Assessment of high performance superconducting wires at low temperatures

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BRUKER

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This work is supported by EASITrain – European Advanced Superconductivity Innovation and Training. This Marie Sklodowska-Curie Action (MSCA) Innovative Training Networks (ITN) has received funding from the European Union's H2020 Framework Programme under Grant Agreement no. 764879

Part I

REVIEW

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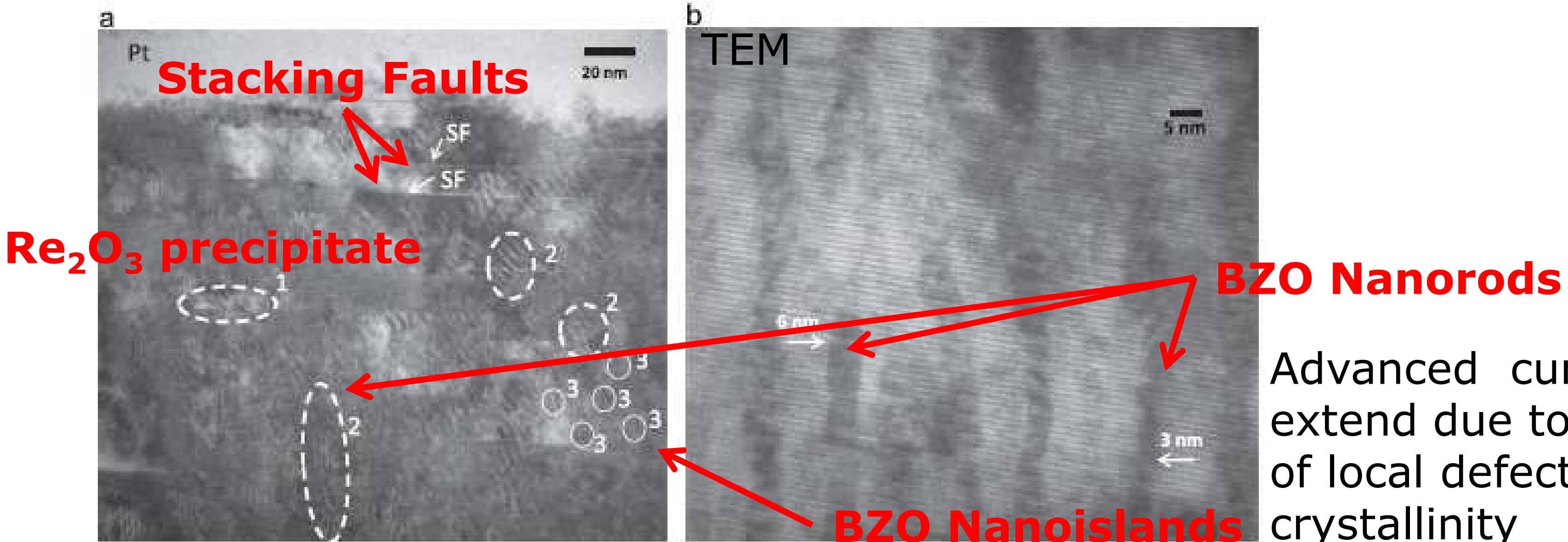
Review – Double Disordered Tapes

- Show record critical current values of 309 A in 31 T fields
- The ratio $\frac{J_c(4.2\ \mathrm{K}, 19\ \mathrm{T})}{J_c(77\ \mathrm{K}, \mathrm{SF})}$ is abnormally high (up to 20)
- ‚intrinsic' and ‚extrinsic' defects in HTS layer
- Designed for magnet applications at low temperatures

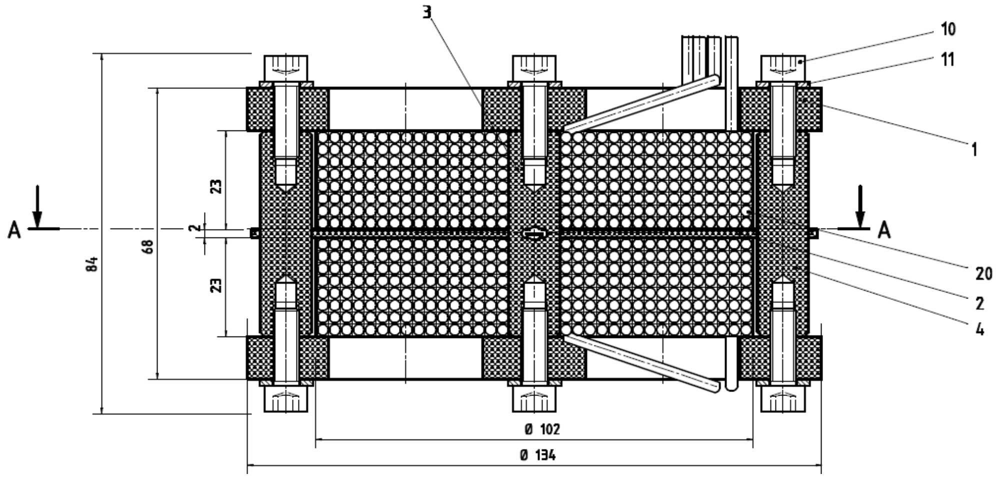


Abraimov et al. 2015

Advanced currents to large extend due to high density of local defects of crystallinity

Review - Tapes in magnetic fields with gradients

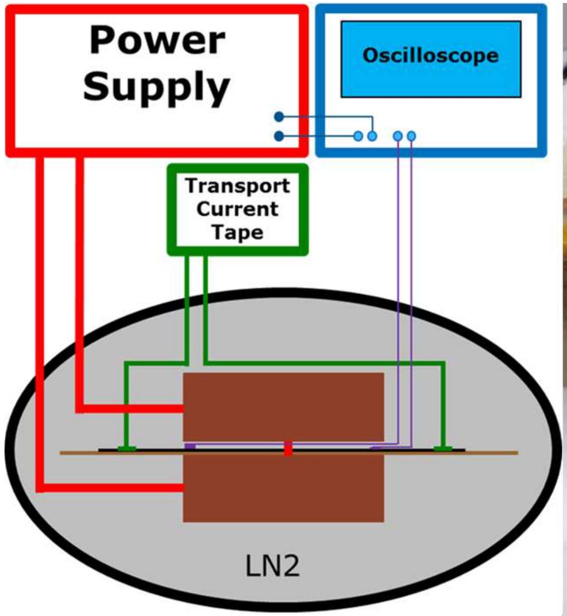
- In a characterization tool for long-length tapes a magnet zone will be implemented.
- At entrance/exit of magnet zone, gradients in the magnetic field will appear.

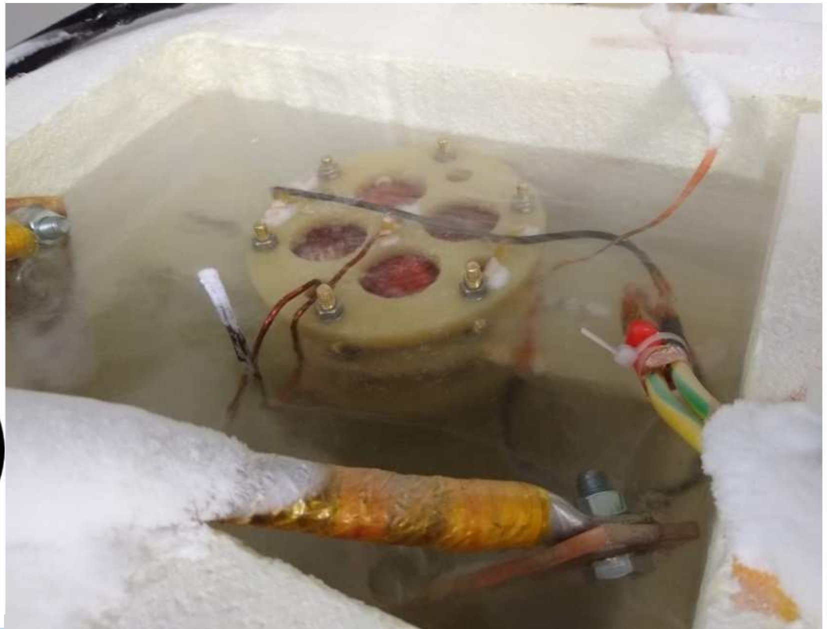


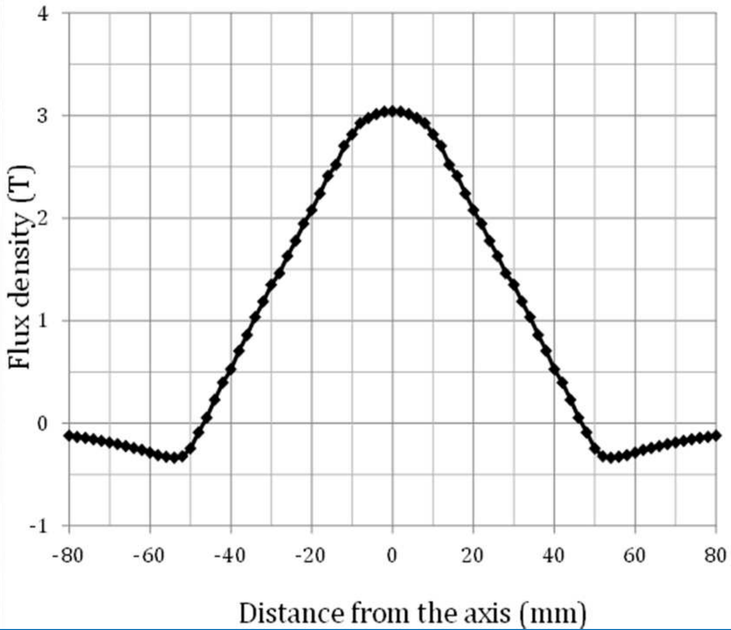
- Magnetic field is depending on position of tape $B \rightarrow B(x)$
- Critical current is depending on B $I_c(B) \rightarrow I_c(B(x))$
- Voltage drop (criterion for I_c) is depending on x $U \rightarrow U(x)$

Review - Tapes in the magnetic field of a 3 T pulsed electromagnet

- Simulation of tape in a field B(x) produced by an electromagnet
- Usage of a 3 T pulsed electromagnet
- 700 A supply current in coil produces B ~ 3.1 T in center of magnet
- Operation in LN2 in 0.3 – 3 s long pulses
- During pulse: dB/dT < 16 T/s
- Fixed sample (20 cm) of tape within slit of magnet
- Imposed transport current on tape 0…10 A.

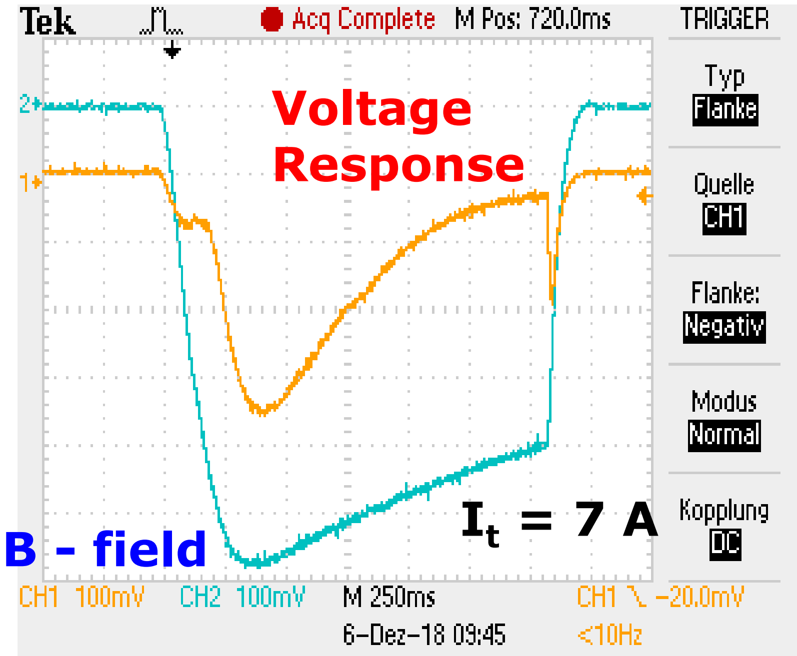


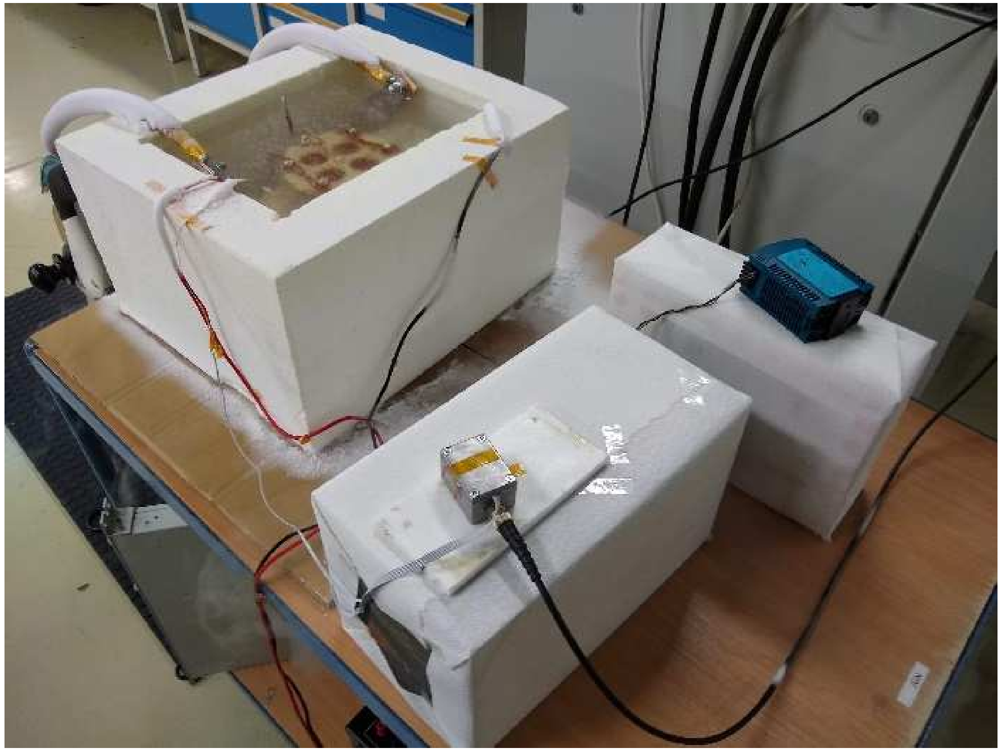




Review – Data Obtained from Experimental Setup

- Voltage response of tape under constant transport current $I_t < 10$ A





- Voltage signal depends on flux density and transport current I_t.
- More detailled view in talk of video conference on 29/01/2019

Part II

PROGRESS

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Extended Alpha Approximation (EAA)

- Evaluation of signals signals
- Basis: approximation of $I_c(B)$ for high fields

$$I_c \sim B^{-\alpha}$$

- I_c-B dependence evaluated from additional samples by $I_c(B)$ - Measurements at TU-Wien at 77 K, 0 - 6 T (May 2018).
- Definition of an „effective" alpha value for I_c at 0-6 T fields.
- $I_c(B) = 10 \cdot B^{-(0.3+0.2 \cdot B)}$

$$\alpha_{\mathrm{eff}} = \alpha_0 + \beta B$$

- Modelling of the voltage drop with n-law

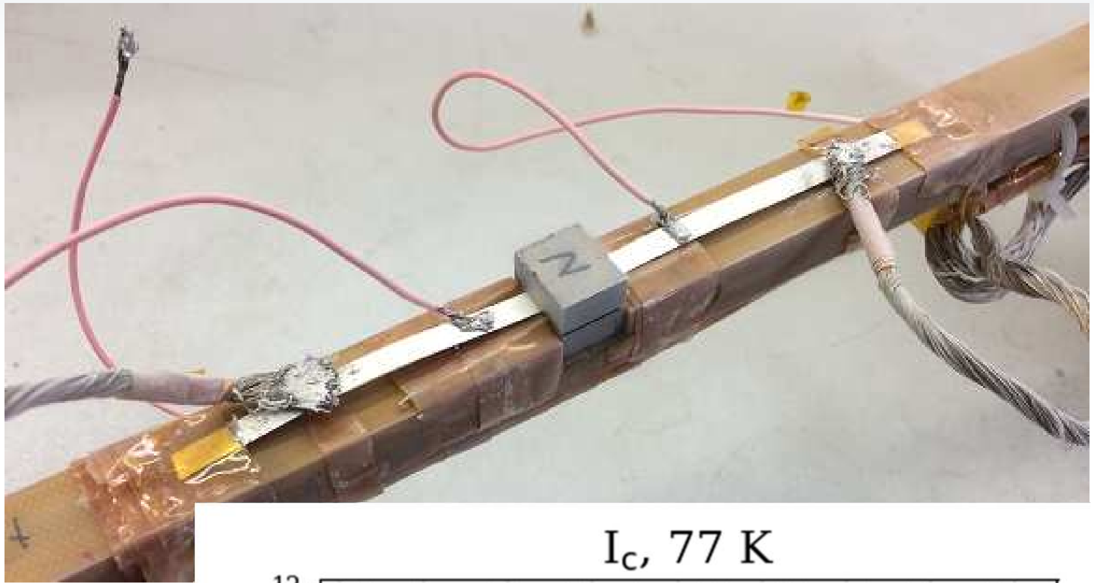
$$U_{\mathrm{tot}} = U_{\mathrm{cr}} \left(\frac{I}{I_c}\right)^n, n \rightarrow n(B(x))$$

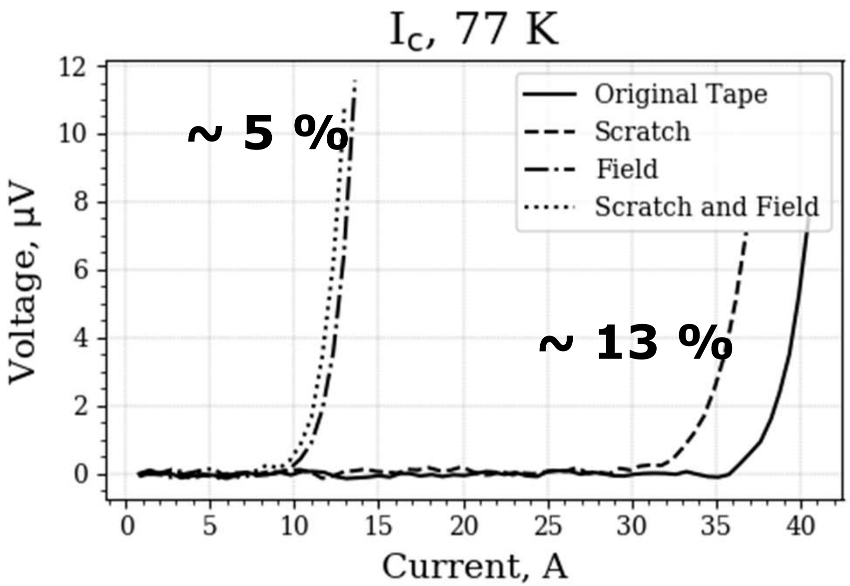
Integration of total voltage drop

- Integration between voltage contacts to take x-dependence of field into account.
- Dependence of electric field on x.
- Comparison experiment vs. model
- Evaluation procedure allows to derive $I_c(B)$ with a precision of < 3 %.
- Results are submitted- „REBCO coated conductors in magnetic field gradients", Supercond. Sci. And Technol. in March 2019

Zooming Effect

- Similar situation in setup with miniature permanent magnets
- Two types of PM magnets
  - Cylindrical
  - Rectangular
- With model developed from EAA: Parts of tape, which are exposed to field, contribute to voltage drop.
- Inhomogeneous electric field
- Influence of artificial defect on I_c in tape is smaller in region of magnetic field. [Usoskin, Betz, Gnilsen et al 2019 Supercond. Sci. Technol. https://doi.org/10.1088/1361-6668/ab2cba]



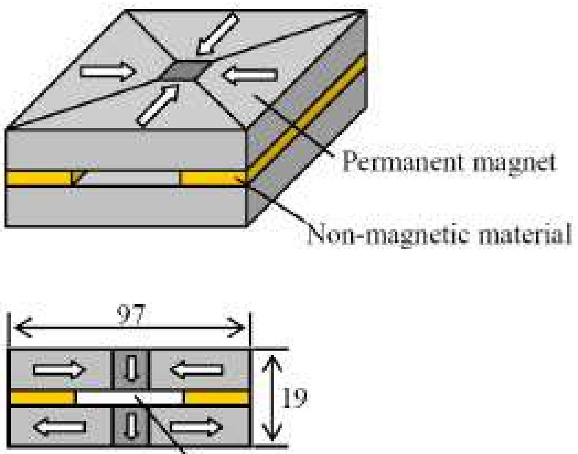


Test Permanent Magnet

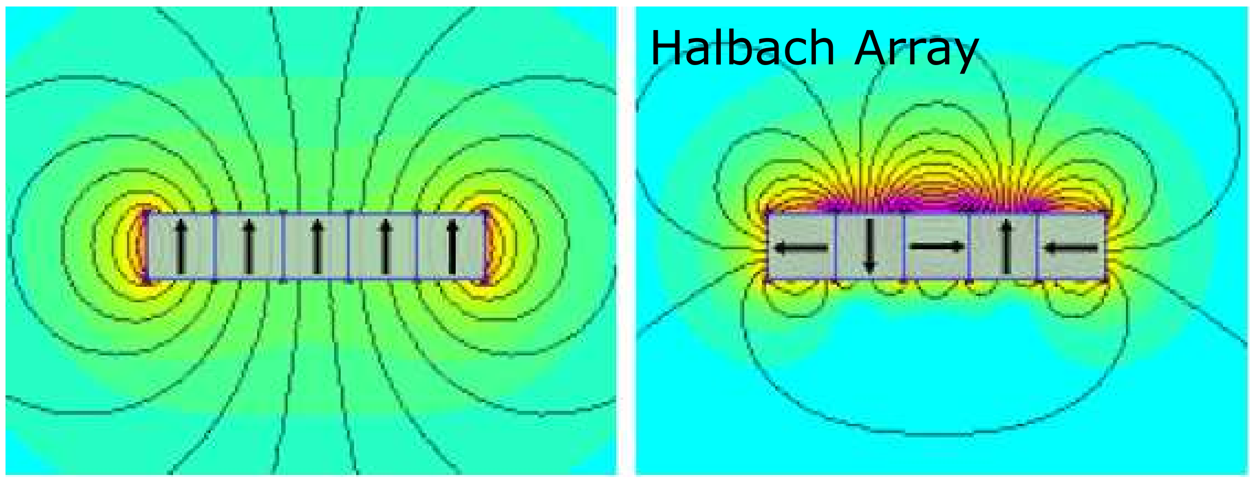
- Option: 2.54 T flux density produced by permanent magnet

- $Nd_2Fe_{14}B$ – material
  - Remanent field B_r = 1.3 T
  - Coercitivity H_c = 1.1 – 1.3 A/m
  - Brittle material, danger of oxidation

- Halbach array → „concentration“ of flux density to 2.54 T



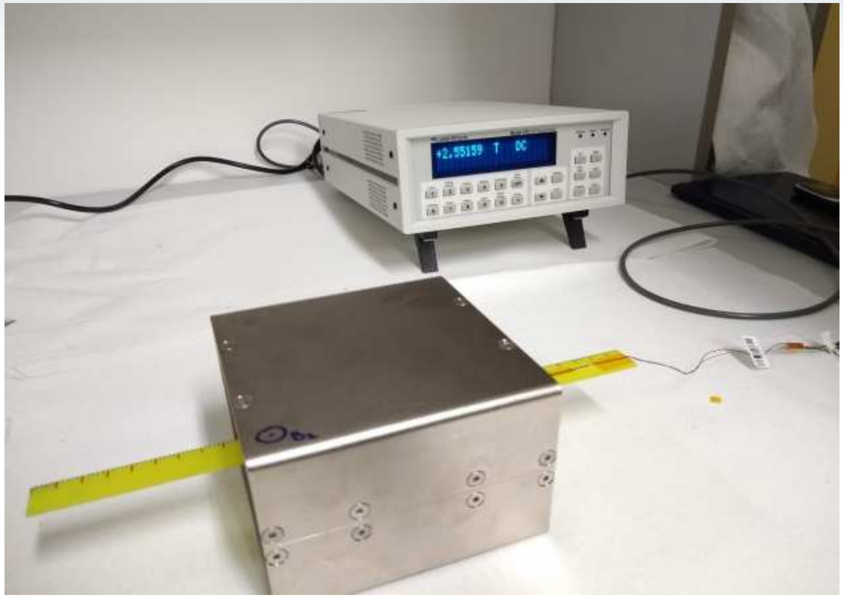
M. Kumada, Y. Hirao, Y. Iwashita, et al., Three Tesla Magnet-in-Magnet, Proceedings of EPAC 2002, Paris

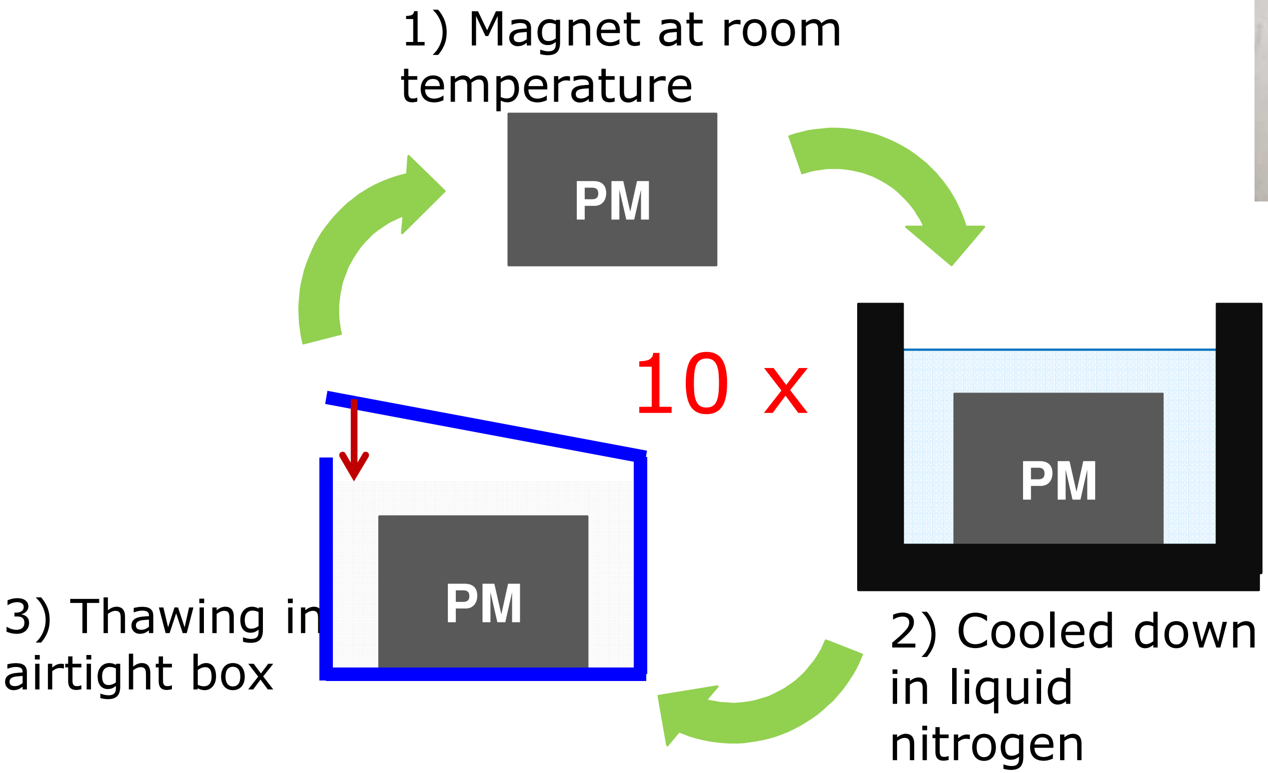


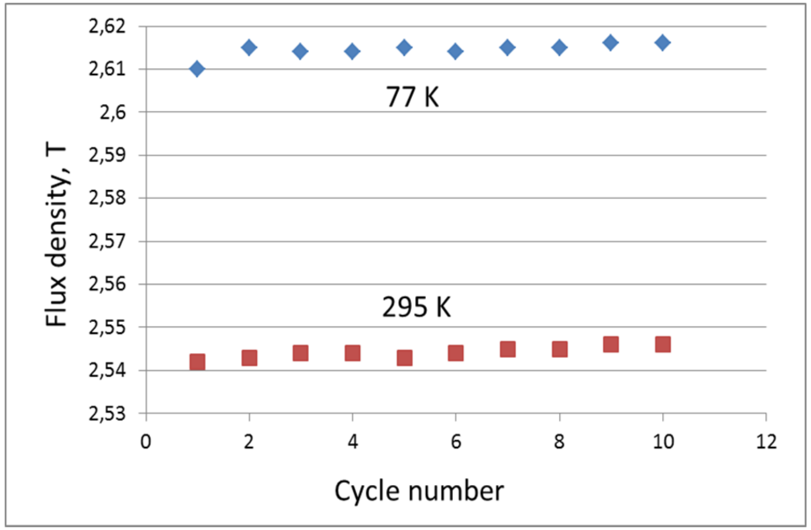
https://www.kjmagnetics.com/blog.asp?p=halbach-arrays

Permanent Magnet Temperature Cycling

- **Test Magnet**
  B_r (295 K) = 2.54 T
  Br (77 K) = 2.61 T
- Investigation of magnet after temperature cycling
- Sufficient stability







Summary

- Development of a model to describe behavior of samples in a magnetic field with gradients
  - Pulsed 3 T electro magnet
  - Miniature permanent magnets (zooming effect)
- Data of model fits to data of experiment
- Results submitted to Supercond. Sci. And Technol. in March 2019
- Tests with a 2.54 T permanent magnet

Acknowledgement

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Innovation with Integrity

Abstract

Abstract talk FCC Week 2019, Brussels
Scientific work progress, J. Gnilsen
To be presented in EASITrain session.
In earlier study a 3 T pulsed electromagnet was the key tool in our experiments. Short pieces (of 20 cm length) of long tapes have been introduced in the magnet channel of the magnet and loaded with up to 10 A transport current. The voltage signal during the magnetic field pulse has been recorded and interpreted in terms of an "extended alpha approximation" approach. To develop this model, the commonly used n- and alpha-approximation, usually taken for critical current approximations at high fields, has been "extended" towards fields in the range of 0-6 T by determining n- and alpha-values of a number of samples at TU-Wien at 77 K and 0-6 T (B//c). Occurring gradients in the pulsed field have been taken into account by integrating the voltage signal along the sample length x by using a function B(x) for the magnetic field.
Furthermore, the field distribution of a 2.54 T permanent magnet has been measured and sufficient stability of the magnetic field has been observed in the course of multiple temperature cycling performed between room temperature and the temperature of liquid nitrogen.
The results of studies of both sources of magnetic field are used in the development of a tape characterization tool in which field gradients may appear.

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