Study of possible frequency dependence of small AC fields on magnetic flux trapping in Niobium

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OUTLINE

• Motivation

• Experimental technique: polarized neutron imaging

• Results: Application of technique to Nb system
Trapped magnetic flux major contribution to residual resistance

Various techniques exist to reduce amount of trapped flux:
- passive: magnetic shielding + „magnetic hygiene“
- fast superconducting transition (avoid sc nucleation)
- small temperature gradients (reduce thermocurrents)

This presentation:
Investigate how a superimposed external AC magnetic field affects the trapping behavior.

Ideas behind this:
- Additional field might aid a flux line to overcome trapping site
- External oscillating field results in B=0 at any location in the sample twice per oscillation period. Does this help to achieve goal of B=0 everywhere after the superconducting transition?
Aim:
Measure magnetic field inside sample directly (other methods, i.e. fluxgates or AMR measure field indirectly)

Method:
Use neutrons to probe field inside sample

neutron has magnetic moment \( \mu_n = \gamma_n \hat{S} \)

interaction of neutron with magnetic field \( B \)

precession around \( B \) at Larmor frequency
\[
\omega_L = \gamma_n B
\]
**Method:**

- use thermal neutrons from reactor
- filter spin polarized neutrons with polarizer
- put sample with trapped flux into trajectory
- if spin and B are not parallel, spin rotates (precedes)
- measure integrated spin rotation with analyzer
Math

Time \( t \) the neutron travels through \( B \) depends on its velocity \( v (=1014 \text{ m/s}) \)
rotation angle \( \phi = \omega_L t \)

\[
\frac{\gamma_n}{v} \cdot \int B(x, y, z) \, ds
\]

\[
= \gamma_n \cdot B_{\text{path}} \cdot t \quad \text{(if B is constant)}
\]

Path integral calculated with the Radon-Transform

\[
R_{\phi}\{B_z(x, y)\} = \int_{-\infty}^{\infty} \int B(x, y) \delta(t - x \cdot \cos(\phi) - y \cdot \sin(\phi)) \cdot dx \cdot dy
\]

Determination of magnetic fields:

- Create a model of \( B(x,y,z) \)
- Calculate Radon Transform
- Create 2D spin-depolarization image (modulo \( 2\pi \))
- Compare with measured image
Simple examples:
Slice patterns from different geometrical shapes

Length path pattern:

**Square**

**Circle**
Experimental setup @ BER II reactor, PONTO (POlarized Neutron Tomography) (closed)

Ponto beamline at HZB BER II reactor
- wavelength $\lambda = 0.32 \, nm \sim 8 \, meV$
- collimation $0.1^\circ$
- 2k x 2k detector, 13.6$\mu$m pixel size
- spatial resolution 125 $\mu$m x 125 $\mu$m
Samples

(1) 99.999% pure single crystal Nb, BCP
(2) intermediate 1400°C bakeout + BCP

field cooling with parameters

(1) cooling speed 1 K/min
(2) 5 mT field amplitude, always axial
(3) field oscillation at 0.1 Hz, 0.25 Hz and 0.5 Hz (faster than cool-down)
(4) offset field of 0 mT, 1 mT, …, 5 mT

Measure two orientations: 0° and 90° of sample with trapped field
Results – untreated sample 0°

Magnetization of sample after superconducting transition with oscillating field of 5 mT

offset DC magnetic field 0 mT … 5 mT

- trapping determined by offset
- trapping independent on oscillation
Results baked sample 0°

offset DC magnetic field 0 mT … 5 mT

- less flux than in „dirty“ case is trapped
- trapping determined by offset
- trapping influenced by oscillation, but not minimized
We aim at Zeroes!

Trapping mostly determined by offset field

- Superimposed external AC magnetic fields do NOT influence the amount of trapped flux significantly
Can superimposed AC magnetic fields during cool-down help to reduce trapped flux?

NO!

But they don‘t harm either.
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Sample preparation and data evaluation:
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