{A_{wo}}{\pi} + {r_o}^2} = 23.781 \ mm$$

Outer wound diameter

$$d_{wo} := 2 \ r_{wo} = 47.561 \ mm$$

Inner wound diameter

$$d_{wi} := 2 \cdot r_{wi} = 13.1 \ mm$$

The width of the outer winding torus (should be less than the width of the inner winding torus.)

$$r_{wo} - r_o = 2.881 \ mm$$

The surface area assuming the part is clamped and potted into a cylinder

$$S_a := 2 \cdot \pi \cdot {r_{wo}}^2 + \pi \cdot r_{wo} \cdot 2 \cdot h_{tot} = 73.784 \ cm^2$$

The surface area assuming the part is a torus with air flow on the inner curved surface as well as the outer curved surface and the flat surfaces

$$S_{a2} := 2 \cdot \pi \cdot \left({r_{wo}}^2 - {r_{wi}}^2 \right) + \left(r_{wo} \cdot 2 + r_{wi} \cdot 2 \right) \cdot \pi \cdot h_{tot} = 81.624 \ cm^2$$

Expected total power loss in the wound component. This comes from your initial 'loss budget'. If you have a target efficiency and a target power throughput for your power electronics system as a whole, you already have starting point for writing a 'loss budget'. Alternatively if the design is near to completion and the expected losses in the core and the windings are known then use the expected figure.

$$P_L := 10 \ W$$

The loss density per unit surface area

$$\psi := \frac{P_L}{S_a} = 0.136 \ \frac{W}{cm^2}$$

Temperature rise above ambient presuming natural convection in free, otherwise still, air

$$\Delta T := 0.2235 \cdot \frac{s^{\frac{845}{341}} \cdot K}{kg^{\frac{413}{500}}} \cdot (\psi)^{0.826} = 86.366 \ K$$

Assumed maximum ambient temperature

$T_{amb} := 30 \ °C$

Wound component surface temperature.

$T := T_{amb} + \Delta T = 116.366 \ °C$

Notes

Around 120°C is 'ok', although it depends on the application and the engineering domain and the standards that must be met. If there is forced air or water cooling available then the free air temperature approximation can be run to quite high values perhaps 160 - 180°C with a reasonable expectation that it will be 'ok'. Again it depends on the cooling available and the thermal resistance from the point of heat generation to the coolant. Only a coupled EM + heat flow FEA and coolant CFD can give detailed predictions and only if the input parameters are physically representative of the system being modelled, and the mesh is well conceived etc. etc.

We can also pot the cores in thermally conducting electrically insulating resin and provide a metallic potting box which has good thermal contact with a cold plate or fins to increase it's surface area in contact with the passing air.

What if the temperature prediction is too high?

One needs to decide if it's core or copper losses that dominate the design and then work to reduce the things that cause the loss.

If it's core losses that dominate then lower the flux density (bigger core cross-sectional area or change the inductance and or impressed voltage in order to change the current). Alternatively lower the frequency or just change to a lower loss material (lower loss materials tend to be more expensive). Lowering the frequency tends to necessitate a larger core. So, all in all, "make the core bigger" is the rule of thumb if it's too hot.

If it's copper loss that dominates try to give yourself more window area (i.e. make the core bigger in order to enclose a larger winding window). Don't be tempted to take less turns and put more copper area per turn as less turns means lower inductance and therefore higher current for a given impressed voltage. Copper losses go with RMS current squared so more current is generally much worse than any reduction in resistance that might obtained.

If the available volume for the part is already fixed, it may be possible to optimise the Ap or Kg of your core for the given volume (for example, https://bearinstruments.co.uk/blog/2021/03/05/are-mechanical-constraints-driving-your-magnetic-core-sizing/).

Of course making the part bigger adds weight and takes footprint away from other components and generally more ferrite + more copper = more money, so, costs go up too.

On the other hand part lifetime reduces strongly super-linearly with increasing temperature.

The choices made in the wound component design should be influenced by the power electronics architecture, the system level design requirements and the overall product requirements/standards and engineering domain. For this reason it is critical to have a close working relationship with trusted wound component designers/suppliers if you're not in a position to take the work in-house.

Design Support from our resident Magnetics Designers

Bear Instruments provides attractive magnetic component solutions including full design documentation, production of samples, test, validation, on-site support and reporting as well as mass production and distribution via our selected partners. Call or email to find out how we can push your product development forward.