Analysis of Quench Propagation in Solenoids

Scope

1. Introductory remarks
2. Material properties
3. Coil parameters
4. Magnetic field interpolation
5. Cycling
6. Critical temperature matrix
7. What is not yet done?

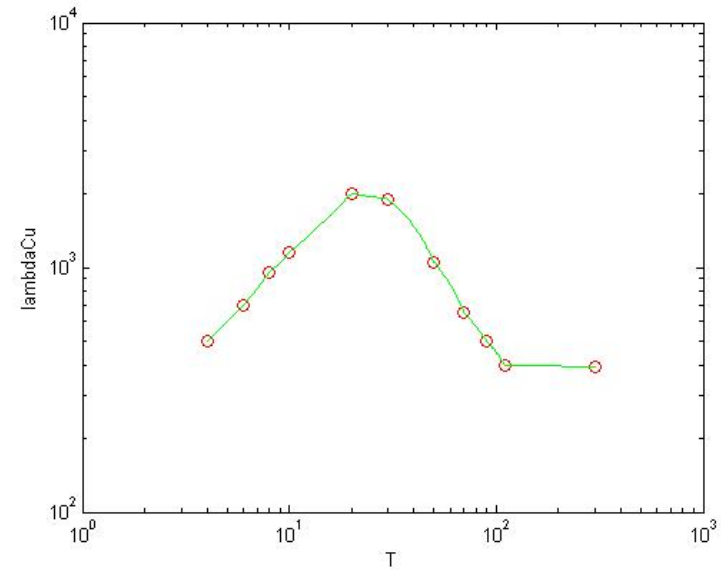
Why do we need it?

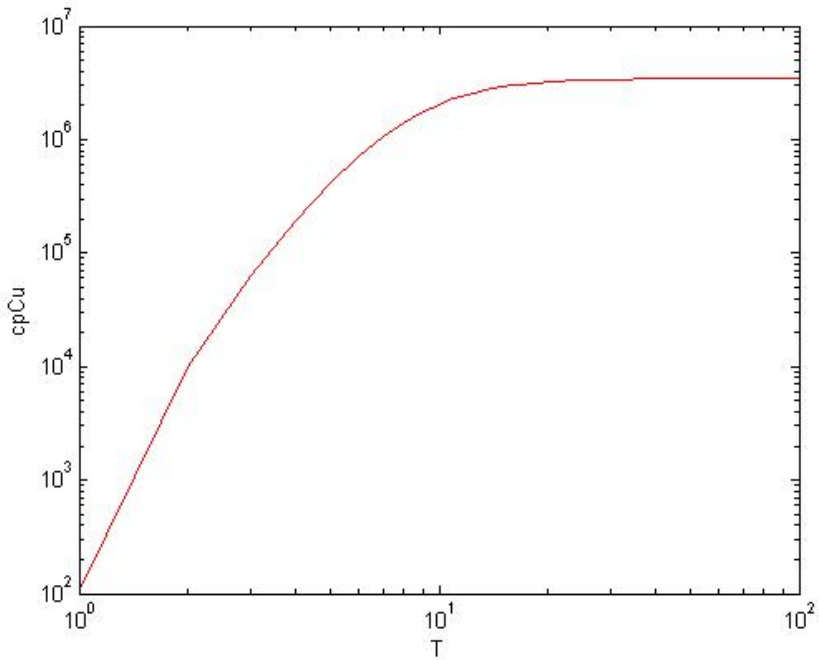
Quench events are inevitable during the testing, so it is very important to make the magnet tests possible with different setups. It gives more options for designers, because all the solenoid parameters could be changed.

Material Properties

T (K)	2	4	6	10	20	50	80	100	200	300
λ(G10)	0.03	0.057	0.082	0.12	0.17	0.24	0.3	0.32	0.45	0.65

- Specific Heat
- Thermal Conductivity
- Specific Resistance
- Critical Surface of NbTi





$\gamma Cu := 0.011$ J/K^2/kg $\rho Cu := 8960$ kg/m^3

$\beta Cu := 0.000744$ J/K^4/kg $cpCu300 := 3.454 \cdot 10^6$ J/K/m^3

$$cpCulow(T) := \left(\gamma Cu \cdot \rho Cu \cdot T + \beta Cu \cdot \rho Cu \cdot T^3\right)$$

$$cpCu(T) := \frac{1}{\left(\frac{1}{cpCu300}\right) + \left(\frac{1}{cpCulow(T)}\right)}$$ **J/K/m^3**

Specific resistance

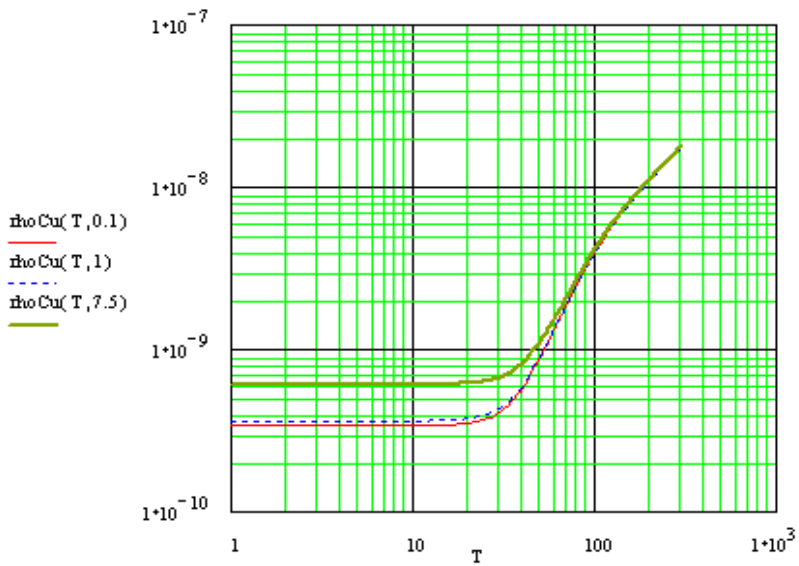
$$\rho 1(T) := \frac{1.171 \cdot 10^{-17} \cdot (T)^{4.49}}{1 + \left[4.5 \cdot 10^{-7} \cdot (T)^{3.35} \cdot e^{-\left(\frac{50}{T}\right)^{6.428}}\right]}$$

$$\rho 2(T) := \left(\frac{1.69 \cdot 10^{-8}}{RRR} + \rho 1(T) + 0.4531 \cdot \frac{1.69 \cdot 10^{-8} \cdot \rho 1(T)}{RRR \cdot \rho 1(T) + 1.69 \cdot 10^{-8}}\right)$$

$$A(T,B) := \log\left(1.553 \cdot 10^{-8} \cdot \frac{B}{\rho 2(T)}\right)$$

$$a(T,B) := -2.662 + 0.3168 \cdot A(T,B) + 0.6229 \cdot A(T,B)^2 - 0.1839 \cdot A(T,B)^3 + 0.01827 \cdot A(T,B)^4$$

$$rhoCu(T,B) := \rho 2(T) \cdot \left(1 + 10^{a(T,B)}\right)$$



Critical Surface Parameterization

$$\frac{J_c(B,T)}{J_{cref}} = \frac{C_0}{B}\left[\frac{B}{B_{c2}(T)}\right]^{\alpha}\left[1-\frac{B}{B_{c2}(T)}\right]^{\beta}\left[1-\left(\frac{T}{T_{c0}}\right)^{1.7}\right]^{\gamma}$$

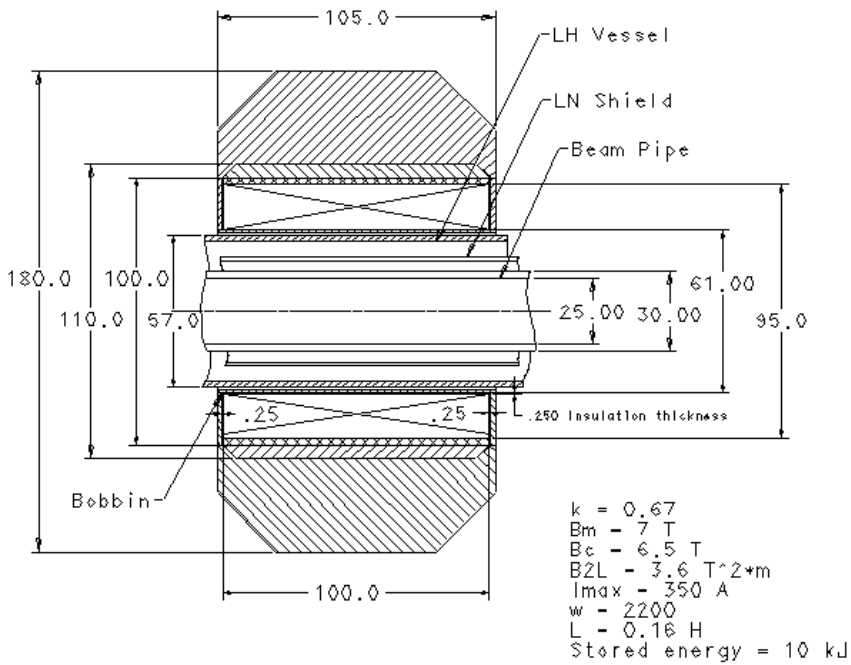
$$B_{c2}(T) = B_{c20}\left[1-\left(\frac{T}{T_{c0}}\right)^{1.7}\right]$$

C0 = 30 T, α = 0.6, β = 1.0, γ = 2.0,
Jcref = 2800 A/mm2, Tc0 = 9.2 K,
Bc20 = 14.5 T.

Coil Parameters

NumLayers = 25
NumTurns = 100-200
Strand dimensions: ws=1mm
hs=1mm

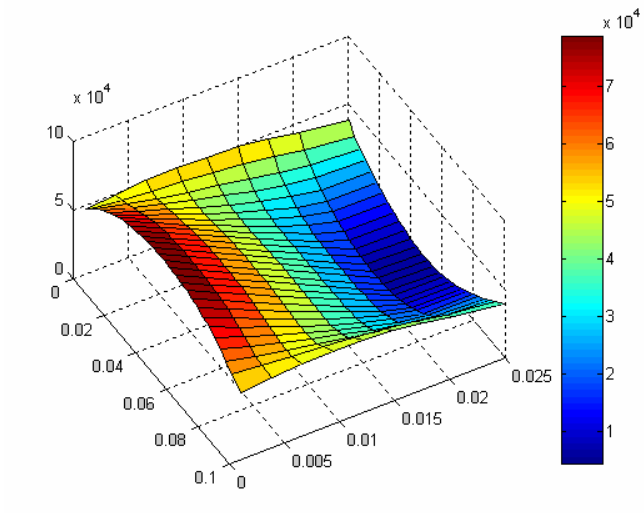
Imax = 350A
L = 0.16 H



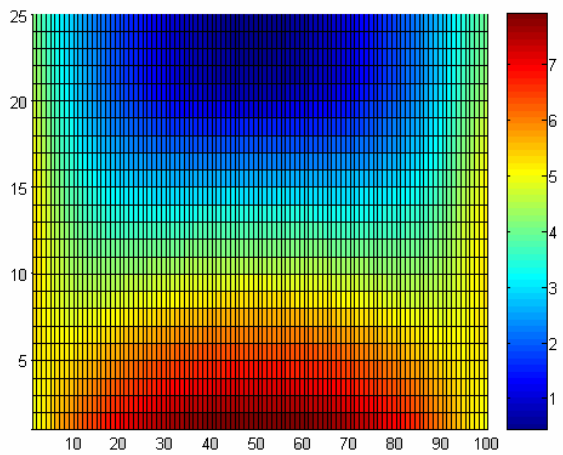
Magnetic field

Input from file

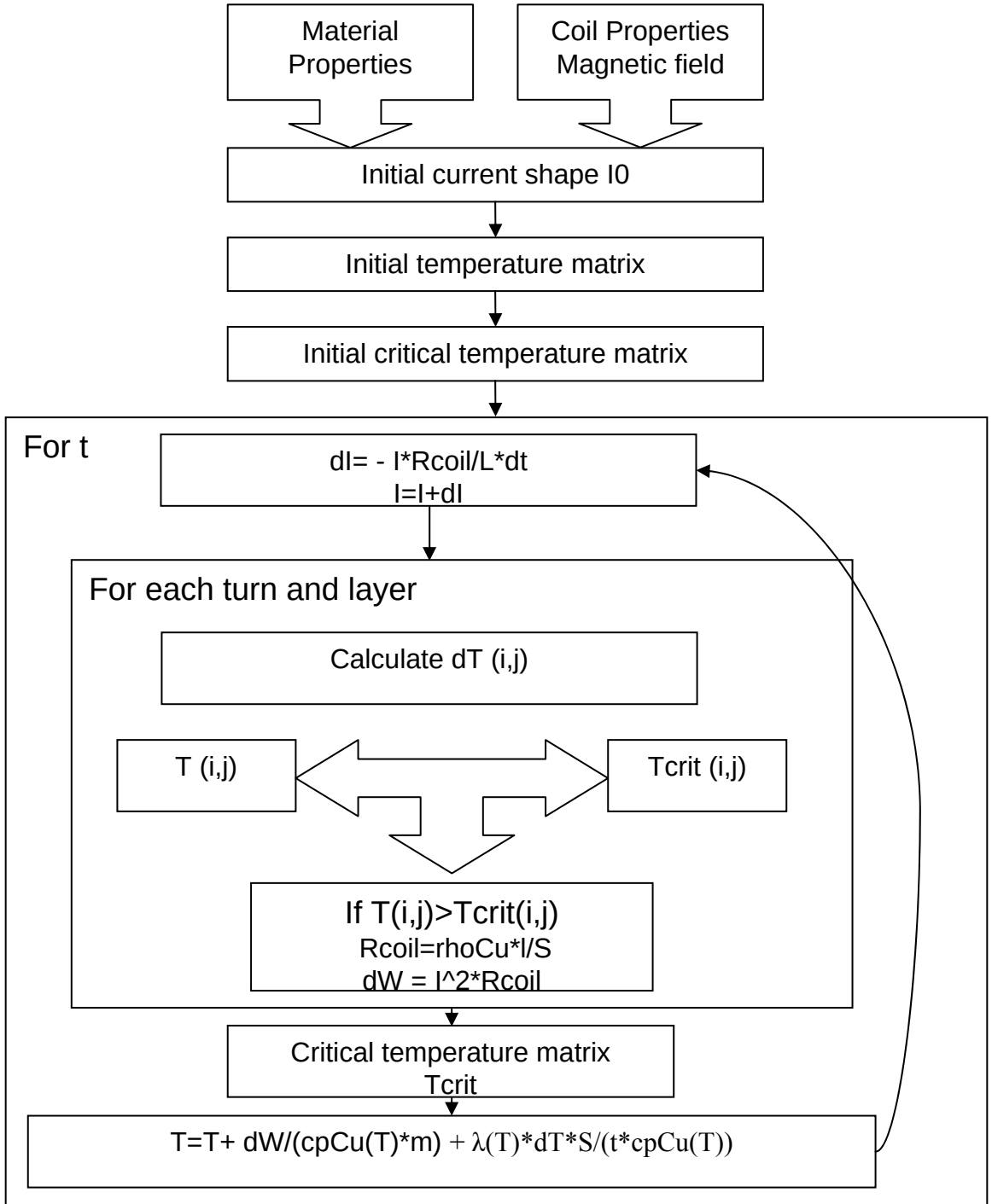
Before interpolation



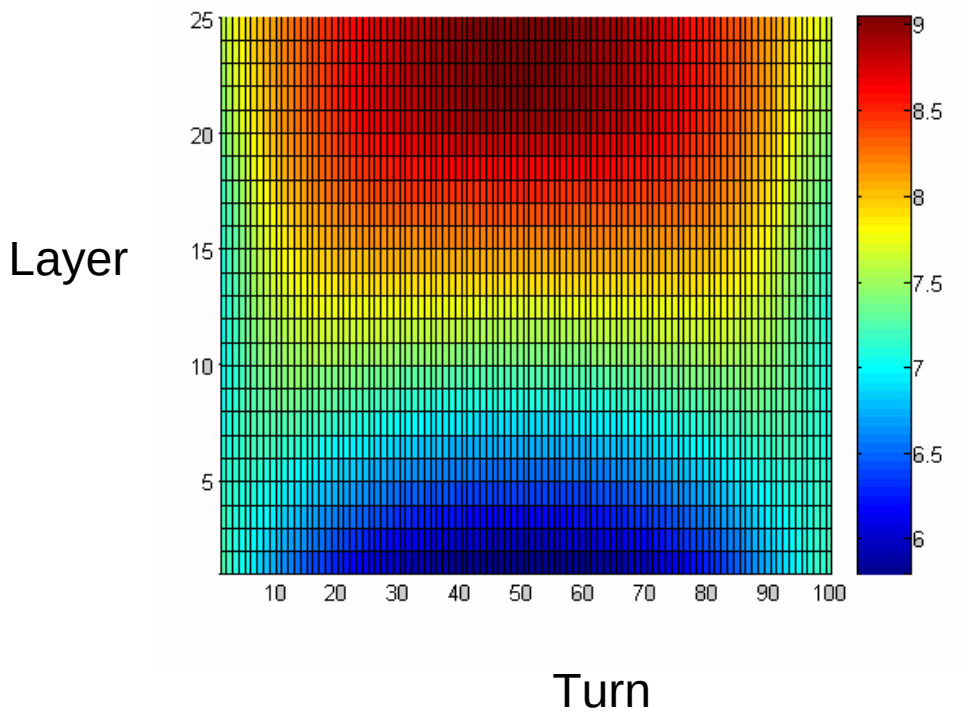
Linear interpolation



Cycling


Material Properties
Coil Properties Magnetic field
Initial current shape I0
Initial temperature matrix
Initial critical temperature matrix
For t
dI= - I*Rcoil/L*dt
I=I+dI
For each turn and layer
Calculate dT (i,j)
T (i,j)
Tcrit (i,j)
If T(i,j)>Tcrit(i,j)
Rcoil=rhoCu*l/S
dW = I^2*Rcoil
Critical temperature matrix
Tcrit
T=T+ dW/(cpCu(T)*m) + λ(T)*dT*S/(t*cpCu(T))

Critical Temperature



What is not yet done

- GUI – Graphic User Interface
- Cycling optimization – it runs so slowly!
- Movie support
- Program documentation not finished
- Still problems with Coil Resistance – if dt is not enough small, dT gets crazy values
- Automatic choice of dt