

ESIPAP March 4, 2014

Exercises “Superconductors and Magnets for Detectors”

Exercise 1 “Sizing a practical superconductor for a 10 T magnet”

Assume you want to make a superconducting magnet of 10T with a bore of 2 m diameter and bore length of 8 m.

- a) Calculate roughly the stored energy.
- b) This stored energy ($0.5LI^2$) needs to be dissipated in an external resistor within 1 minute (assume linear decrease to zero) and the voltage ($V=LI/t$) is limited to 1000V.
What is the minimum safe operating current of this magnet.
- c) So we need a cable, but how does it look? For a 10T magnet at 4.2K, which superconductor do we need?
- d) Assume a wire with 1.0 mm diameter, critical current density 4000 A/mm² at 10 T and 40 % superconductor in the wire.

What is the area of superconductor in the wire?

Which current can this wire take when we assume we take a margin of 70%?

- e) How many wires do I need in the cable to make 33 kA: ?
- f) When we make a twisted Litze cable (3x3x3xetc.), what would be the size, the diameter of this cable?

Exercise 2 “Understanding the effective resistivity of a superconductor”

$R=0$ in a superconductor when it is perfect, uniform, free of defects etc. In practice, however it is never perfect and we can take as a criterion 1 or 10 μV per meter of wire.

For MRI applications Philips Healthcare requires some 50 km of wire in one piece and perfectly connected in a persistent mode. A typical MRI magnet has 3 T in a volume of say 1 m^3 and the magnet operates at 200A.

- a) What is the inductance of the magnet ?

- b) What is the voltage drop across the coil with 50 km of wire operating at $1 \mu\text{V}$ per meter ?

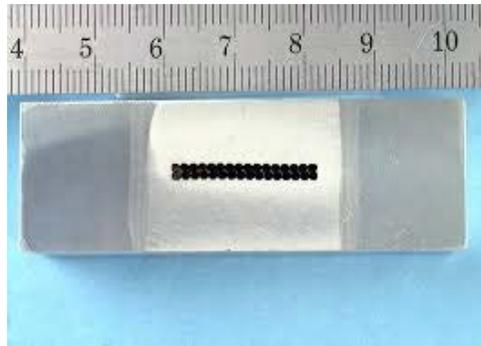
- c) What is the effective resistance of the magnet ?

- d) What is the current decaying time constant of the magnet ?
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- e) Is this a good value for an MRI magnet that should be stable in 1ppm/h ?

- f) What would be the maximum resistance tolerated across the wire and the maximum voltage per meter?

Exercise 3 “Understanding a typical conductor for a Detector Magnet”



Write a half page summary on what we see in this picture.

Mention all relevant issues determining the shape and internal layout of this conductor.

Exercise 4 “Flux penetration into a practical (type II) superconductor”

Following the Critical State Model, magnetic field is penetrating a superconductor from outside inwards. Consider a type II superconducting plate made of NbTi featuring a critical current density of 1000 A/mm^2 . The plate thickness is $100 \mu\text{m}$.

Draw the cross section of the plate and assume the external magnetic field is parallel to the plate surface.

- a) The magnetic field is increasing from 0 to a field where the center of the plate is not yet reached. Make a plot of the field profile inside the plate following CSM and draw the current density distribution as well.
- b) The magnetic field is increased to a value higher than the field of full penetration. Again make a plot of the field and current density distribution.
- c) The magnetic field is increasing now to a value twice the full penetration field. Make a plot of the field and current density distribution.
- d) Now the temperature of the plate is reduced by a significant step up. Again make a plot of the new magnetic field and current density distribution.
- e) Next the magnetic field is going down to half the value. Make a plot of the new field and current density distribution.
- f) Next the external magnetic field went down to zero. Make a plot of the new field and current density distribution. Is there any magnetic field due to the current pattern you see outside the plate?
- g) Then the magnetic field goes down below zero to minus half the penetration. Make a plot of the new field and current density distribution.
- h) Then instantly the temperature goes up and is higher than the critical temperature. Make a plot of the new field and current density distribution.
- i) Assume the pattern as drawn in (a). Now we add a significant transport current in the plate running parallel to the direction of the external magnetic field. Make a plot of the new field and current density distribution with transport current present.

Exercise 5 “Minimum propagation zone / Minimum quench energy / Adiabatic filament stability”

A 0.8 mm diameter superconducting wire used in the magnet of problem 1 has 40 % copper in it, and is electrically insulated with an epoxy resin, with the following properties at 4.2K and 15T:

- Electrical resistivity : $\rho = 3 \cdot 10^{-10} \Omega \text{ m}$
- Thermal conductivity of Cu: $\lambda = 200 \text{ W m}^{-1} \text{ K}^{-1}$.
- Thermal conductivity of wire insulation: $\lambda = 0.03 \text{ W m}^{-1} \text{ K}^{-1}$.

The magnet is running at 4.2K with 2.6K temperature margin. Current is 187.5A at 15T.

What's the local current density in the Cu if the winding locally becomes normal (assume all current flows in the Cu)? Using the thermal margin ΔT work out the length L of the minimum propagation zone.

The specific heat of Cu and Nb₃Sn under the magnet working conditions are given below.

- Specific heat copper : $c_{\text{Cu}} \approx 800 \text{ J m}^{-3} \text{ K}^{-1}$
- Specific heat Nb₃Sn : $c_{\text{Nb}_3\text{Sn}} \approx 11\,000 \text{ J m}^{-3} \text{ K}^{-1}$

Work out the minimum quench energy MQE, i.e. the energy required to establish a minimum propagation zone.

What is the Lorentz force F_L acting on the wire in the maximum-field zone of the magnet? If the wire slips over a distance dx under influence of this Lorentz force, how big would this distance need to be for the energy released to establish a minimum propagation zone? Is this a likely disturbance?

Under normal operation, what's the current density in the Nb₃Sn filaments? Still using the same thermal margin ΔT , work out the maximum allowable filament diameter d_{fil} to ensure adiabatic filament stability. How many filaments must the wire minimally contain? Is this realistic?