Magnets alignment using vibrating wire: latest results

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PACMAN

Particle Accelerator Components' Metrology
& Alignment to the Nanometre Scale

European Commission

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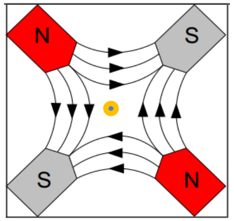
Outline

- Introduction / new challenges
- Alignment of short quadrupole & dipole combine function magnets (CFM) with Vibrating Wire using compensating dipole: proof of principle experiments
- Alignment of long CFM using Vibrating Wire and Hall Probe: demonstration experiments
- Conclusion

Introduction / New challenge

Vibrating Wire technique* is well established and was used in many occasions for quadrupole magnets alignment.



Field is “zero” on magnetic axis, straight geometry

New challenge – combine function magnets (CFM) for 4-th generation of SR sources

APS - U

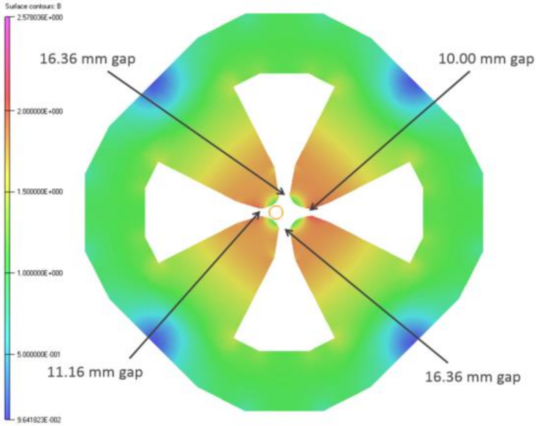
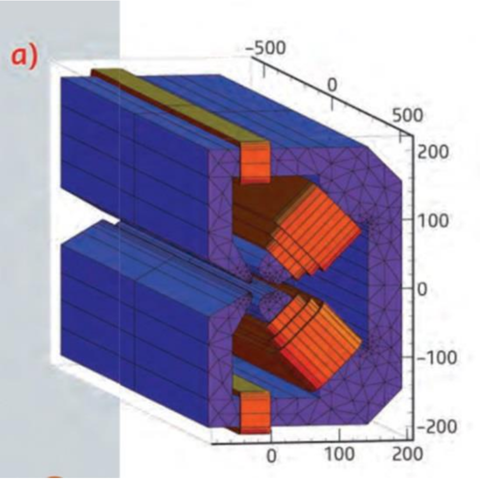


Figure 3.79. Cross section of the M4 Q-bend magnet.

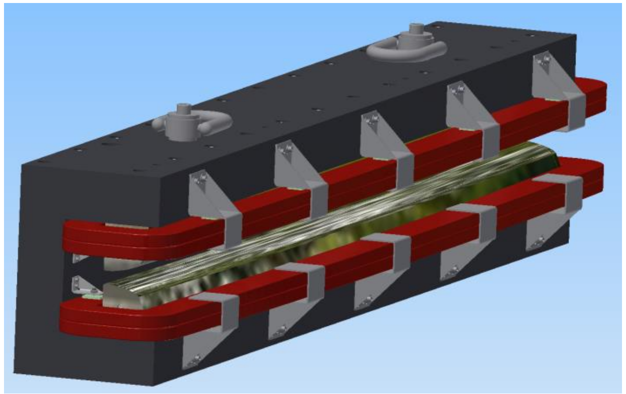
Type	Dipole Field	Quad Gradient
CFM (VP)	~0.6 T	~48 T/m

ESRF Upgrade



Dipole field ~ 0.529 T
Quad Gradient ~ 34.6 T/m
Bore radius 18mm

CHESS - U



Dipole field ~ 0.637 T
Quad Gradient ~ 8.76 T/m

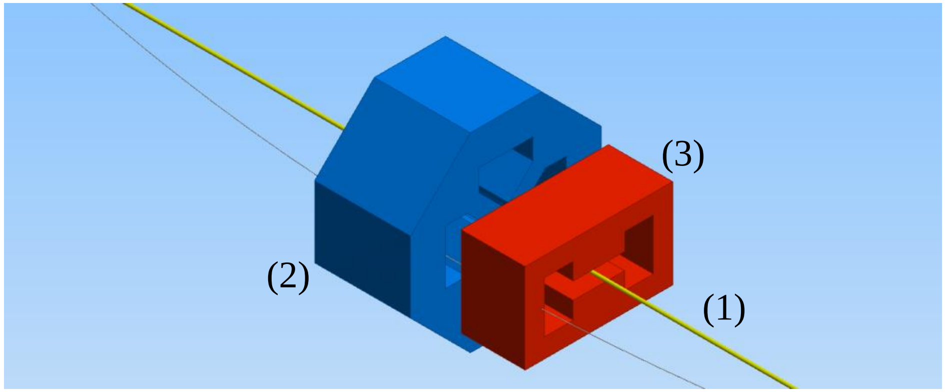
**A. Temnykh, Vibrating wire field-measuring technique, NIMA 399 (1997) 185-194*

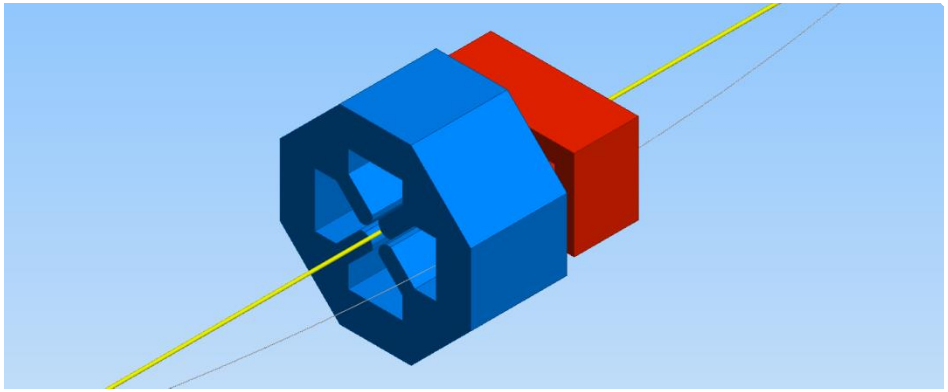
Short CFM (APS-U type) alignment

Idea: use compensating dipole magnet

Setup

1) Vibrating Wire
2) Short combine function magnet, APS-U type
3) Well characterized dipole magnet with vertical field





Procedure

Step 1: Place wire on designed beam axis

Step 2: Excite dipole magnet with a current producing nominal field integral with opposite sign

Step 3: Excite quad magnet with current required for nominal gradient and move it in horizontal and vertical planes to “zero” wire vibration

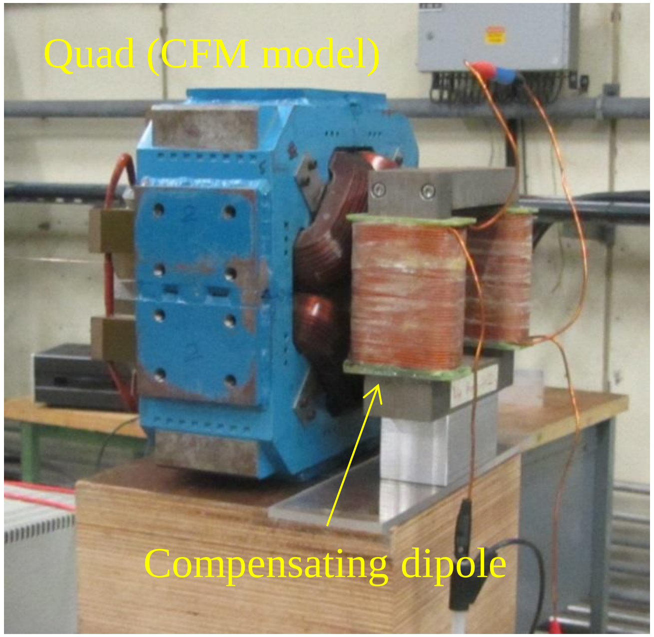
Vertical field integral of the dipole magnet should be equal and opposite to CFM nominal dipole field integral.

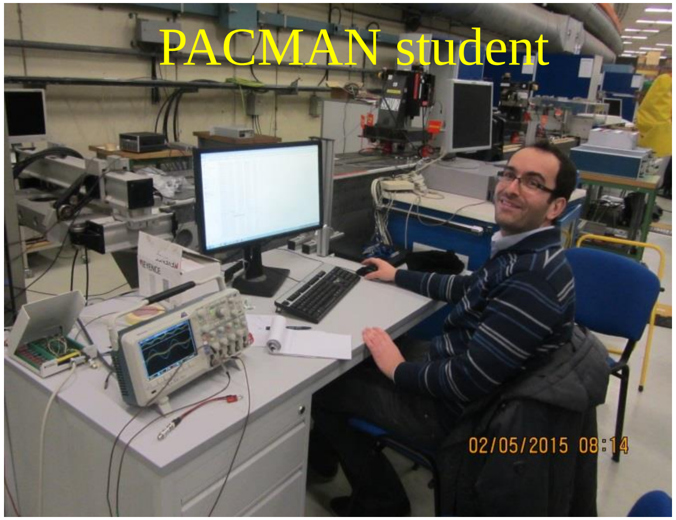
Short CFM (APS-U type) alignment

Demonstration experiment: CERN, Feb 6 2015

Domenico Caiazza (1), Carlo Petrone (1) and Alexander Temnykh (2)

(1) CERN, (2) Cornell University





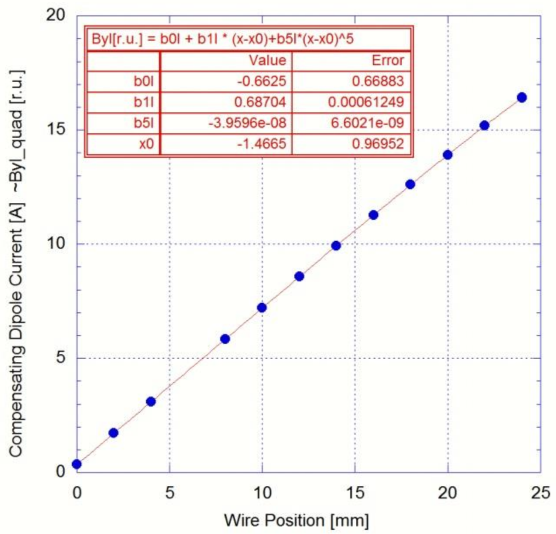
Short CFM (APS-U type) alignment: demonstration experiment

Procedure:

1. Quad current = 2.5A (~1T/m or less)
2. Moved wire by 1mm step in horizontal plane
3. At each wire position the dipole current was adjusted to “zero” wire vibration, i.e. to compensate vertical field integral

Results:

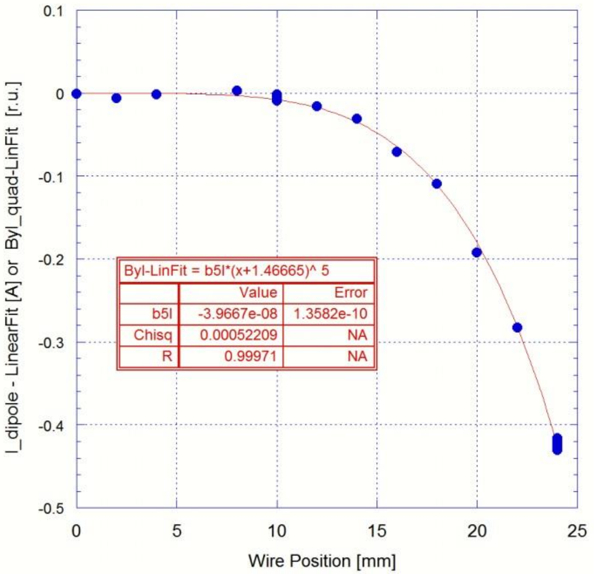
**Compensating Dipole Current (Quad vertical field integra
versus Wire Position, I_Quad = 2.5A**



ByI[r.u.] = b0I + b1I * (x-x0)+b5I*(x-x0)^5

	Value	Error
b0I	-0.6625	0.66883
b1I	0.68704	0.00061249
b5I	-3.9596e-08	6.6021e-09
x0	-1.4665	0.96952

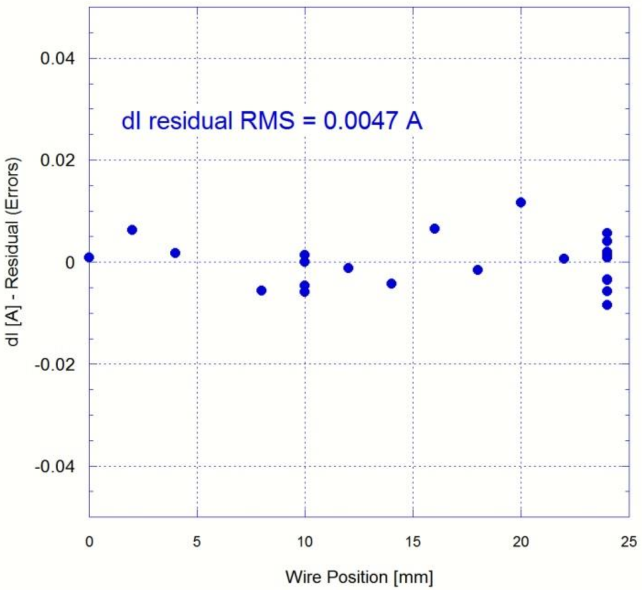
**Dipole Current (Quad vertical field integral)
versus wire position with subtrcted linear term**



ByI-LinFit = b5I*(x+1.46665)^ 5

	Value	Error
b5I	-3.9667e-08	1.3582e-10
Chisq	0.00052209	NA
R	0.99971	NA

**Compensating Dipole Current
fitting residuals**

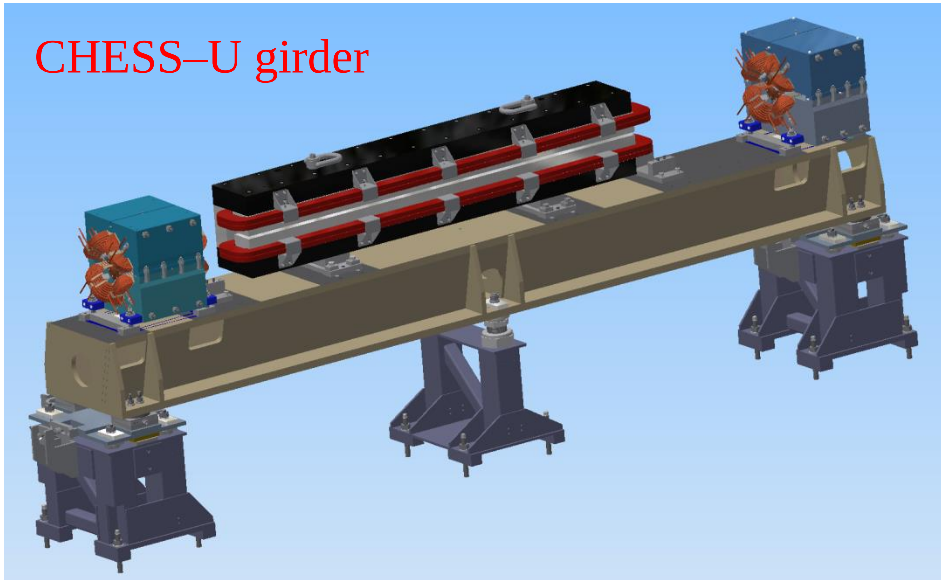


dI residual RMS = 0.0047 A

0.0047 A of dI RMS translates into 0.0068 (!) mm RMS misalignment

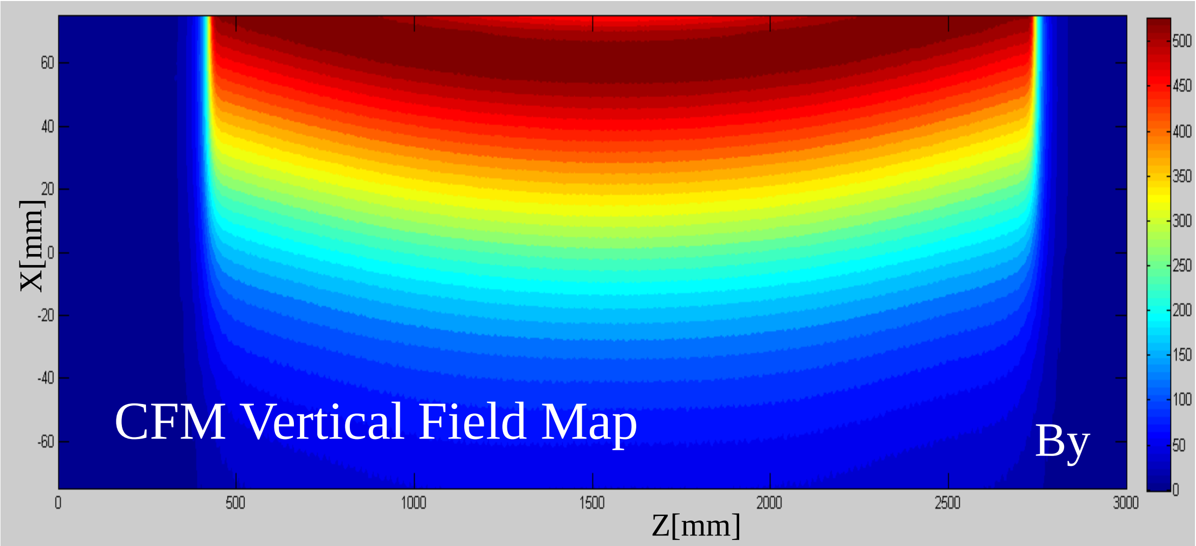
For CFM with stronger gradient (~50T/m) this method will provide submicron alignment accuracy.

Long CFM (CHESS-U type) alignment in respect to quadrupole magnets



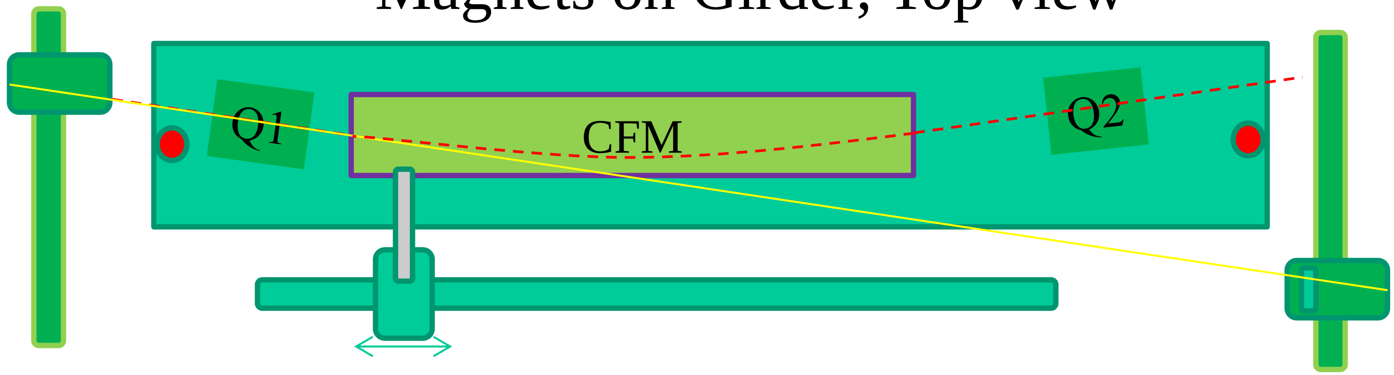
2.3m CHESS–U CFM
Dipole field = 0.637 T;
Gradient 8.76 T/m
Poles excursion 21.5mm

CFM and quad magnets alignment tolerance to be 0.05mm or better



Alignment procedure

Magnets on Girder, Top view



🟩 Movable VW stages
— Vibrating Wire (VW)
▯ Wire position sensor

● Girder fiducials
▯ Hall Probe
■ Quadrupole Magnet

🟩 DQ Magnet
- - - - Beam trajectory

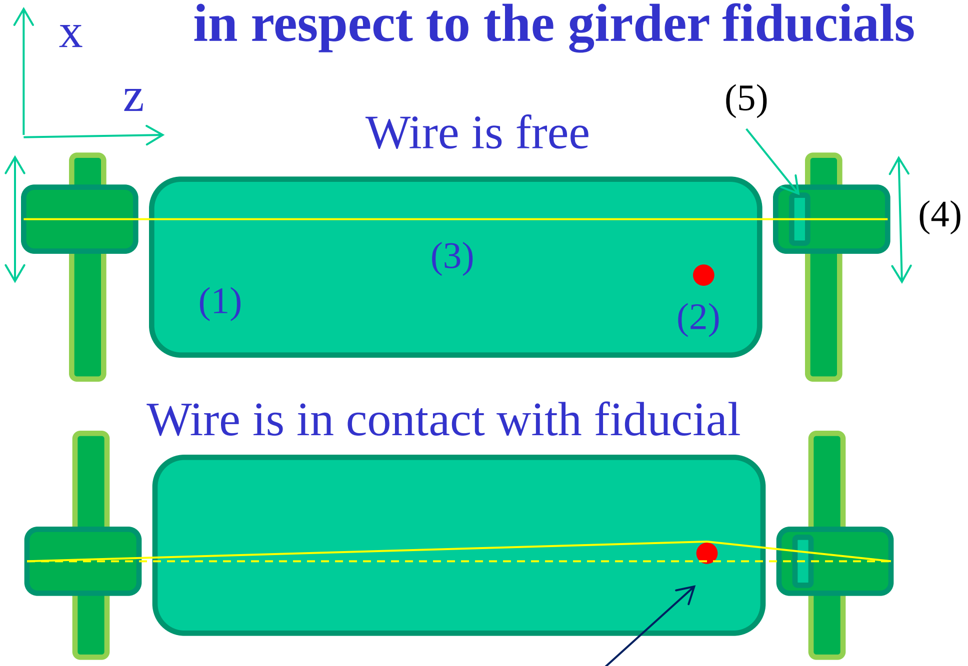
Local coordinate system is defined by the girder fiducials

Alignment procedure

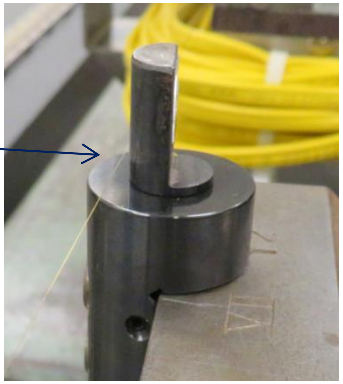
Step 1: Establish Vibrating Wire position in respect to girder fiducials
Step 2: Establish Hall probe position relative to wire
Step 3: Survey quadrupole magnets with WV and place them at required position
Step 4: Survey CFM (DQ) with Hall probe and place the magnet at required position

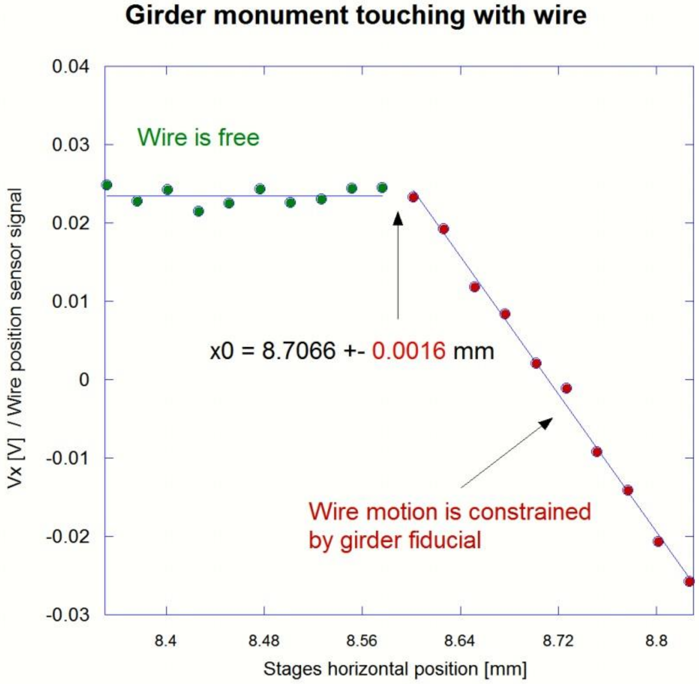
Vibrating Wire precise positioning

Establishing Vibrating Wire position in respect to the girder fiducials



1) Girder
2) Girder fiducial
3) Stretched wire
4) Moving stage
5) Wire position sensor





Optical Wire position sensor
(Motorola H21A1)

dV/dx ~ 1.8 mV/micrometer

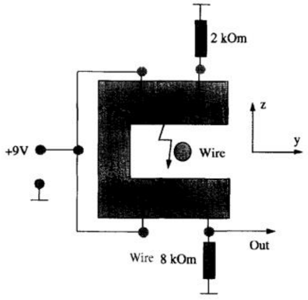
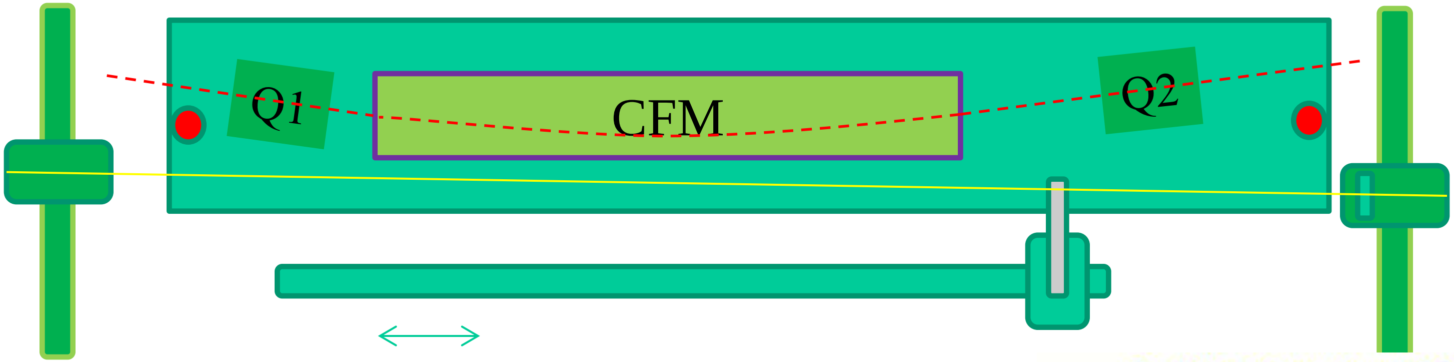
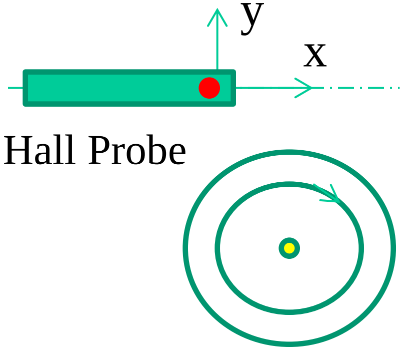


Fig. 2. Schematic view of LED-phototransistor assembly used as a wire position detector.

Hall probe precise positioning in respect to wire

1) Measure magnetic field generated by current diving through the wire.



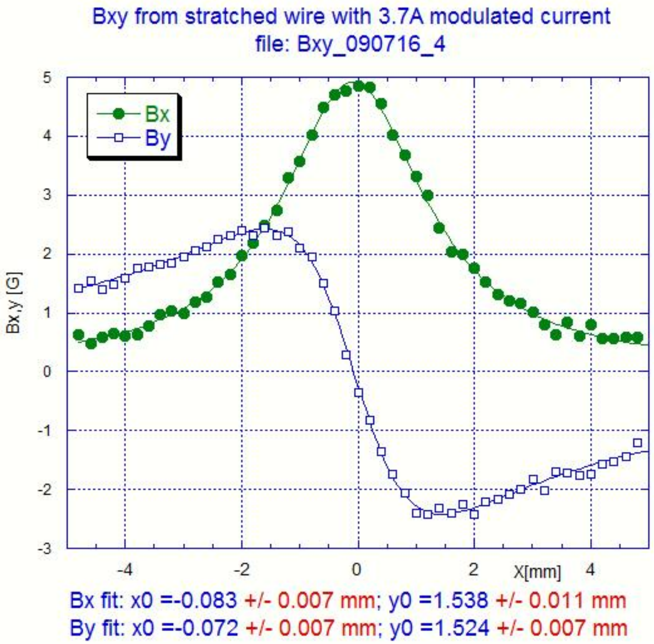


Stretched wire position : x0, y0

From Amper Law:

$$B_y(x) = \frac{\mu_0}{2\pi} I \frac{x - x_0}{{y_0}^2 + (x - x_0)^2};$$

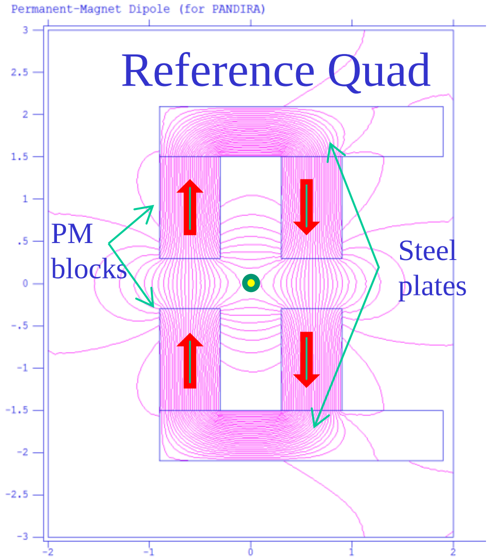
$$B_x(x) = \frac{\mu_0}{2\pi} I \frac{y_0}{{y_0}^2 + (x - x_0)^2}$$

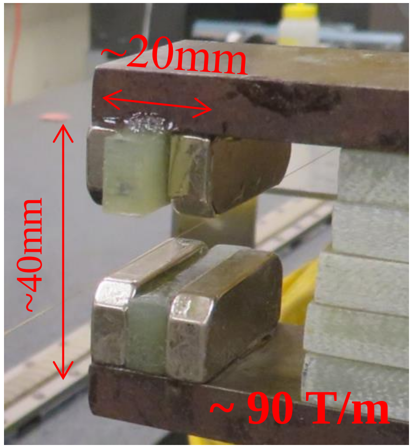


Bx fit: x0 =-0.083 +/- 0.007 mm; y0 =1.538 +/- 0.011 mm
By fit: x0 =-0.072 +/- 0.007 mm; y0 =1.524 +/- 0.007 mm

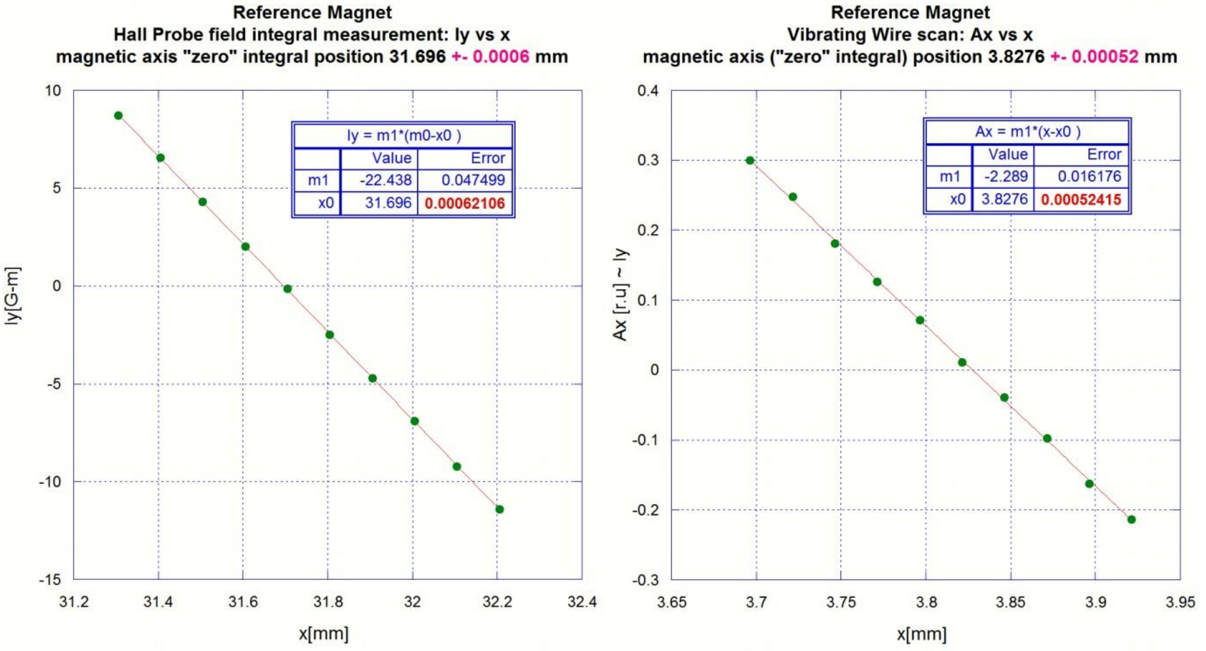
Hall probe precise positioning in respect to wire

2) Measure location of reference quad magnetic axis (“zero” field) position with Vibrating Wire and Hall Probe





Reference Quad magnetic axis position measured with Hall Probe (left) and Vibrating Wire (right)



Hall Probe and Vibrating wire position can be correlated with submicron precision.

Conclusion

- Precise alignment of a short CFMs can be done using Vibrating Wire technique in combination with compensating dipole. This, as well, can be used for of a small aperture magnets characterization.

- Alignment of quadrupole magnets and long CFM in respect to girder’s fiducials requires the following:

a) Accurate positioning of vibrating wire relative girder fiducials
b) Accurate positioning of Hall probe in respect to vibrating wire
c) Alignment of quadrupole magnets using Vibrating Wire
d) Alignment of CFM based on the field mapped with Hall Probe

Demonstrated accuracy:

“a”: ~0 .002 mm

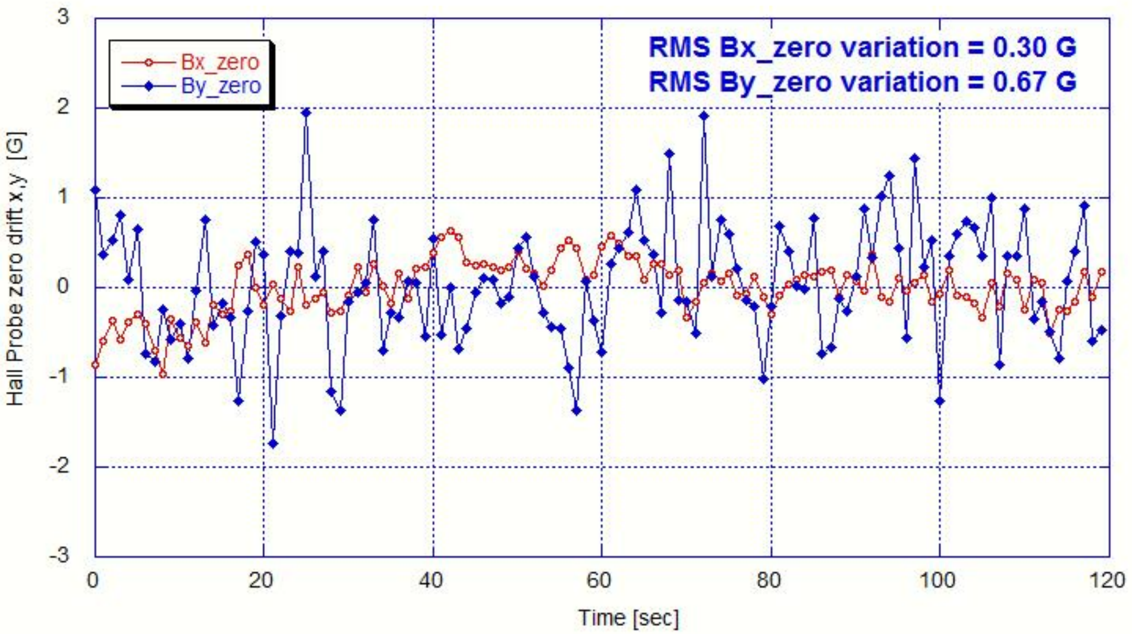
“b”: better than 0.001 mm

“c”: better than 0.001 mm

“d”: 0.003 mm in vertical plane and 0.006mm in horizontal. The use of Hall probe with lower noise can significantly reduce the later numbers.

Appendix: Hall Probe “zero” drift

SENIS F3A Hall Probe Performance verification: measurement of Bx,y zero_drift

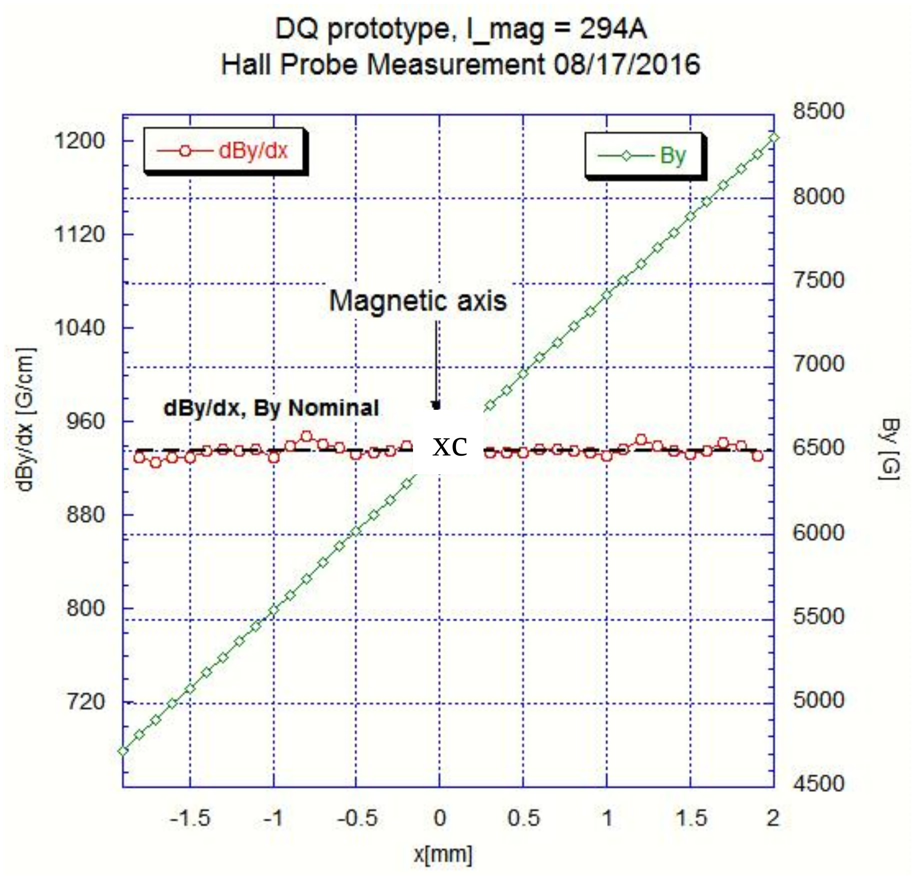


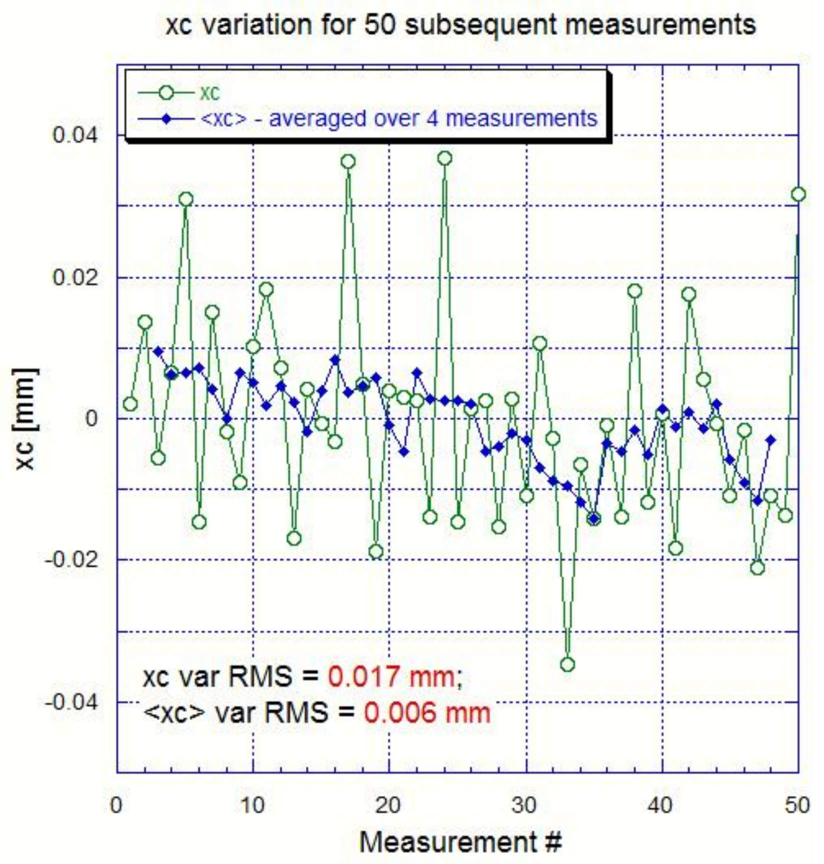
Hall probe model	Number of Axis	Spatial Resolution	Noise over 0.01-10Hz, peak to peak
SENIS F3A (used in experiments)	3	150x10x150μm	100μT (1G)
SENIS I3C (low noise)	3	100x10x100μm	5-10μT (0.05-0.1G)

Appendix: CHESS-U CFM prototype alignment

Vertical field versus horizontal position

xc variation for 50 sequential measurements



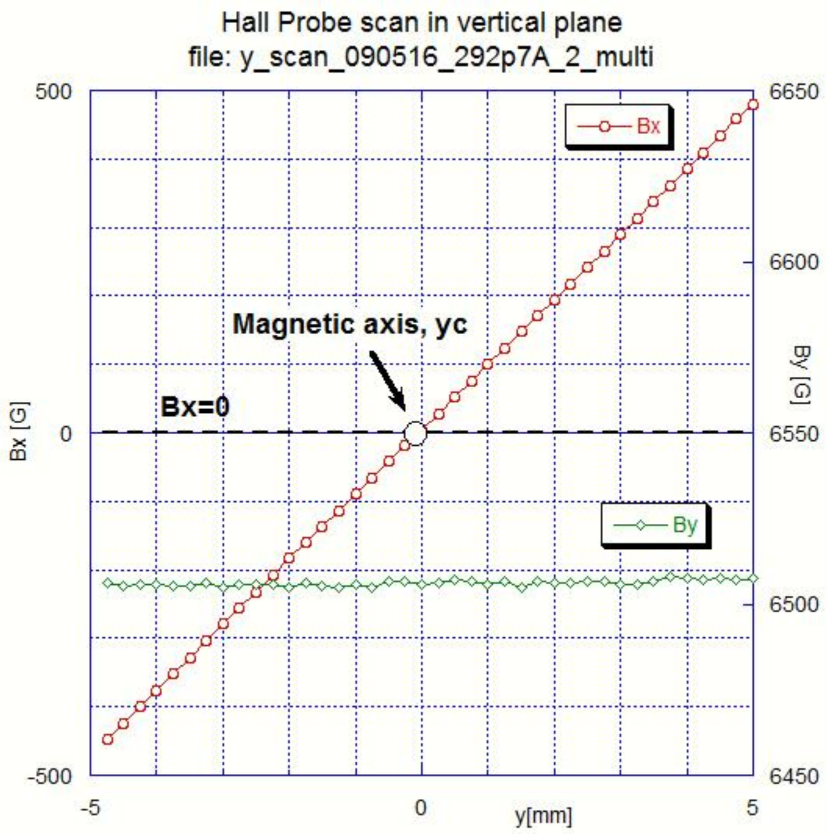


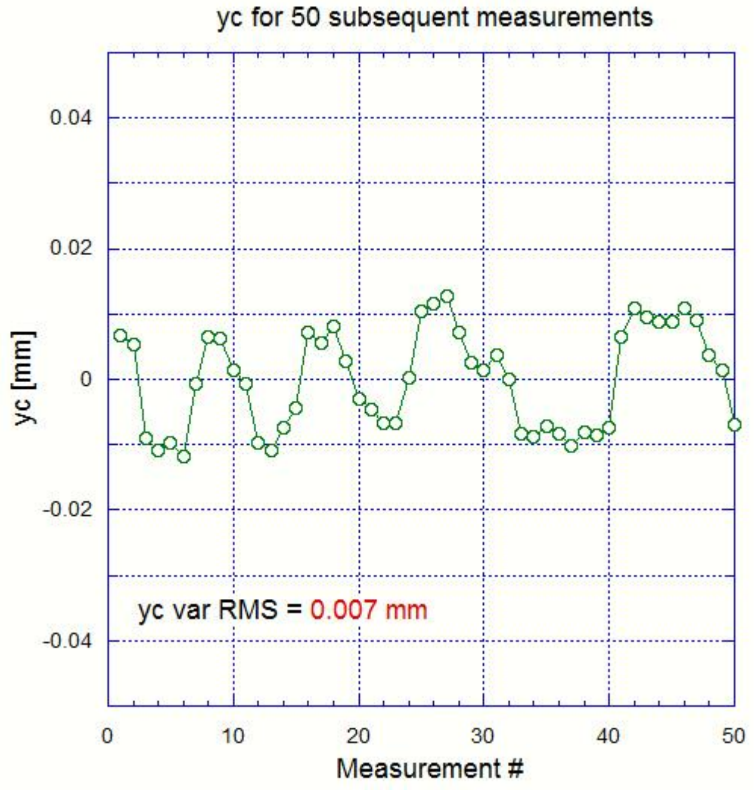
Expected uncertain in “x” axis localization due to Hall Probe “zero” drift is By_zero_drift / (dBy/dx)= 0.007 mm

Appendix: CHESS-U CFM prototype alignment

Horizontal field versus vertical position

“yc” variation for 50 sequential measurements





Expected precision of “y” axis localization due to Hall Probe “zero” drift: Bx_zero_drift / (dBx/dy)= 0.003 mm

Appendix: CHESS-U CFM prototype perfomance

Hall Probe (SENIS F3A) measurements