Recent results on passive field error correction in superconductive undulators

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1. Field drifts in SCUs

- identification of sources

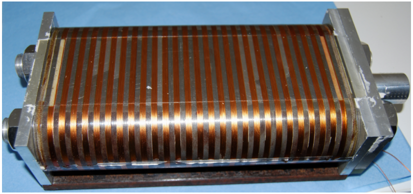
2. Induction shimming

- recent measurements
- outlook

Identifying field drifts in SCUs

- Background
  - Observed in orbit position measurements at ANKA [PAC09]
  - Temporally decaying undulator field from seconds to hours
  - Dependence on ramp rate and cycling history
  - Hypothesis: Yoke eddy currents, wire dynamics (flux creep etc)
- Recent experiments: Local Hall probe measurements on short models
- RL network model

Short models for field drift measurements



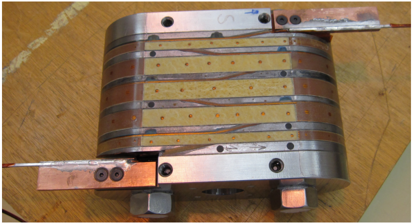


Table: Parameters of the two short models

	CERN-SCW	KIT-SCU
geometry:	vert. racetrack	
straight [mm]	100	60
radius [mm]	50	30
period length [mm]	40	15
# full periods	1	13
wire:	NbTi multifilament, rect.	
dim's (insulated) [mm^2]	1.25×0.73	0.77×0.51
Cu:Sc-ratio	1.71	1.32
twist pitch [mm]	18	25
RRR Cu-matrix	> 100	> 65
experimental conditions		
operation current [A]	730	500
ramp rate [A/min]	84	150
max. field @ conductor [T]	3.3	2.3
field grad. along wire [T/m]	1.3	3.0

Experimental results

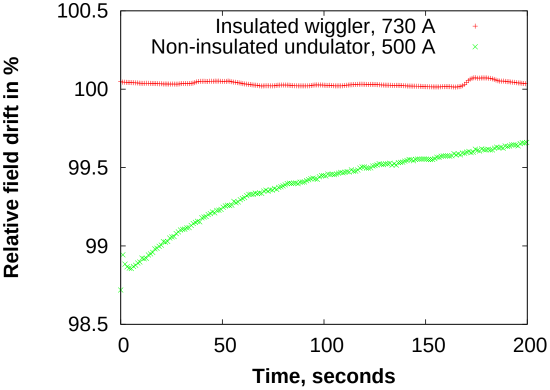
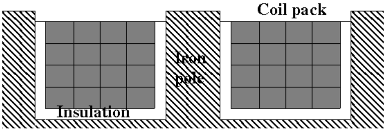
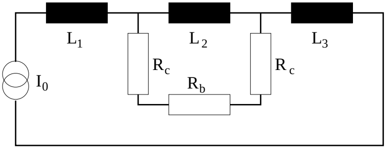


Figure: Field drifts after ramp from a wiggler short-version and from a short undulator half, relative to the measured value 430 s after ramping.

RL network model





Stored energy $\Rightarrow$ *Inductance*

$$L_2 = 2\frac{\int_V \mathbf{H}\cdot\mathbf{B}\,dV}{I_0^2} \Rightarrow$$

$L_{21} = 4.7\,\mathrm{mH}$, $L_{22} = 0.33\,\mathrm{mH}$

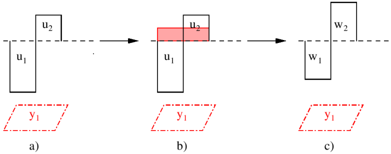
$$\tau = \frac{L_2}{2R_c + R_b}.$$

From measurements:
$\tau_1 = 460 \pm 20\,\mathrm{s}$, $\tau_2 = 32 \pm 1\,\mathrm{s}$

Summary - Field drifts

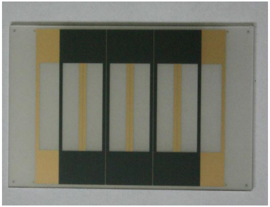
- Leak currents largest sources to drift $\rightarrow$ insulation motivated
- Yoke eddy currents two orders of magnitude smaller
- Wire dynamics probably negligible

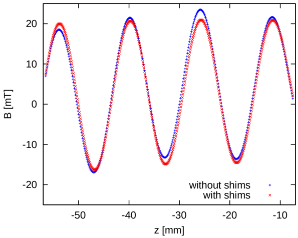
Inductive Shimming



Basic Idea

- Closed sc loops covering each period
- Field integral $\neq 0$ corrected by induced current
- Overlap: coupling and global correction





Aims of next experimental steps

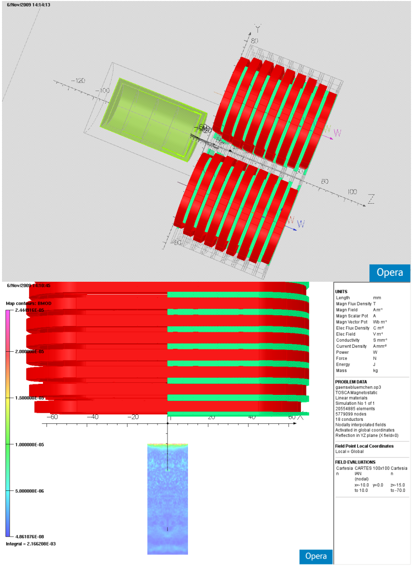
- Quantitative analysis of phase error reduction
- Investigation of hystereses and long term stability
- Investigation of coupling and alternative schemes

Induction shimming measurements

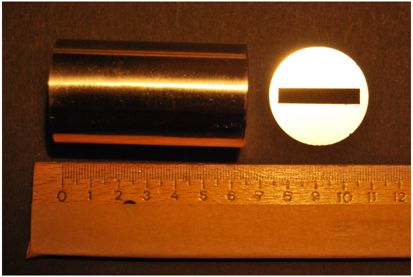
- Measurement setup
  - Zero-Gauss-Chamber
  - Shim system
- Results
  - Field maps
  - Hysteresis

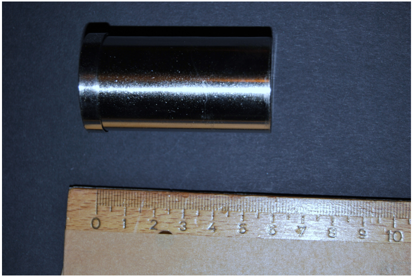
Setup: Zero-Gauss-Chamber, Simulations

- Screening of stray fields
- Cryo-compatible highly permable material CRYOPERM10
- $B_{\mathrm{res}} < 10^{-4}\,\mathrm{T}$



Zero-Gauss-Chamber: Realisation and Test





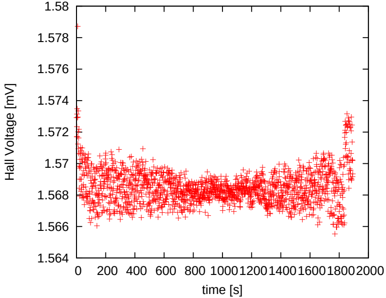
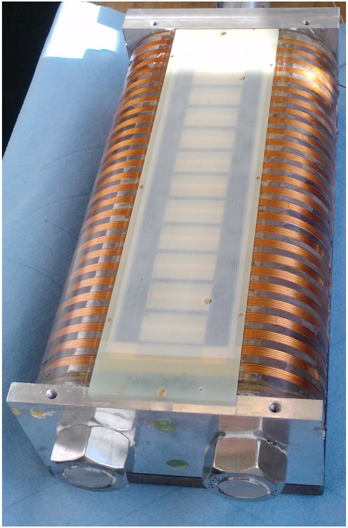


Figure: Hall probe signal in zero-gauss-chamber during quench training

Shim system



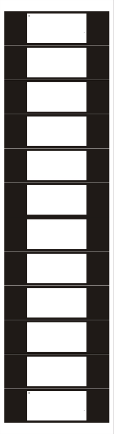


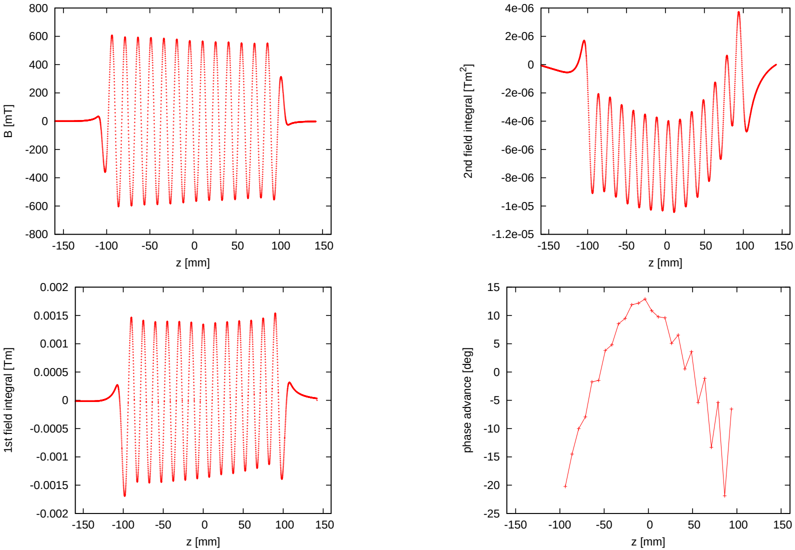
Table: Undine 1, basic parameters

period length [mm]	15
# full periods	13
matching coils	2 (1/4;3/4)
conductor	NbTi multiflmt.
	$0.77 \times 0.51\ mm^2$

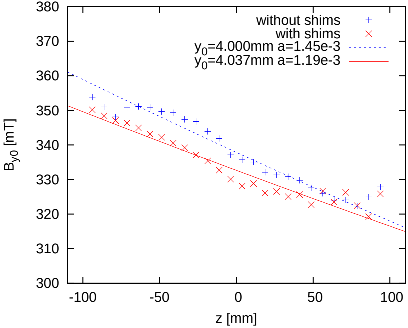
Table: Shim loops YBCO, sputtered, structured with wet chemical process

substrate	Al_2O_3, 0.5 mm
loops	YBCO, 300 nm
coating	Au, 200 nm
period	15 mm
# loops	12
circuit path	
- broad	10 mm
- narrow	1 mm

Undine 1: field maps



Systematic Error due to Adjustment



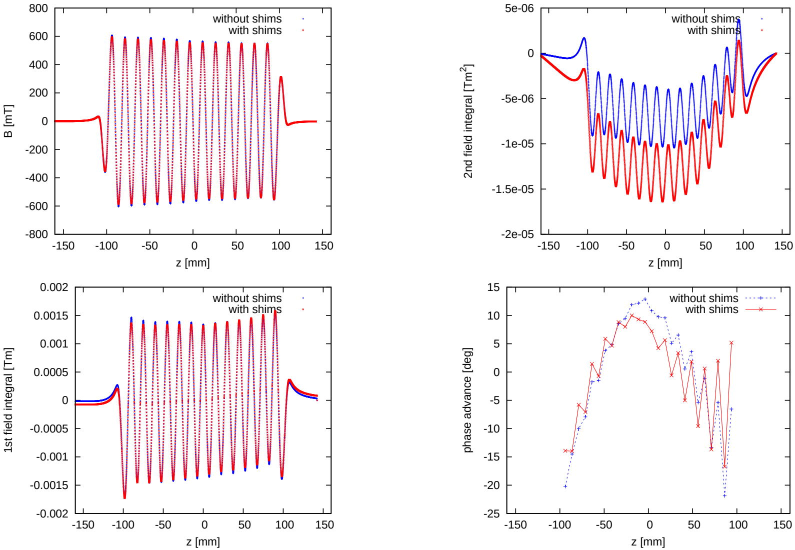
Model:

$$\tilde{B}_y = \tilde{B}_0(\cosh ky(z) - \sinh ky(z))$$

$$y(z) = y_0 + az$$

$$k = \frac{2\pi}{\lambda_u}$$

Integrals and Phases, 500A



Saturation and Hysteresis

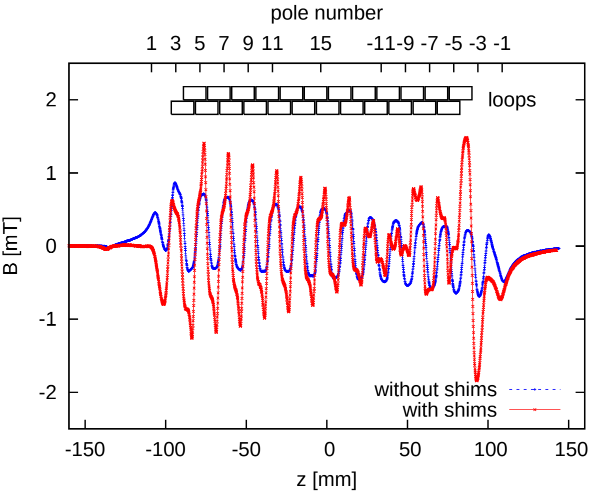


Figure: Field due to persistent currents in shims after operation at 50 A

Reason: Field Amplitude Overshoots at Poles 4,-4

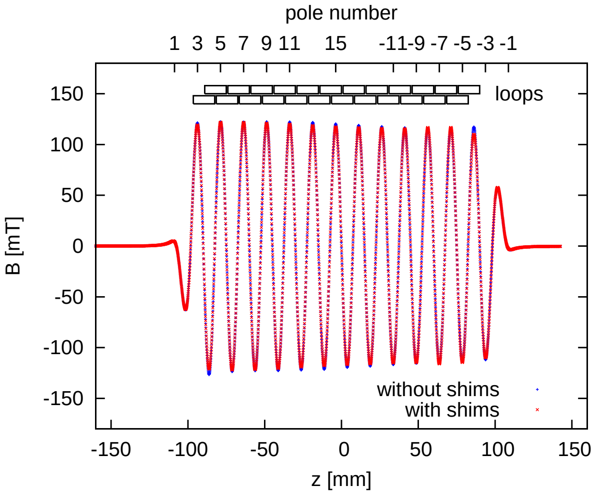


Figure: Field maps at 50 A

Persistent Currents and Coupling

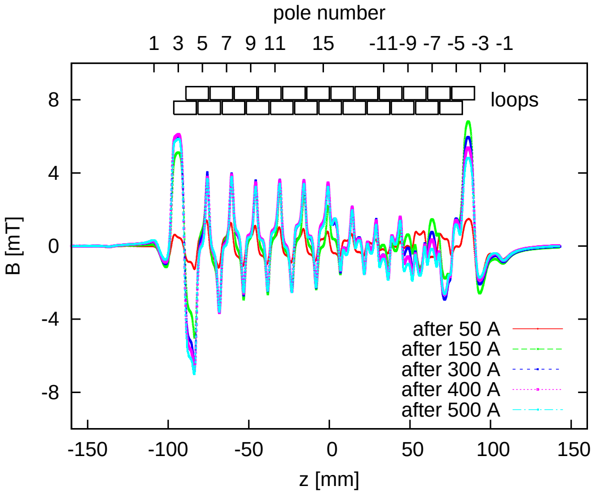
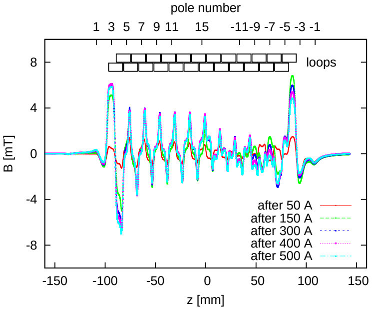
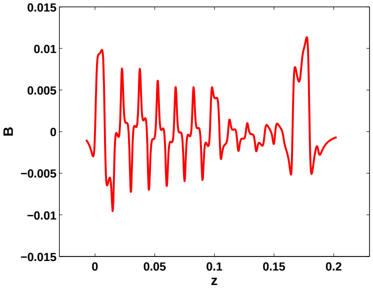


Figure: Field due to persistent currents in shims after operation at different currents

Persistent Currents and Coupling





- Biot-Savart approximation using current array: [-100 140 -140 120 -140 115 -115 110 -100 100 -100 90 -90 40 -40 30 -30 25 -25 0 -40 10 -150 -20]

Summary - Induction shimming

- Undulator short model and zero-gauss-chamber successfully tested
- Alignment to be improved by at least one order of magnitude both in terms of accuracy and reproducibility (under way)
- Shim system must cover only poles 5..-5 (shortening and symmetrisation in preparation)

Next steps

- Quantitative analysis of systematic errors
- Experiment with two coils and abovementioned modifications
- Further technical development:
  - Thinner substrates
  - Extension to $\sim$100 periods

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Undine 1: Quench test