Summary of the Alignment Session of IMMW15

Fermilab, Batavia IL
August 21- August 24, 2007

Heiner Brueck, DESY

The Alignment Session @ IMMW15

- 3 talks
  - Sextupole Magnet Axis with Vibrating Wire
    by A.TEMNYKH
  - Measurements of Wire Sag for Vibrating Wire
    by A. JAIN
  - Solenoid Axis Measurements
    by J. DIMARCO
- Talks on https://indico.fnal.gov

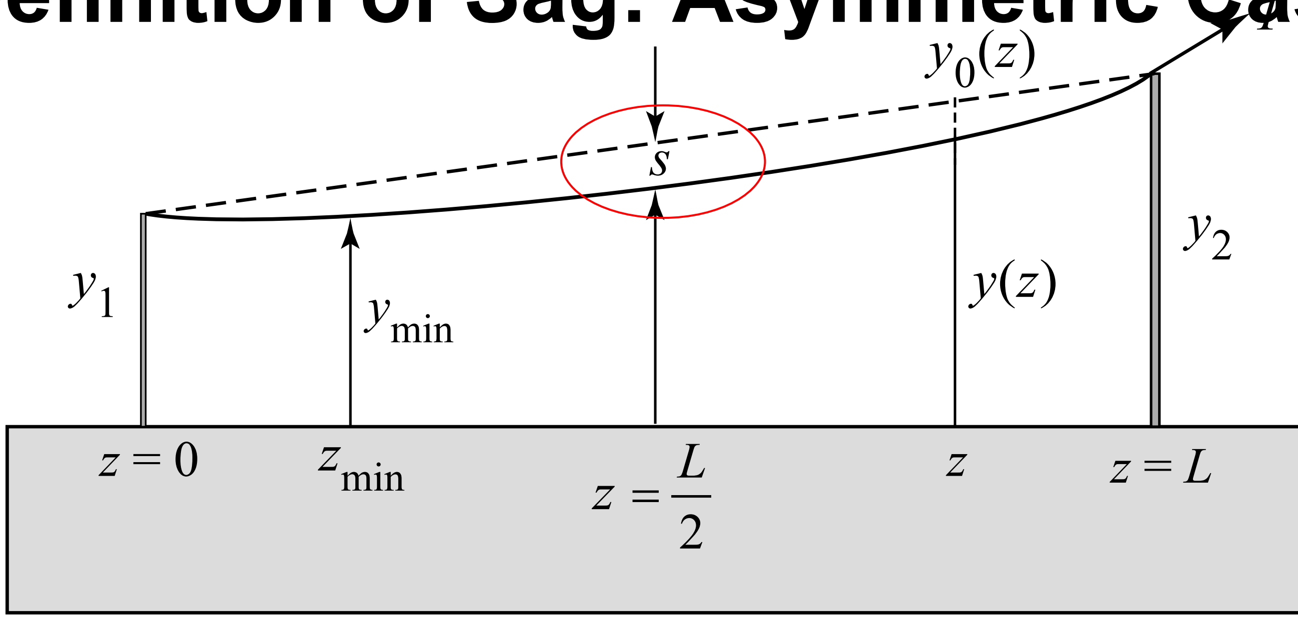
Alignment

- All talks describe topics related to Stretched Wire Systems
- Stretched Wire Systems are used to measure the
  - Axis of magnets (x, y)
  - Magnetic field angles (roll, yaw and pitch angle)
  - Field integrals
- Normally applied to dipoles and quadrupoles, as shown here also used for measuring sextupoles and solenoids

Measurement of the Wire Sagging A. Jain

- NSLS-II requires a very tight tolerance on the relative alignment of quadrupoles and sextupoles on a girder, which is ~ 6 m long.
- Use the vibrating wire technique for aligning magnets to each other.
- Cu-Be wire sags 500-600 μm for ~6 m length.
- Accurate calculation of the sag correction is essential in order to correct for it.
- How well does the sag formula work?

Definition of Sag: Asymmetric Case



$$y_0(z) = \frac{y_2 - y_1}{L} z + y_1$$

$$y_0(z) - y(z) = \left(\frac{m_\ell g}{2T}\right) z(z-L)$$

Deviation from straight line at any position.
This has the same form as the symmetric case.

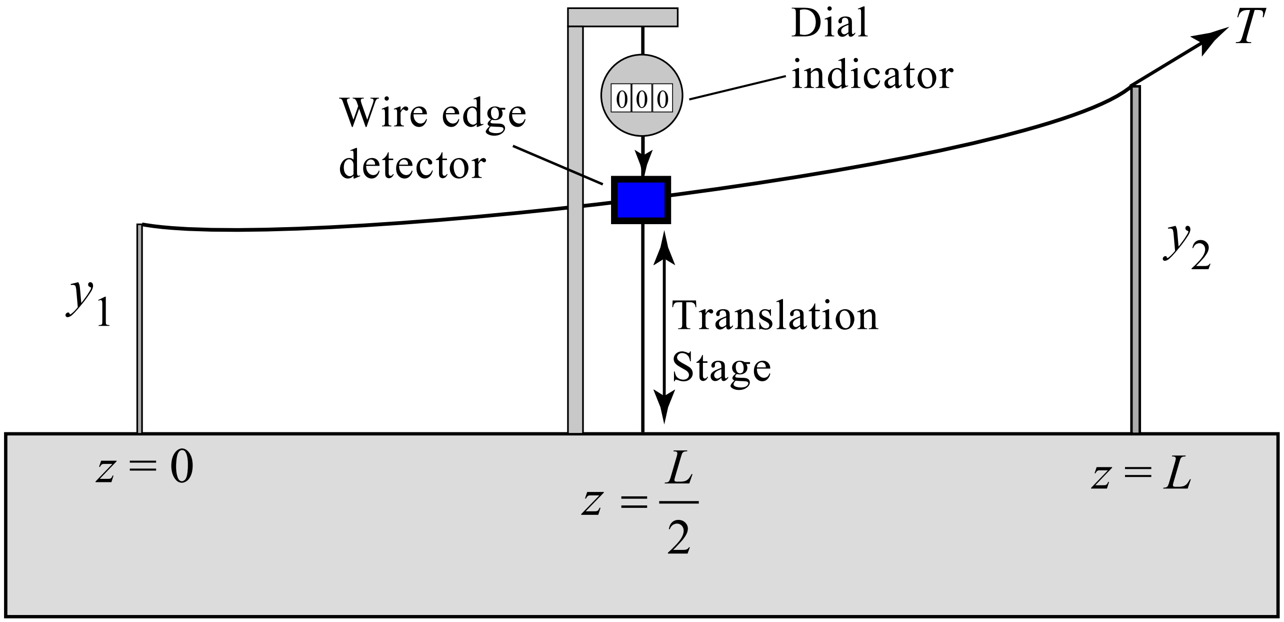
If we define "sag" as the maximum departure from a straight line then:

$$\text{Sag} = s = \left[y_0(z) - y(z)\right]_{\max} = \left(\frac{m_\ell g L^2}{8T}\right) = \frac{g}{32 f_1^2}$$

Same as the symmetric case

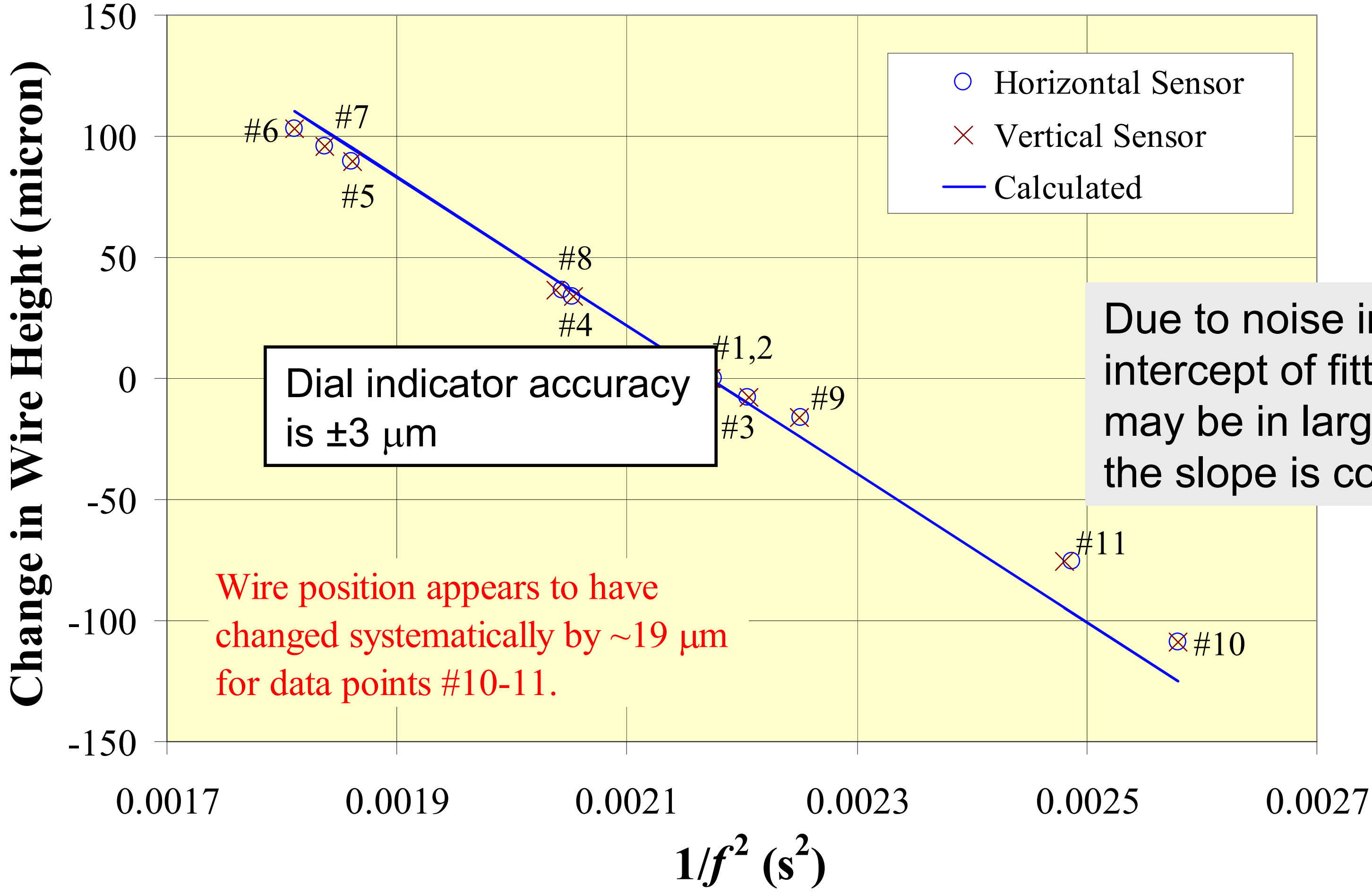
Maximum departure from straight line always occurs at the midpoint.

Measurement of Sag: Concept

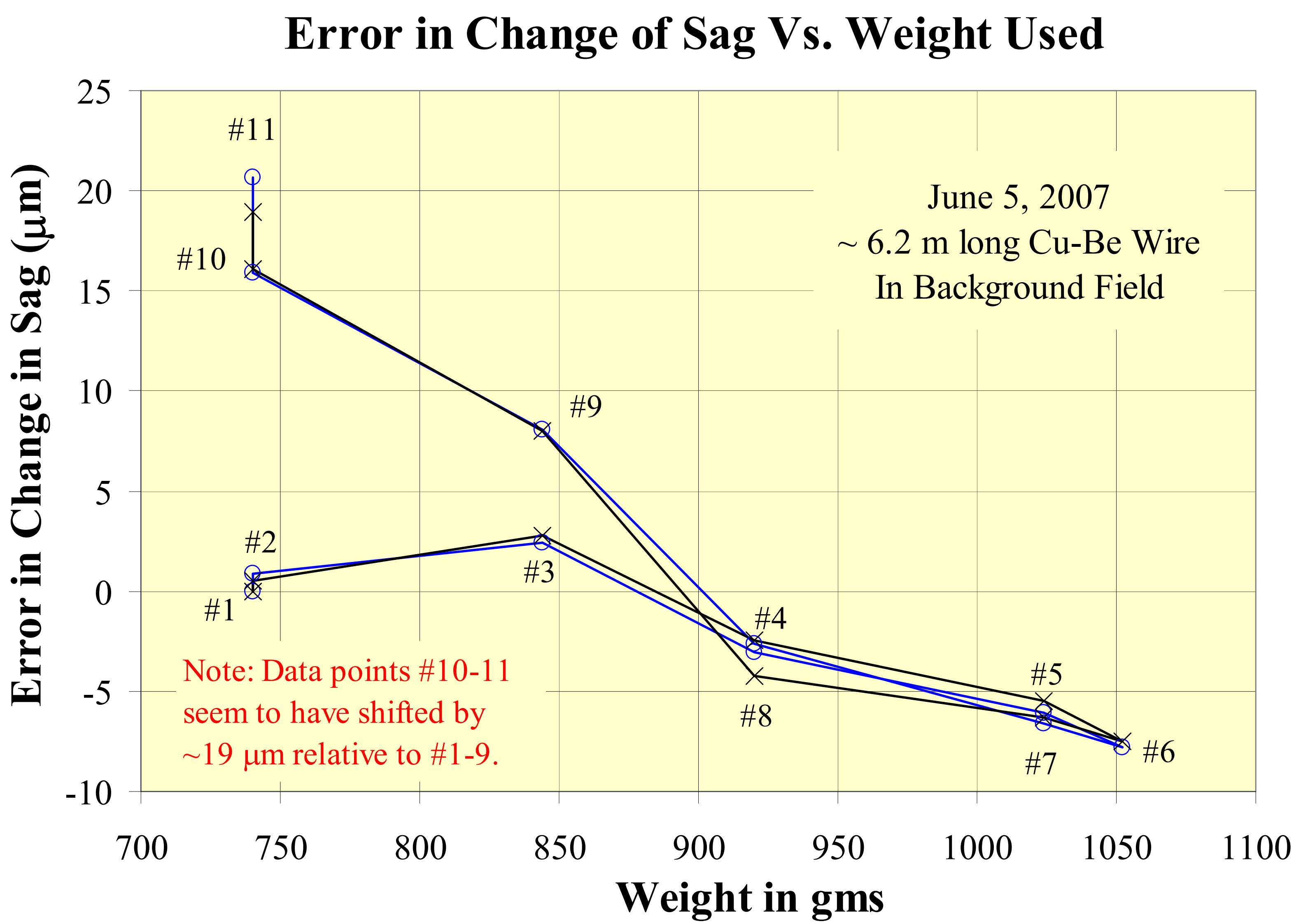


- Set up a wire position detector mounted on a translation stage at the mid point.
- For a given tension, adjust position of detector until null output is obtained.
- Change the tension, and adjust detector again. Measure the amount moved using digital dial indicators.
- Study as a function of tension (or resonant frequency) and compare to theory.

Sag: Measured Vs. Calculated



Due to noise in the data, intercept of fitted straight line may be in large error, unless the slope is constrained.



Error in Change of Sag Vs. Weight Used
June 5, 2007
~ 6.2 m long Cu-Be Wire
In Background Field
Note: Data points #10-11
seem to have shifted by
~19 µm relative to #1-9.
#1
#2
#3
#4
#5
#6
#7
#8
#9
#10
#11
Error in Change in Sag (µm)
Weight in gms
25
20
15
10
5
0
-5
-10
700
750
800
850
900
950
1000
1050
1100

Summary

Measurement of the Wire Sagging, A. Jain

- A simple set up was used to measure changes in sag as a function of applied tension.
- Noise in the data due to dial indicator resolution, detector noise, wire vibrations, etc. was up to ±5 μm in wire height.
- The set up was not very robust mechanically and unexpected changes in wire position were sometimes seen.
- The experiment will be repeated with a better set up when the R&D vibrating wire system at BNL will be operational.

Determination of Magnetic Axis in a Sextupole magnet using Vibrating Wire Technique Alexander Temnykh

- Work was motivated by NSLS-II project requirement of precise alignment of a string of quadrupole and sextupole magnets on a ~6 m long girder within a tight tolerance of ±10-20 microns.
- Similar requirement is anticipated for ILC damping ring.

Sextupole magnet field properties

- Sextupole magnetic field:

$$B_y(x,y) = b_2(x^2 - y^2); \quad B_x(x,y) = -2b_2xy$$

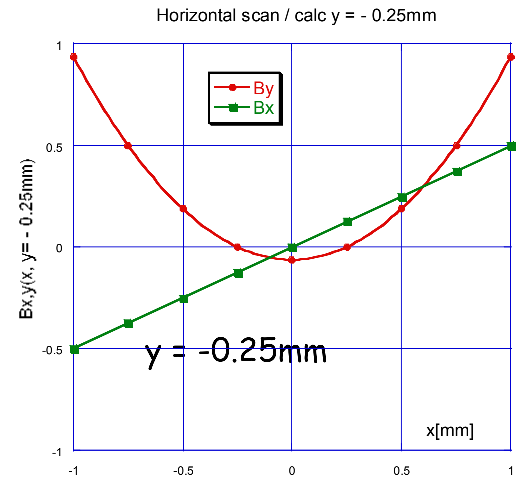
- Horizontal scan:

$$B_y(x, y = y_{off}) = b_2x^2 - b_2y_{off}^2; \quad B_x(x,y) = -2b_2xy_{off}$$

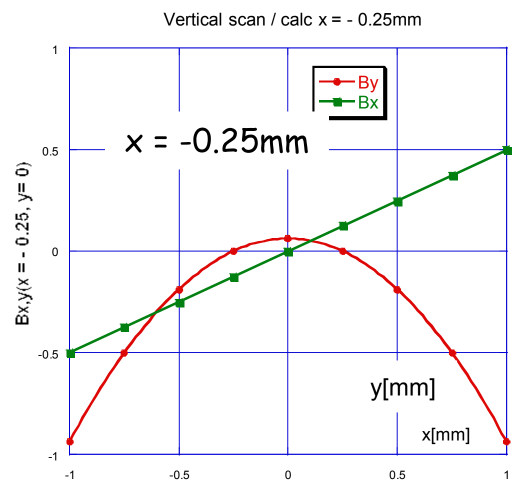
- Vertical scan:

$$B_y(x_{off}, y) = -b_2y^2 + b_2x_{off}^2; \quad B_x(x,y) = -2b_2x_{off}y$$

Horizontal scan



Vertical scan



Sextupole magnet field properties

- Algorithm for magnetic center finding from horizontal scan:

$B_{x,y}(x)$ - horizontal and vertical field components

measured as a function of horizontal position.

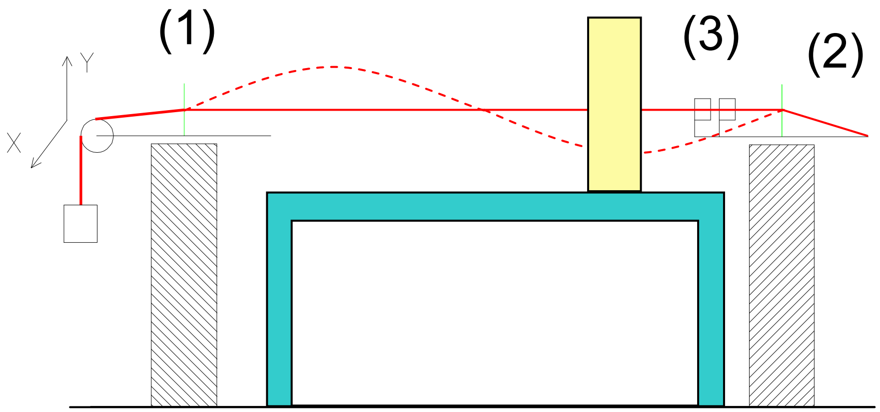
$$B_y(x) = m_2 x^2 + m_1 x + m_0 = b_2 (x - x_c)^2 - b_2 y_c^2;$$

$$B_x(x) = n_1 x + n_0 = 2 b_2 x y_c;$$

$$x_c = -\frac{m_1}{2m_2}; \quad y_c = \frac{n_1}{2m_2}$$

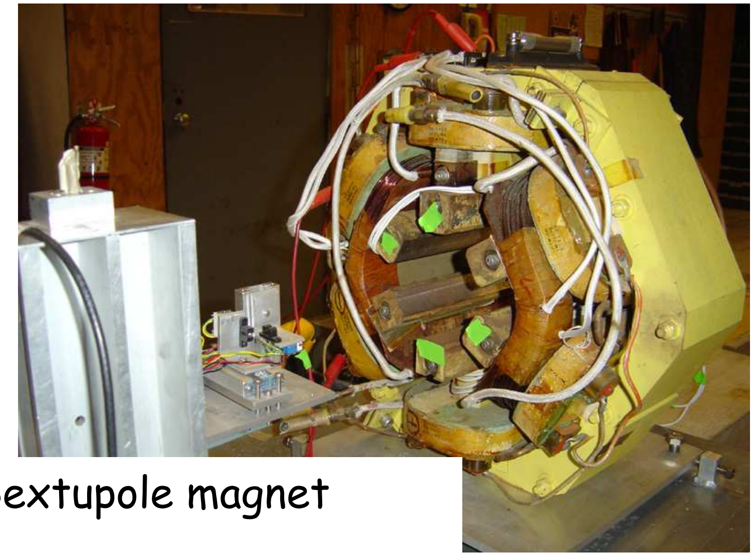
Same result obtained for the vertical scan

Experimental Setup



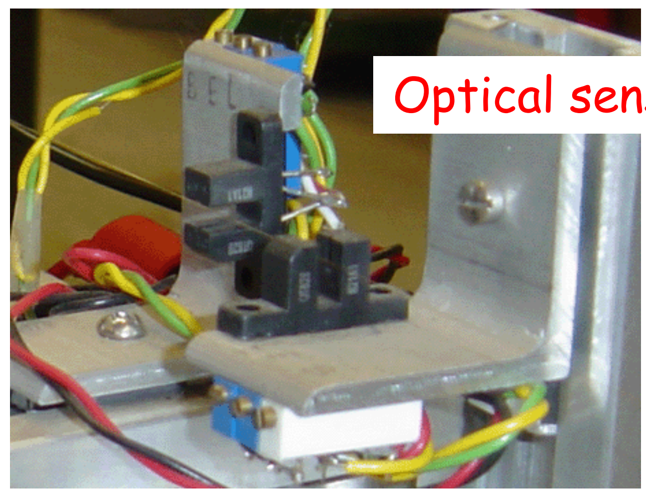
Vibrating Wire:
Length ~ 2200mm
Driving current ~ 60mA (RMS)
Fundamental freq ~ 47Hz
For measurement used 2-nd vibrating mode

(1) Stage with tension mechanism
(2) Stage with wire position sensors
(3) Horizontal and vertical wire position sensors (LED-Phototransistor assemblies)



Sextupole magnet

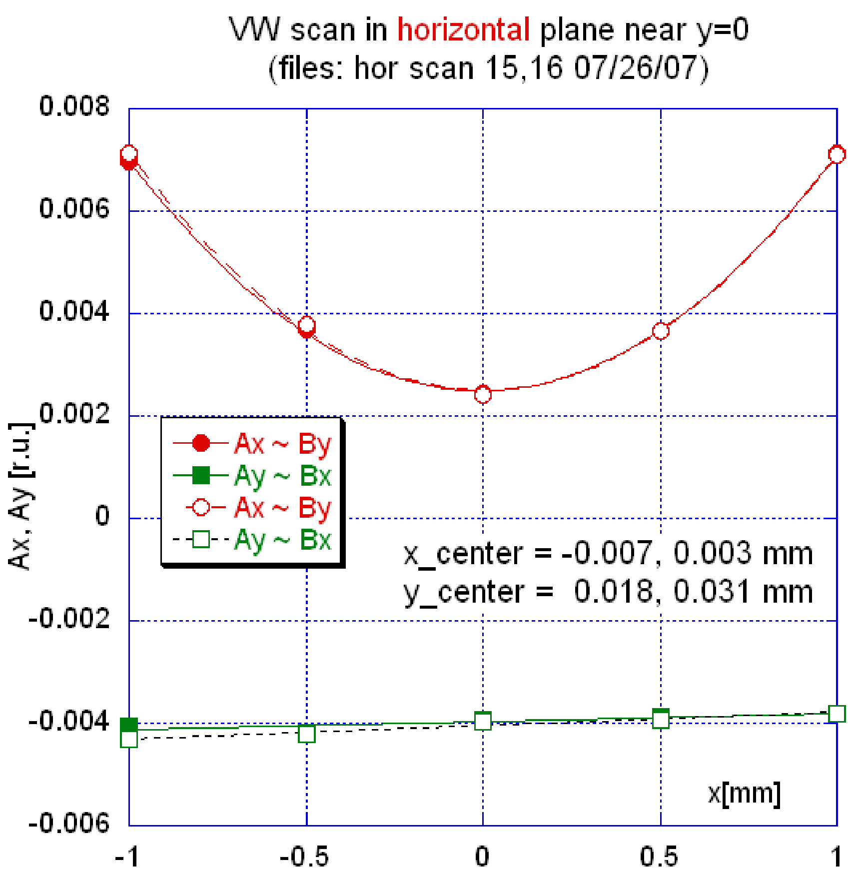
b2l ~ 10.9Gm/cm^2
Length ~ 24cm
Bore radius ~5.5cm

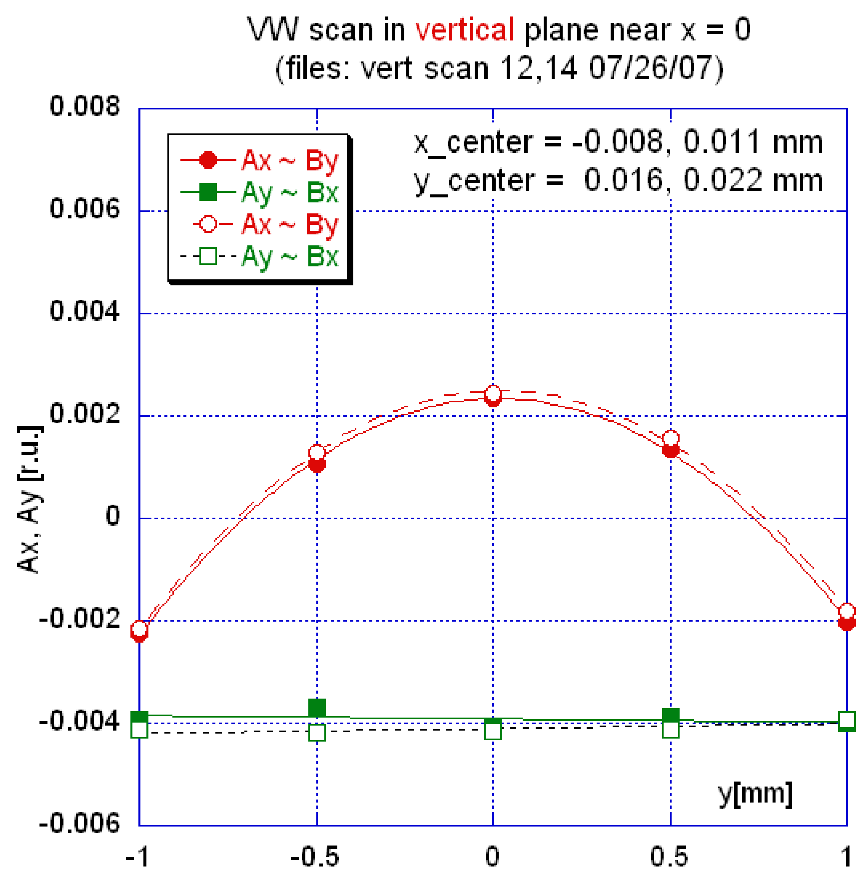


Optical sensors

Example of the experimental results

Horizontal and vertical scans near sextupole magnetic center





Two independent runs are shown

Summary

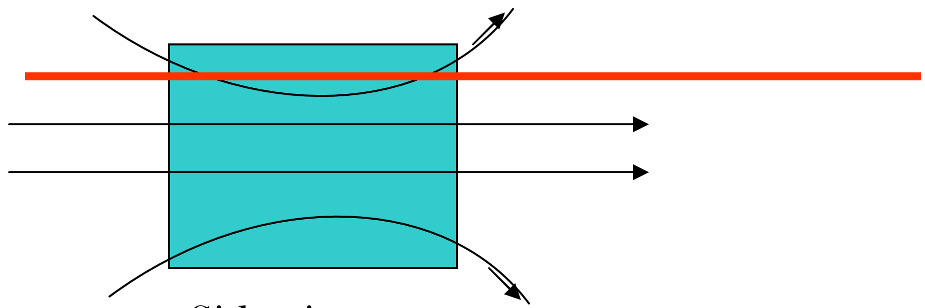
Magnetic Axis in a Sextupole magnet, A. Temnykh

- Vibrating wire technique has been applied to sextupole magnet magnetic axes finding.
- Demonstrated precision, ~10microns, is adequate to the alignment requirement of NSLS - II project and, very likely, of ILC damping ring.
- Coupling of horizontal and vertical sensor can be calibrated and corrected
- Even pitch and yaw angle can be measured

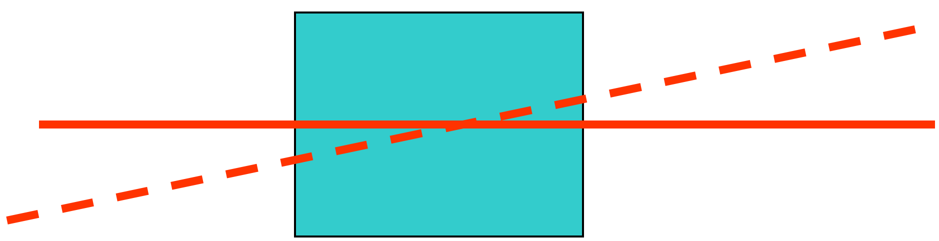
Solenoid axis measurement, J. DiMarco

- Stretched wire used to measure axis (x,y) and pitch and yaw angle in a solenoid
- Magnet (small) powered by AC current
- Amplitude of voltage induced at a certain wire position is measured

Vertical offset



Side view

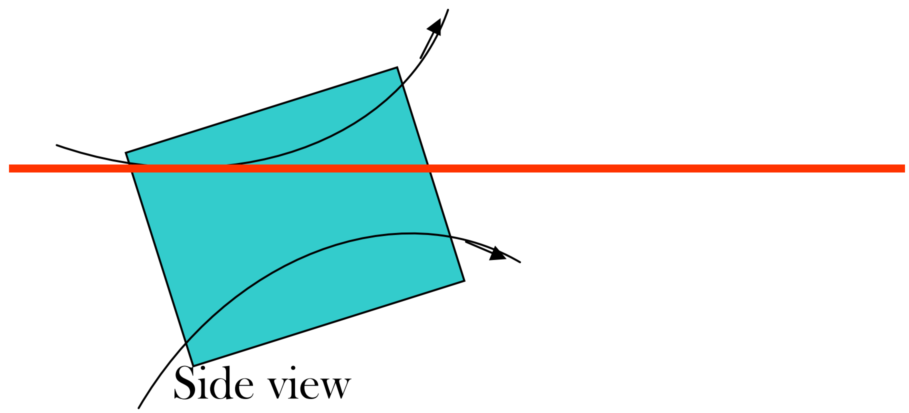


Overhead view

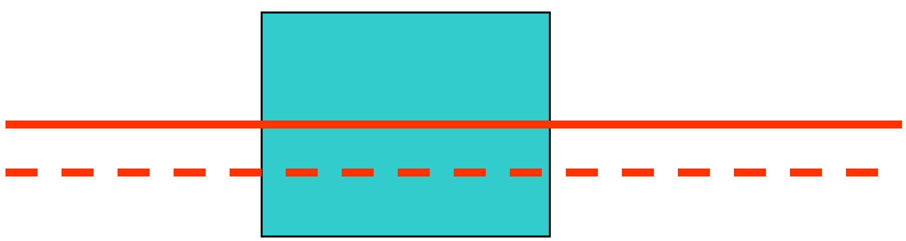
Wire offset vertically cuts flux lines if moved horizontally – but need counter-directional wire motion since field direction is reversing

Make counter-wire flux measurements as function of stage offset to find center

Angle offset



Side view



Overhead view

Magnet pitch –

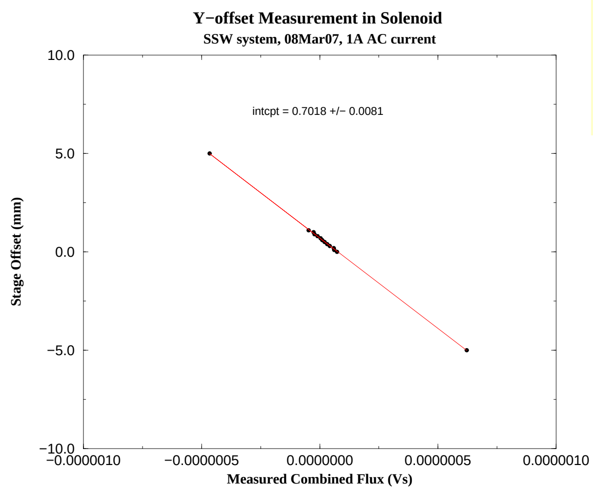
Horizontal wire motion cuts flux lines if magnet is pitched (flux 0 if not pitched)

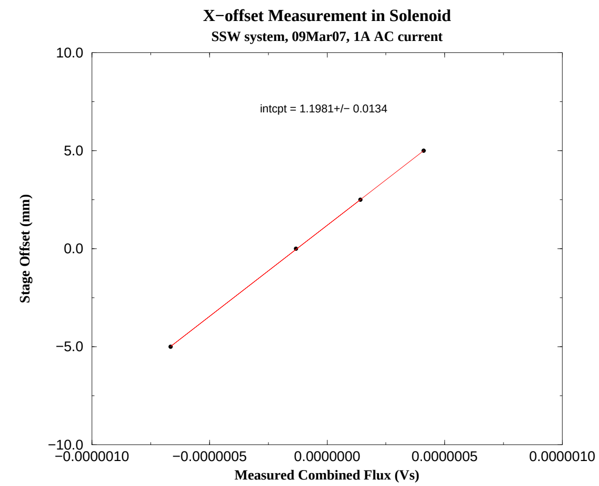
Make co-directional flux measurements as function of stage offset to find pitch

Results

Error in intercept about 10µm

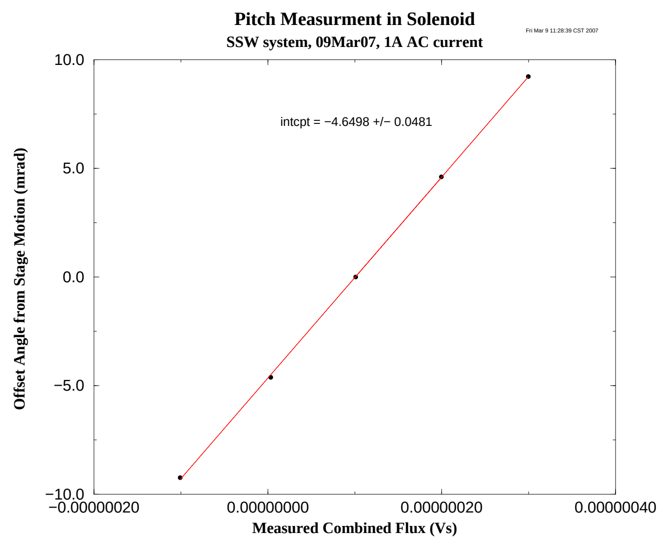
Offset of Wire





Flux

Angel of Wire



Error in intercept about 50µrad

Flux

Summary
Solenoid axis measurement, J. DiMarco

- Can use SSW to align to the HINS solenoid axis at level of 10 microns and 50 microrad
- AC measurements