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. Kiesewetter
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 dynanics
- this talk → focuses on AC field measurement using the mole

Methods commonly applied for pulsed magnets

- synchotrons → since 50^{th}
  - 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 synchotron magnets

normal conducting

- dipole
  - field integral $\int B_y \mathrm{d}l$
  - field homogeneity $\frac{B_y}{\mathrm{d}x} \rightarrow$ "normal multipoles"
  - angle $\rightarrow$ pole shape
- quadrupole
  - field integral $\int G_y \mathrm{d}l$
  - axis (w.r.t. pole shoes)
  - field homogeneity (multipoles)

super conducting

- dipole
  - $\int B \mathrm{d}l$
  - angle (no mech. ref.)
  - field homogeneity (multipoles)
  - "axis" (shape of the magnet at cold)
- quadrupole
  - $\int G \mathrm{d}l$
  - axis
  - angle
  - field homogeneity (multipoles)

Difference measuring sc $\leftrightarrow$ nc synchotron magnets

- chosen system must
  - provide angle
  - axis
  - supress vibration (round anti cryostat in rectangular aperture)
- coil probe:
- DC $\longrightarrow$ rotating
- AC $\longrightarrow$
  - 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

$$\Phi(t) = Re\left[\sum_{n=0}^{N} \mathbf{K_n} \mathbf{C_n} e^{\mathrm{i}n\theta(t)} \right]$$

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

$$V(t) = -n\,\dot{\theta}(t)\ Re\underbrace{\left[\sum_{n=0}^{N}\mathbf{K_n}\left\{\mathbf{C_n} + \frac{\mathrm{d}\mathbf{C_n}}{\mathrm{d}t}\right\} e^{\mathrm{i}n\theta(t)}\right]}_{\mathrm{d}\Phi(t)/\mathrm{d}t}$$

Spurious harmonics due to mechanical artifacts

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

$$\mathbf{C}^{\mathbf{sd}}_{\mathbf{p+1}} \approx \frac{\mathbf{K_1}}{\mathbf{K_{p+1}}} \frac{t}{2} \mathrm{i}\mathbf{C_1} \qquad \mathbf{C}^{\mathbf{sd}}_{\mathbf{p-1}} \approx \frac{\mathbf{K_1}}{\mathbf{K_{p-1}}} \frac{t}{2} \mathrm{i}\overline{\mathbf{C_1}}$$

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

$$\mathbf{C}^{\mathbf{sq}}_{\mathbf{p+1}} \approx \frac{\mathbf{K_2}}{\mathbf{K_{p+1}}}\ t\ \mathrm{i}\mathbf{C_2} \qquad \mathbf{C}^{\mathbf{sq}}_{\mathbf{p+1}} \approx \frac{\mathbf{K_2}}{\mathbf{K_{p+1}}}\ t\ \mathrm{i}\overline{\mathbf{C_2}},$$

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

$$\mathbf{C}^{\mathbf{sq}}_{\mathbf{p+1}} = \frac{\mathbf{K_1}}{\mathbf{K_{p+1}}} \frac{\mathbf{d}}{2R_{Ref}}\ -\mathrm{i}\mathbf{C_2} \quad \mathbf{C}^{\mathbf{sq}}_{\mathbf{p-1}} = \frac{\mathbf{K_1}}{\mathbf{K_{p-1}}} \frac{\mathbf{d}}{2R_{Ref}}\ \mathrm{i}\overline{\mathbf{C_2}}.$$

Mechanical Requirements

- based on a radial compensation coil
  - first coil probe CERN LHC head #41 $\longrightarrow$ 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

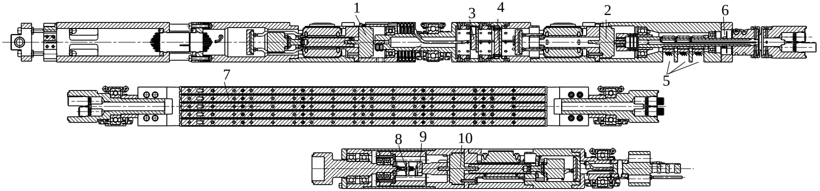
		abs		cmp		*unit*
Dipole						
	p		2		10	
	t	0.5	80		7.5	*mrad*
Quadrupole						
	p		3		12	
	t	0.5	45		5	*mrad*
	d	0.2		5		*mm*

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

Choise 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

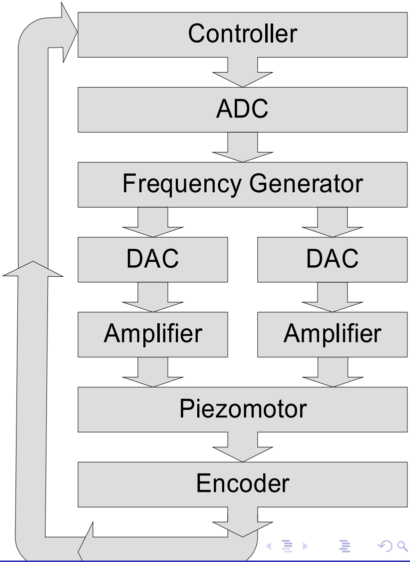
Angular positioning I/II

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

Signal Generation / Control Loop

- function generator realised in FPGA
- must produce variable 50.5 − 51kHz 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

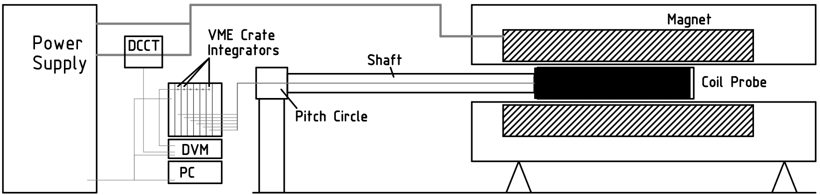
Angular positioning II/II

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

First test

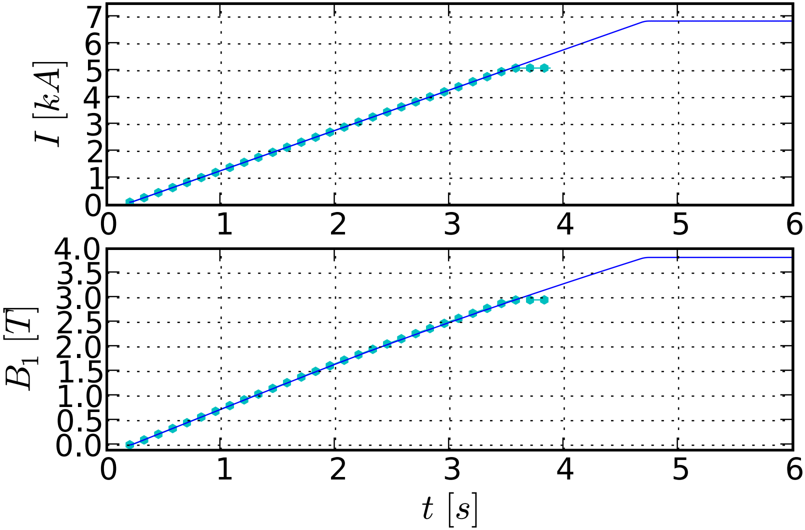
- GSI 001 (modified RHIC magnet) on the test bench
- mole not available . . . but LHC quadrupole coil probe
- test of power supply reproducibility

Bricolage set up I/II



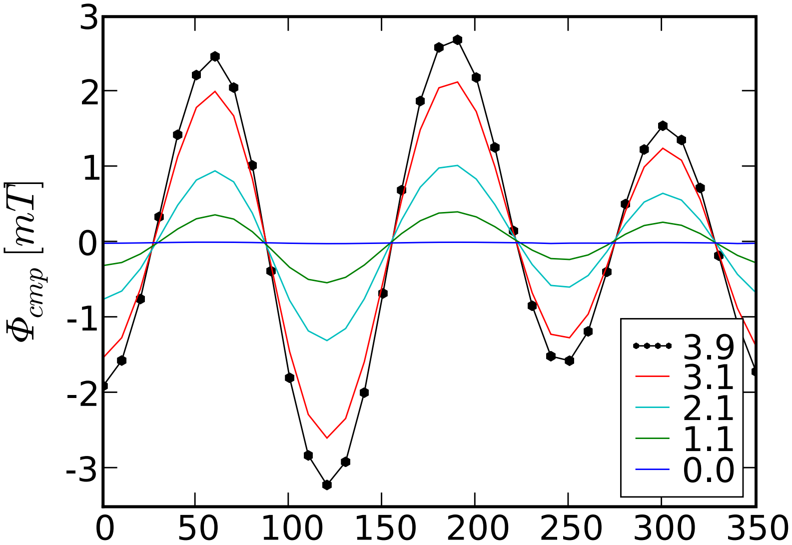
Bricolage set up

- 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



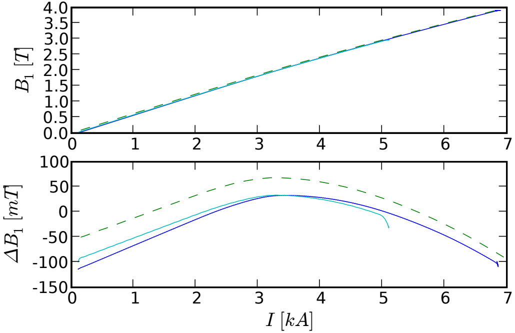
To 3 and 4 Tesla with ≈ 1 T /s

Flux measured by compensation array

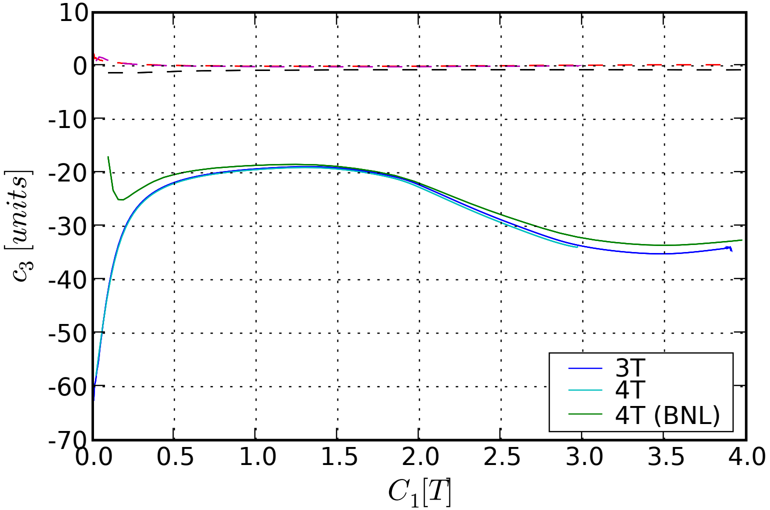


Main dipole strength

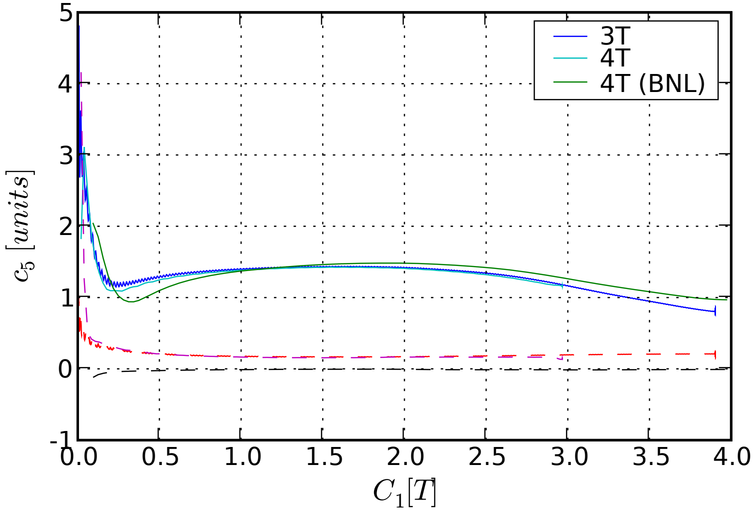
Start offset due to missing rotating coil measurement. Integrator trigger to 3 T 40 Hz, to 4 T 500Hz, different coil length different positions dashed lines → Measurement by A. Jain @ 2 T/ s.



Harmonics C_3



Harmonics C_5



green

Conclusion

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