

A mole for measuring pulsed superconducting magnets

Pierre Schnizer

Gesellschaft für Schwerionenforschung
Plankstraße 1
64291 Darmstadt

IMMW 15@FNAL 21 - 24 August 2007

Thanks to

GSI

Helge. R. Kiewewetter
Thomas Mack
Thomas Knapp
Franz Klos
Stefan Rauch
Reinhold Werkmann

TU - Darmstadt

Maximilian Manderla
Martin Schnecker

CERN

Olaf Dunkel
Guy Deferene
Louis Walckiers

Data for comparison

Animesh Jain and his
team

Outline

- 1 Measuring pulsed fields
 - Methods applied today
 - Superconducting magnets: is there a difference?
- 2 Mole
 - Overview
 - Angular postioning
- 3 First measurements
 - Test setup
 - Power supply Cycles

Outline

FAIR @ GSI

- many rings, 2 superconducting syncotrons
- SIS 100: 2 T , 4 T / s, 3.5 m long dipoles, 5 m long quadrupole plus correctors
- SIS 300: 2 T , 4 T / s,
 - describe / compare the quality of the magnet(s)
 - managable data for users: e.g. beam dynamics
- this talk → focuses on AC field measurement using the mole

Methods commonly applied for pulsed magnets

- synchotrons → since 50th
 - theoretical understanding (strong focusing, Courant - Snyder)
 - also measured since then ?
- typically normal conducting
 - search coils (dipole), rotating coil (quadrupole)
 - bent to the radius for small magnets
 - pole → mechanical reference
 - sliding on the pole plane (@ GSI)
 - a stack of coils (@ CERN)
- but nowadays superconducting synchotrons
 - Nuclotron @ Dubna
 - SIS 100, SIS 300 @ GSI
 - injector change @ CERN

⋮

Difference measuring sc \leftrightarrow nc synchrotron magnets

normal conducting

- dipole
 - field integral $\int B_y dl$
 - field homogeneity
 $\frac{B_y}{dx} \rightarrow$ “normal multipoles”
 - angle \rightarrow pole shape
- quadrupole
 - field integral $\int G_y dl$
 - axis (w.r.t. pole shoes)
 - field homogeneity (multipoles)

super conducting

- dipole
 - $\int B dl$
 - angle (no mech. ref.)
 - field homogeneity (multipoles)
 - “axis” (shape of the magnet at cold)
- quadrupole
 - $\int G dl$
 - axis
 - angle
 - field homogeneity (multipoles)

Difference measuring sc \leftrightarrow nc synchrotron magnets

- chosen system must
 - provide angle
 - axis
 - suppress vibration (round anti cryostat in rectangular aperture)
- coil probe:
- DC \rightarrow rotating
- AC \rightarrow
 - regularly (in ϕ) placed sensors
 - measure the magnet at different angles from ramp to ramp **can that be done ?**

Circular Multipoles

Magnetic field representation in circular multipoles

$$\mathbf{B}(\mathbf{z}) = \sum_{n=1}^N \mathbf{C}_n \left(\frac{\mathbf{z}}{R_{Ref}} \right)^{(n-1)}$$

Flux through a coil probe

$$\Phi(t) = \text{Re} \left[\sum_{n=0}^N \mathbf{K}_n \mathbf{C}_n e^{in\theta(t)} \right]$$

Sensitivity for a radial coil probe array

$$\mathbf{K}_n = \frac{NL}{n} \left[\left(\frac{R_2}{R_{Ref}} \right)^n - \left(\frac{R_1}{R_{Ref}} \right)^n \right]$$

Induced voltage

$$V(t) = -n \dot{\theta}(t) \operatorname{Re} \underbrace{\left[\sum_{n=0}^N \mathbf{K}_n \left\{ \mathbf{C}_n + \frac{d\mathbf{C}_n}{dt} \right\} e^{in\theta(t)} \right]}_{d\Phi(t)/dt}$$

Spurious harmonics due to mechanical artifacts

Torsional vibrations in a dipole of $T = t \cos(p\Theta)$

$$\mathbf{C}_{p+1}^{\text{sd}} \approx \frac{\mathbf{K}_1}{\mathbf{K}_{p+1}} \frac{t}{2} i \mathbf{C}_1 \quad \mathbf{C}_{p-1}^{\text{sd}} \approx \frac{\mathbf{K}_1}{\mathbf{K}_{p-1}} \frac{t}{2} i \overline{\mathbf{C}_1}$$

Torsional vibrations in a quadrupole of $T = t \cos(p\Theta)$

$$\mathbf{C}_{p+1}^{\text{sq}} \approx \frac{\mathbf{K}_2}{\mathbf{K}_{p+1}} t i \mathbf{C}_2 \quad \mathbf{C}_{p-1}^{\text{sq}} \approx \frac{\mathbf{K}_2}{\mathbf{K}_{p-1}} t i \overline{\mathbf{C}_2},$$

Transveral vibrations in a quadrupole of $\mathbf{D} = \mathbf{d} \cos(p\Theta)$

$$\mathbf{C}_{p+1}^{\text{sq}} = \frac{\mathbf{K}_1}{\mathbf{K}_{p+1}} \frac{\mathbf{d}}{2R_{\text{Ref}}} - i \mathbf{C}_2 \quad \mathbf{C}_{p-1}^{\text{sq}} = \frac{\mathbf{K}_1}{\mathbf{K}_{p-1}} \frac{\mathbf{d}}{2R_{\text{Ref}}} i \overline{\mathbf{C}_2}.$$

Mechanical Requirements

- based on a radial compensation coil
 - first coil probe CERN LHC head #41 → allows to “buck” the dipole and quadrupole by a factor of 1000 and 100 respectively
 - insert in relevant formulae

Coil probe parameters

Mechanical parameters of the coil probes of the array

	A	B	C	D	E
$R_2[mm]$	20.378	12.242	4.000	12.157	20.482
$R_1[mm]$	12.458	4.322	-3.920	4.237	12.562
N	64	64	64	64	64
$L[mm]$	699.5	699.5	699.5	699.5	699.5

Required Mechanical Precision

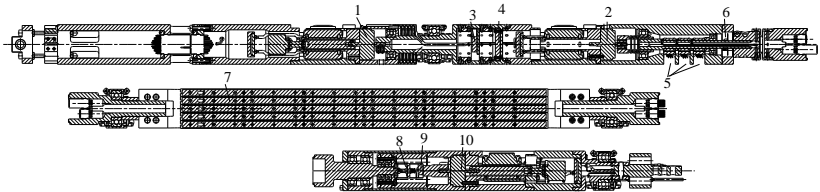
	abs	cmp	unit
Dipole			
p		2	10
t	0.5	80	7.5 <i>mrad</i>
Quadrupole			
p		3	12
t	0.5	45	5 <i>mrad</i>
d	0.2	5	<i>mm</i>

- compensation measurement uses bucking (A -C for dipole)
- compensation measurement uses bucking (A -B -C + D for quadrupole)

Choice of Method

- “bucking” relaxed mechanical parameters
- small team @ GSI, different apertures
- → step by step method
- previously applied by:
 - Nikolay Smirnov, Piotr Shcherbakov; UNK @ IHEP
 - Alexander Kovalenko; Nuclotron @ Dubna
 - A. Dael; superconducting models for CERN SPS @ Saclay
 - Hallbach and Bill Hasenzahl?

Sketch of the Mole



1,

levelling piezo motor 1 2 coil rotation piezo motor 3, 4
inclinometers 5 slip rings 6 angular encoder with 512 ticks, 7
coil probes 8 angular encoder with 7500 counts 9 its
inclinometer and 10 levelling motor

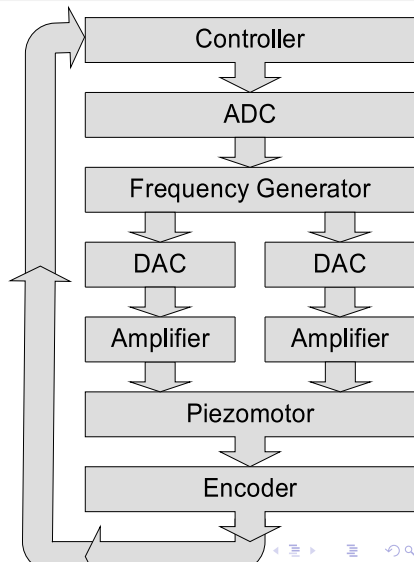
Angular positioning I/II

- piezo motor → allows precise positioning
- chosen type (SHINSEI USR 30) → default driver only allows 8 mrad.
- piezo motors → far better → study at TU Darmstadt → 0.1 mrad reachable (see IMMW 14)

Signal Generation / Control Loop

- function generator realised in FPGA
- must produce variable $50.5 - 51\text{kHz}$ within 10 Hz steps
- must shift phase between channel A and B

Courtesy of S. Rauch, T. Mack



Power Amplifier

- piezo motor → capacitive load
- amplifies signal to 15 V / 3 A
- separation transformer → 110 V
- still requires a parallel inductance



Courtesy of T. Mack, T. Knapp, R. Werkmann

Angular positioning II/II

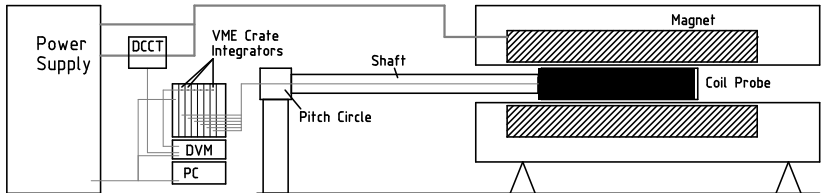
- Angles below .5 mrad reachable (only limited by the encoder)

First test

- GSI 001 (modified RHIC magnet) on the test bench
- mole not available ... but LHC quadrupole coil probe
- test of power supply reproducibility

Bricolage set up

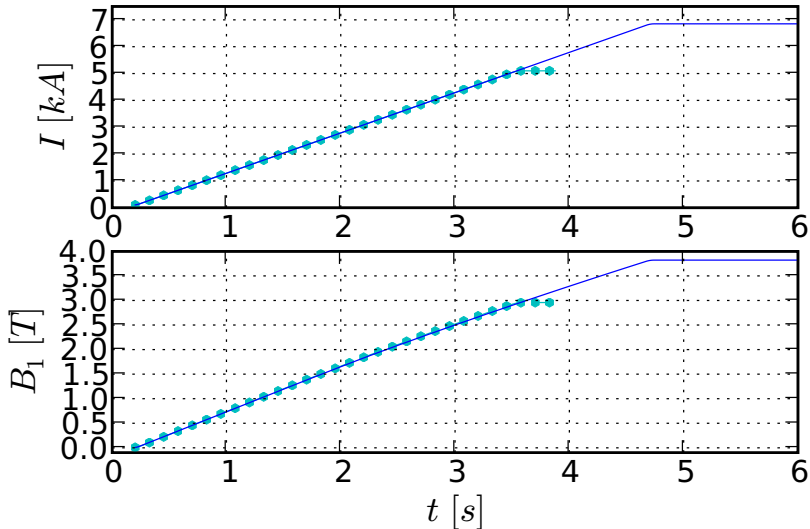
I/III



Bricolage set up

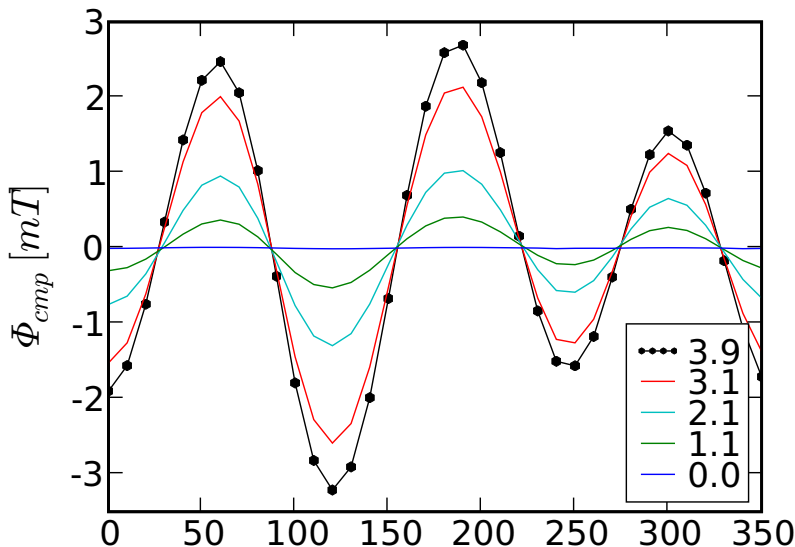
II/II

- coil was hold by teflon rings
- coil fixed with teflon and capton to carbon tube
- carbon tube fixed to pitch circle
- step by step turned by hand
- data compared to BNL Measurements (at 2 T / s)
- power supply reproducibility found to 2.5 units



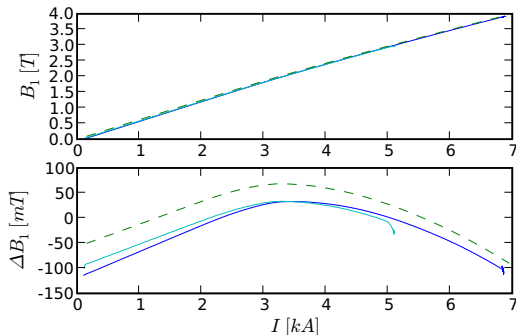
To 3 and 4 Tesla with $\approx 1 \text{ T / s}$

Flux measured by compensation array

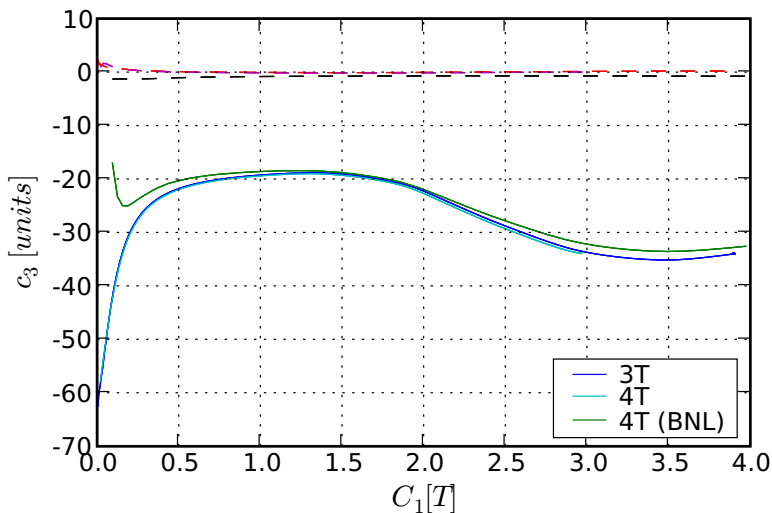


Main dipole strength

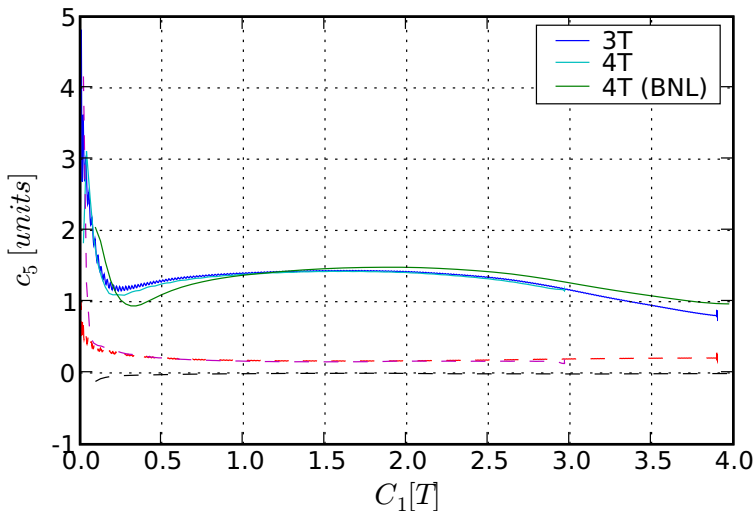
Start offset due to missing rotating coil measurement. Integrator trigger to 3 T 40 Hz, to 4 T 500Hz, different coil length different positions dashed lines → Measurement by A. Jain @ 2 T/s.



Harmonics C_3



Harmonics C_5



green

Conclusion

- Mechanical requirements (bucking) → allow step by step
- power supply reproducibility → good
- piezo motor can do angular steps
- bricolage test shows good results for harmonic quality
- main field measurement requires improvement