Sigmaphi SHMS Magnet Projects
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Current Bus Safety in the SHMS Dipole

Martin N Wilson

1. Introduction

Here I define the current bus as the superconducting link running down the neck tube between the helium vessel of the CCR and the magnet. At present, it is planned to make the current bus from two bare cables connected in parallel. I show that this arrangement is at risk of burn out if the helium level falls, and suggest a simple fix.

2. Calculations

If liquid in the CCR falls, temperature of the current leads from room temperature will rise by conduction and Ohmic heating, and this will quench the current bus. The bus is many metres long, so it is a fair approximation to assume adiabatic conditions where it is not in liquid. We may therefore use the U(θ) function to estimate its temperature rise:

$$U(\theta) = \int_0^\infty J^2(t)\, dt = \int_{\theta_o}^{\theta_m} \frac{\gamma\, C(\theta)}{\rho(\theta)}\, d\theta$$

where γ = density, C(θ) = specific heat and ρ(θ) = resistivity.

Fig 1 plots U(θ) for the bare pair of cables which contain 56.6% copper and 31.4% NbTi (the rest is voidage).

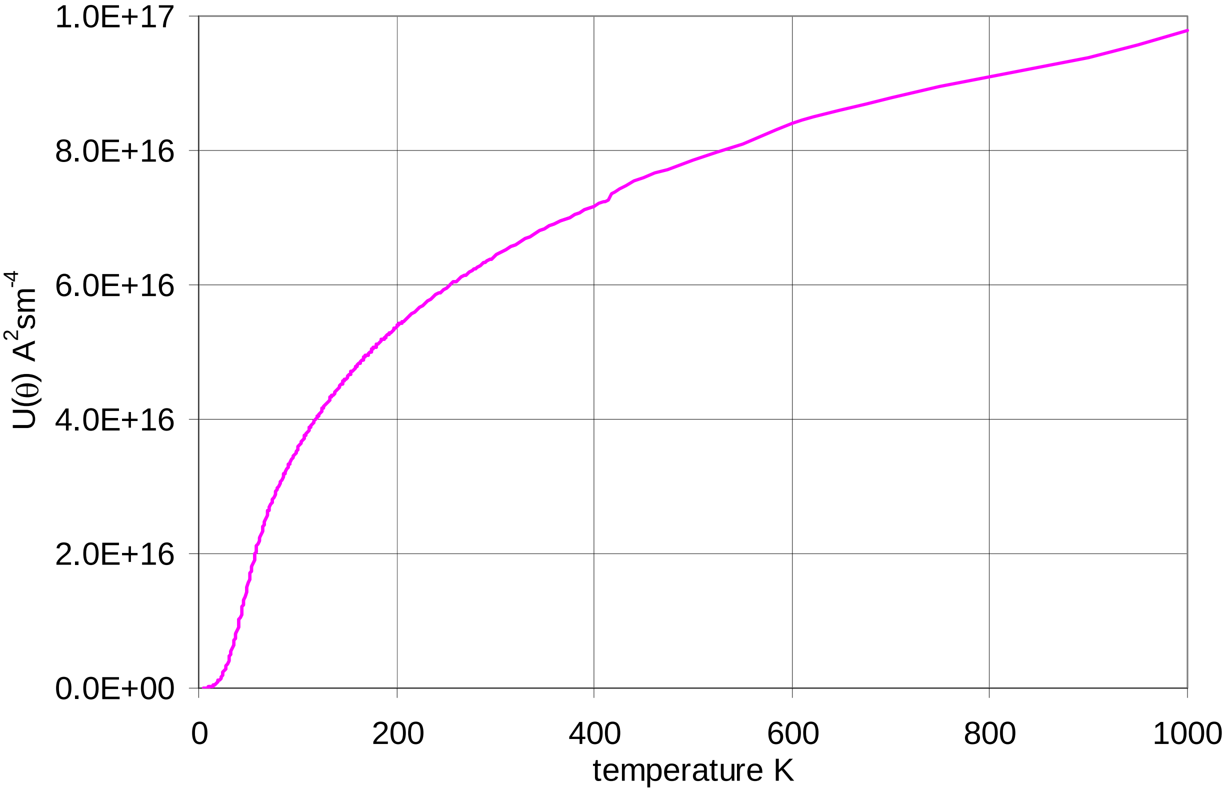

Fig 1: U function for current bus made from two bare cables

Let us assume that the safety system opens the circuit breaker immediately the current bus quench is detected, so that the magnet current decays through the protection resistor R_p. The magnet current will then decay as:

$$I(t) = I_o e^{-\frac{R_p t}{L_m}}$$

where R_p is the protection resistor and L_m is the magnet inductance, thus:

$$\int_0^\infty I^2 dt = I_o^2 \frac{L_m}{2R_p}$$

For I_o = 3465A, L_m = 2.7H and R_p = 0.075Ω, we have $\int I(t)^2 dt = 2.16\times10^8$ A^2s. For the bare cables, the unit cell area is A_u = 27.1mm^2, so that $\int J(t)^2 dt = 1/A_u^2 \times \int I(t)^2 dt = 3.18\times10^{17}$ $A^2m^{-4}s$. This level of heating is way off scale on Fig 1, corresponding to several thousand K, ie vaporization of the bus. If this were to happen, the stored magnetic energy would dissipate in an arc, probably burning through the CCR vessel and causing a major accident.

Fortunately it is easy to avoid by adding some copper stabilization. For example, the cables could be soldered to a copper braid. Fig 2 shows the resulting U(θ) function for an extra 20mm^2 of copper. It is slightly changed by the greater proportion of copper, but the biggest change comes from the increased area, hence lower J, which gives $\int J(t)^2 dt = 9.72\times10^{16}$ $A^2m^{-4}s$. The maximum temperature is thus 294K.

Doubling the extra copper to 40mm^2 gives an even more comfortable result of $\int J(t)^2 dt = 4.8\times10^{16}$ $A^2m^{-4}s$ and a maximum temperature of 77K – also shown in Fig 2.

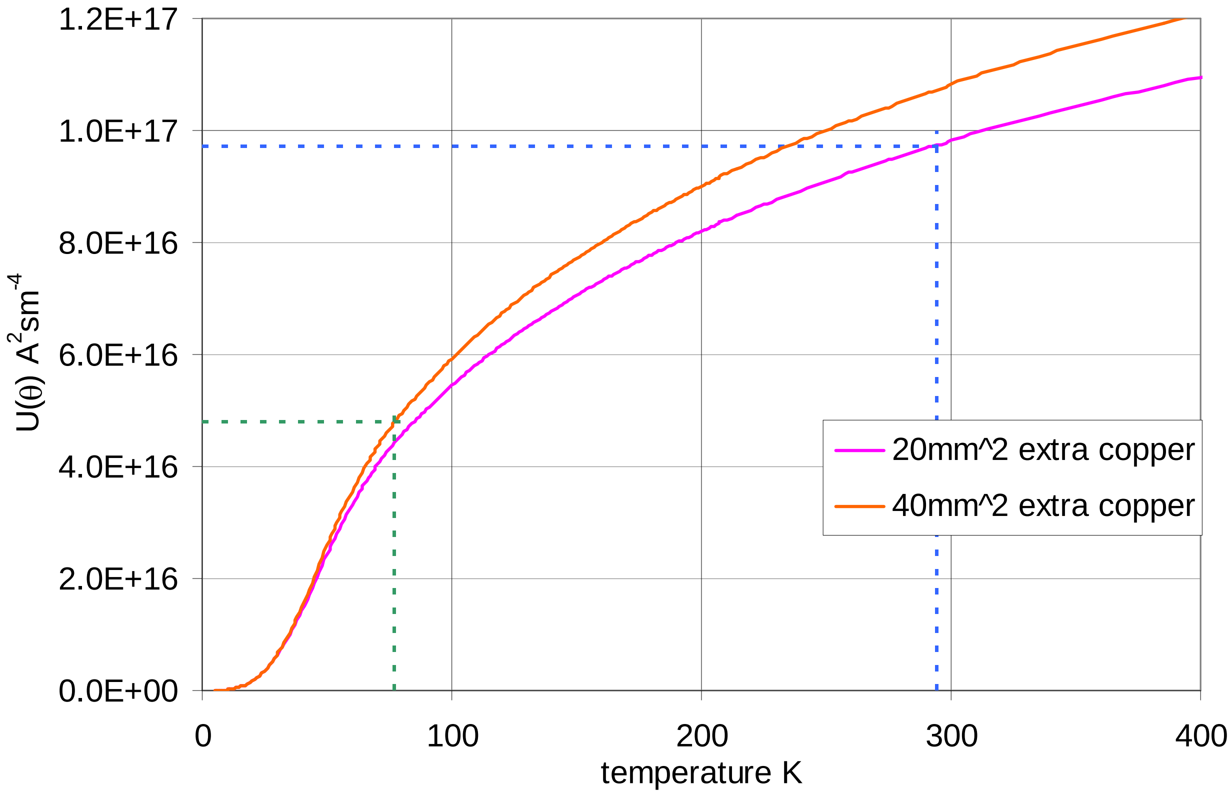

Fig 2: U(θ) function with added copper.

4. Concluding Remarks

The inference is clear: we should solder some extra copper to the current bus cables, regular earthing braid seems like a good option to keep some flexibility. 20mm^2 of extra copper keeps the temperature rise to room temperature, 40mm^2 keeps it down to nitrogen temperature, ie negligible thermal expansion.

Appendix 1: Areas and filling factors

2) Bare wire geometry

wire dia $d_w := 0.65 \cdot mm$ number of wires $N_w := 36$ $mat := 1.8$

cable size from Paul Berindza email 3 Dec $w_{cab} := 11.68mm$ mean thick's $t_{cab} := \frac{(1.271mm + 1.0530mm)}{2} = 1.162 \cdot mm$

wire area $A_w := 2 \cdot N_w \cdot \frac{\pi}{4} \cdot d_w^{\,2} = 23.892 \cdot mm^2$ area occupied by cable $A_{cab} := 2 \cdot w_{cab} \cdot t_{cab} = 27.144 \cdot mm^2$ $\lambda_{cab} := \frac{A_w}{A_{cab}} = 0.88$

wire copper area $A_{wcu} := A_w \cdot \frac{mat}{1 + mat} = 15.359 \cdot mm^2$ wire NbTi area $A_{NbTi} := A_w \cdot \frac{1}{1 + mat} = 8.533 \cdot mm^2$

$\lambda_{wcu} := \frac{A_{wcu}}{A_{cab}} = 0.566$ $\lambda_{NbTi} := \frac{A_{NbTi}}{A_{cab}} = 0.3143$ check $\lambda_{wcu} + \lambda_{NbTi} = 0.88$

3) Minimum Stabilizer

area stabilizer $A_{st1} := 20 \cdot mm^2$ area solder $A_{so} := A_{cab} - A_w = 3.253 \cdot mm^2$

unit cell area $A_{u1} := A_{st1} + A_{wcu} + A_{so} + A_{NbTi} = 47.144 \cdot mm^2$

$\lambda_{cu1} := \frac{A_{st1} + A_{wcu}}{A_{u1}} = 0.75$ $\lambda_{NbTi1} := \frac{A_{NbTi}}{A_{u1}} = 0.181$ $\lambda_{so1} := \frac{A_{so}}{A_{u1}} = 0.069$

$\lambda_{cu1} + \lambda_{NbTi1} + \lambda_{so1} = 1$

4) Comfortable Stabilizer

area stabilizer $A_{st2} := 40 \cdot mm^2$ area solder $A_{so} := A_{cab} - A_w = 3.253 \cdot mm^2$

unit cell area $A_{u2} := A_{st2} + A_{wcu} + A_{so} + A_{NbTi} = 67.144 \cdot mm^2$

$\lambda_{cu2} := \frac{A_{st2} + A_{wcu}}{A_{u2}} = 0.824$ $\lambda_{NbTi2} := \frac{A_{NbTi}}{A_{u2}} = 0.127$ $\lambda_{so2} := \frac{A_{so}}{A_{u2}} = 0.048$

$\lambda_{cu2} + \lambda_{NbTi2} + \lambda_{so2} = 1$