Study of Trapped Magnetic Flux in Superconducting Niobium Samples

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Motivation

Trapped magnetic flux is known to be one cause of residual surface resistance.
In order to minimize residual losses in an SRF cavity, trapped magnetic flux has to be avoided. Therefore, we studied the flux trapping behavior of niobium samples with different treatment history.

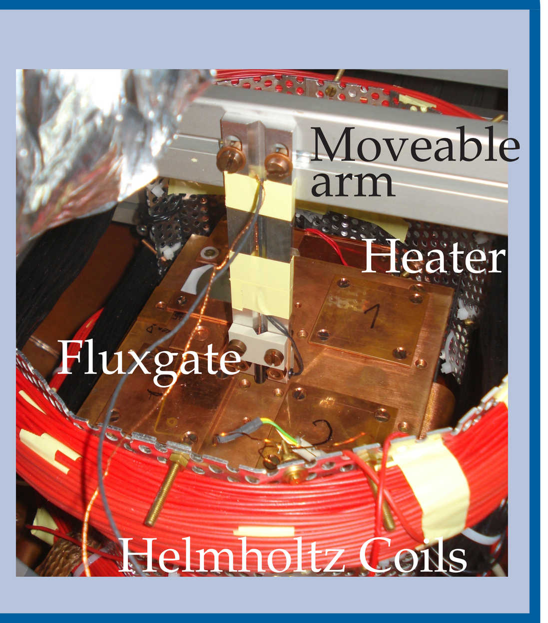
Samples

Sample	Crystal Structure	Treatment
1	polycrystalline	–
2	polycrystalline	BCP
3	polycrystalline	BCP + 800°C
4	single crystal	BCP
5	single crystal	BCP + 800°C
6	single crystal	BCP + 1200°C

Experiment

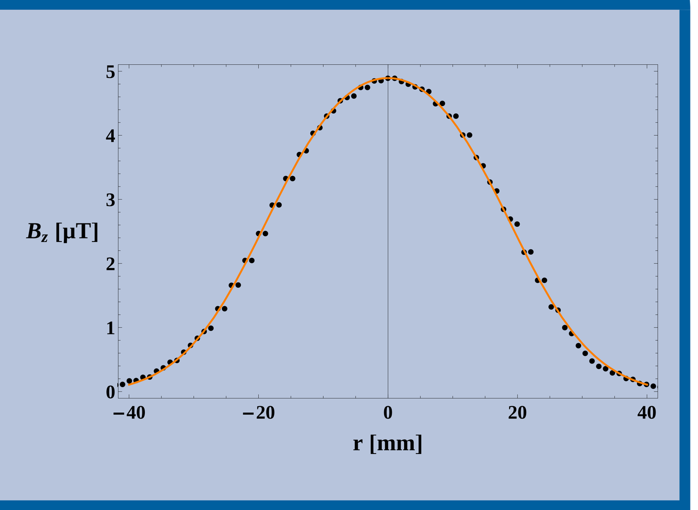
For the trapped flux measurements a device was build which provided:

- four sample positions
- the generation of magnetic fields up to 2.3 mT via Helmholtz coils
- the generation of magnetic fields in two preferential orientations
- fast cycling (∼ minutes) between normal and superconducting state
- mK-precise control of the warm-up/cooldown speed
- direct measurements of the magnetic field via a foerster probe
- the possibility of scanning the magnetic field over the sample



Field Simulation

All measured magnetic fields have to be corrected due to the distance between sample surface and the field probe. To calculate the relation between the magnetic field at the field probe and on the sample surface, the field of a homogeneously magnetized disc was simulated. The calculated field was compared with a measured scan of the trapped field of a sample that had trapped 100% of the flux.
Agreement between measurement and simulation was to within 3%.



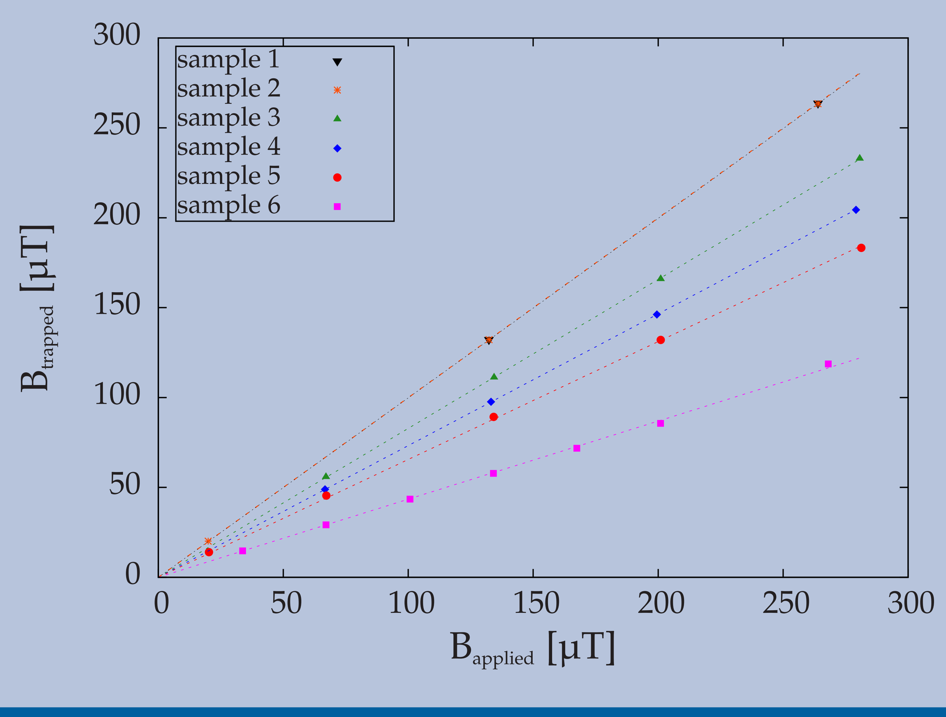
Results: Flux trapping

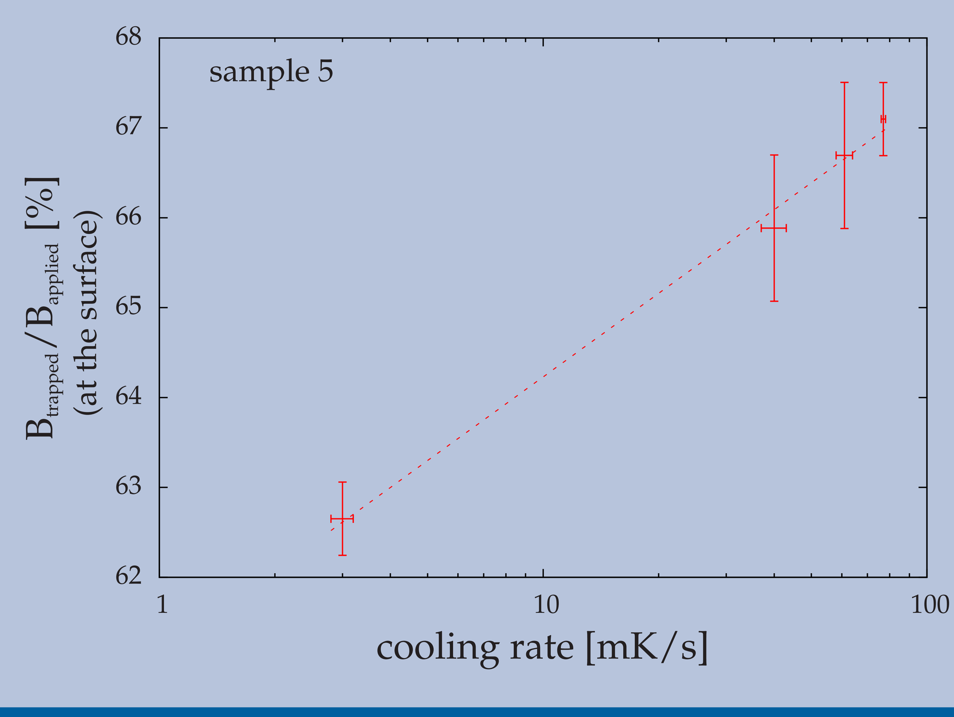
The measurements show that all polycrystalline samples trap more field than the single crystal samples. It was found that tempered samples trap less flux than untempered ones, but the BCP seems to have no influence on the trapped fraction.

Sample	Crystal Structure	Treatment	Fraction of Trapped Flux
1	polycrystalline	–	100%
2	polycrystalline	BCP	100%
3	polycrystalline	BCP + 800°C	(83.1 ± 0.8) %
4	single crystal	BCP	$[(72.9 + 0.1 \ln v) \pm 0.8]$ %
5	single crystal	BCP + 800°C	$[(61.6 + 1.3 \ln v) \pm 0.8]$ %
6	single crystal	BCP + 1200°C	$[(42.1 + 0.13 \ln v) \pm 0.6]$ %

Fraction of trapped flux

None of the samples showed a saturation of the fraction of the trapped field. The fraction remained constant up up to 0.3 mT. Moreover, the polycrystalline samples without tempering did not show a saturation up to an applied field of 2.3 mT (highest generated field).



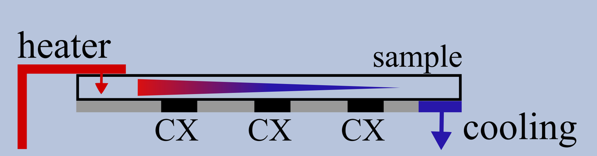


Impact of the cooling rate

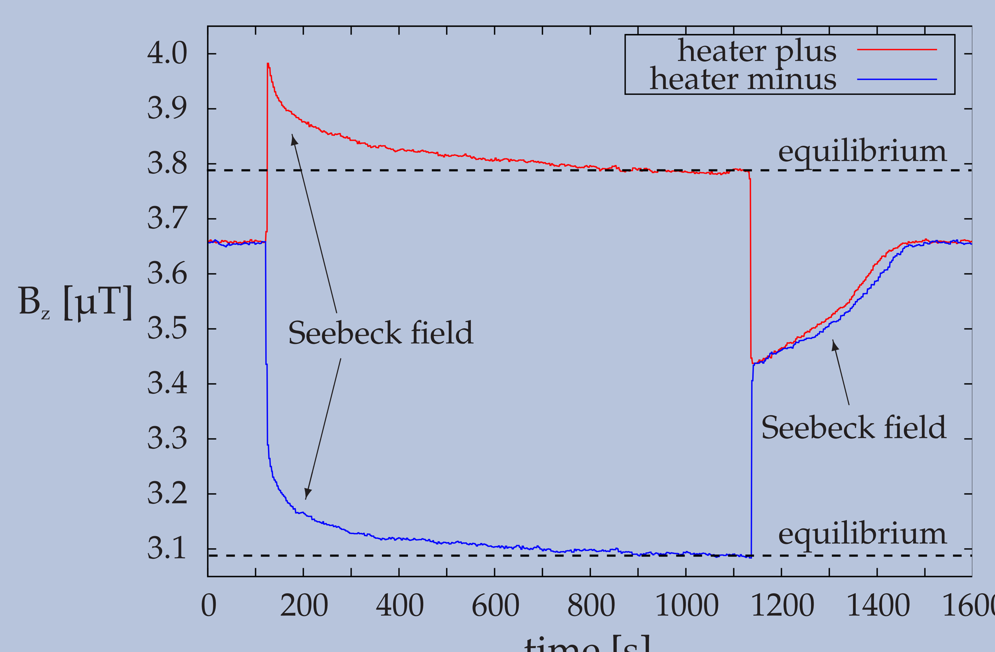
All single crystal samples exhibit a logarithmic dependency on the cooling rate v. No dependency on the cooling rate was found for the polycrystalline samples

Results: Thermal currents

One of the sample positions allowed the generation of a local temperature gradient over the sample.

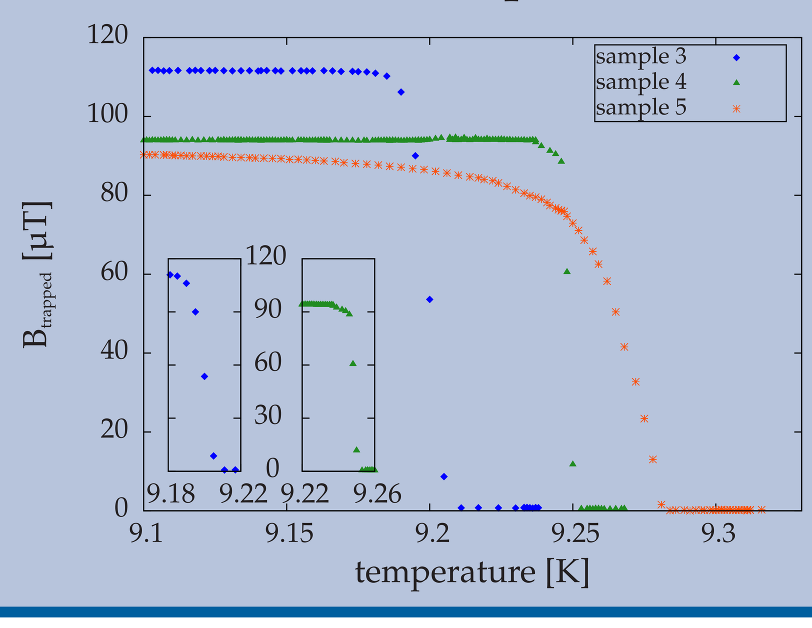


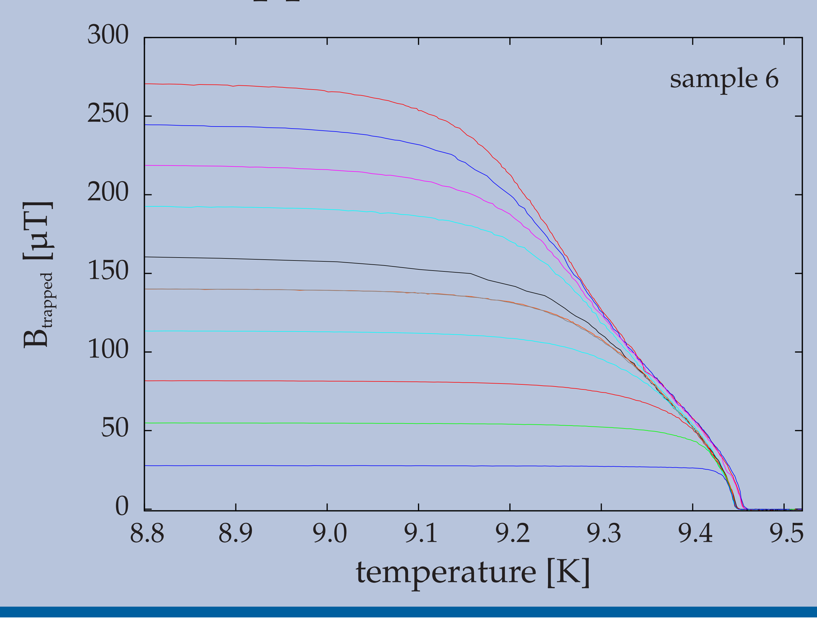
It could be shown that a local temperature gradient produces additional magnetic fields due to the Seebeck effect.
We distinguished the *Seebeck field* from the field produced by the heater foils by changing the direction of the heater current.



Results: Flux release

Each sample was warmed up slowly in order to release a previously trapped field. We observed that the tempered single crystal samples release the trapped field within a much broader temperature range during warm up than all other samples. Additionally, it was observed that the release of the trapped field starts at smaller temperatures the higher the trapped field is.





Outlook

Future measurements might investigate how electro-polished samples behave and if there is a maximum (absolute) field that can be trapped. Further studies are necessary dealing with the trapping of field produced by thermal currents and the consequences for the operation of SRF cavities.

Acknowledgments

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