A study of undulator magnet characterization using the vibrating wire technique

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A.Temnykh et al., Nucl. Instr. And Meth. A622 (2010) 650-656

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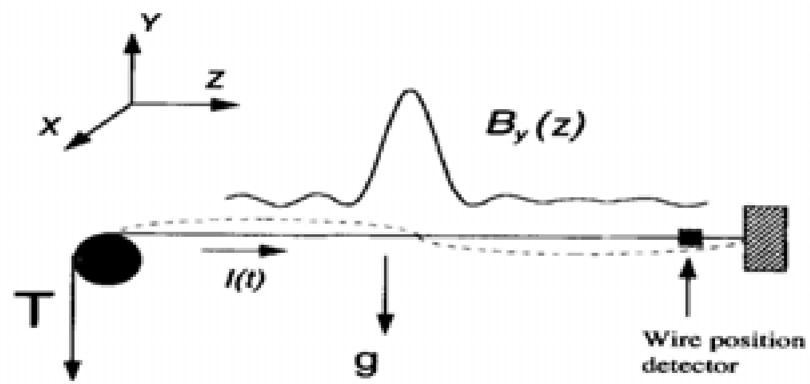
Introduction



$$\mu \frac{\partial^2 Y}{\partial t^2} = T \frac{\partial^2 Y}{\partial z^2} - \gamma \frac{\partial Y}{\partial t} - \mu g + B_y \cdot I_0 \exp(i\omega t)$$

- Magnetic field sensing element - stretched wire
- Amplitudes and phases of various vibrating modes depend on field distribution
- Driving current as a reference for lock-in wire motion detection
- Magnetic field could be reconstructed from the measurements (details in *)

Applications

- Successfully used for finding magnetic axis and alignment
- Small gap/bore undulators
- Quick check of field integrals in the tunnel with limited access to the tested field
- Elliptical and variable polarization undulators

* A. Temnykh, Nucl. Instr. And Meth., 399 (1997) 185.

Measurement principle

$$Y_d(z,t) = \frac{1}{\mu}\sum_{n=1}^{\infty}\frac{B_n \sin\left(\frac{\pi n}{L}z\right)}{(\omega^2 - \omega_n^2 + i\gamma\omega)} I_0 \exp(i\omega t)$$

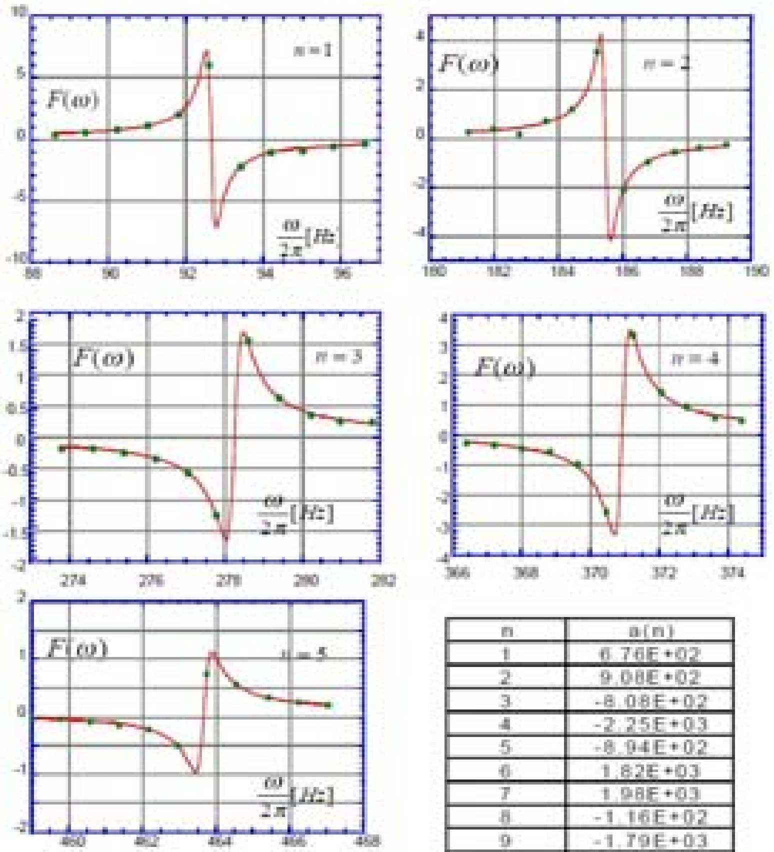
$$F(\omega) = \sum_{n=1}^{\infty}\frac{B_n I_0^2}{2\mu}\sin\left(\frac{\pi n}{L}z_s\right)\frac{(\omega-\omega_n)}{4\omega(\omega-\omega_n)^2+\omega\gamma^2}$$

$$F(\omega) = F_n(\omega) = a_n\frac{(\omega-\omega_n)}{4\omega(\omega-\omega_n)^2+\omega\gamma^2}$$

$$B_n = a_n\frac{1}{\sin\left(\frac{\pi n}{L}z_s\right)}\frac{2\mu}{I_0^2}$$

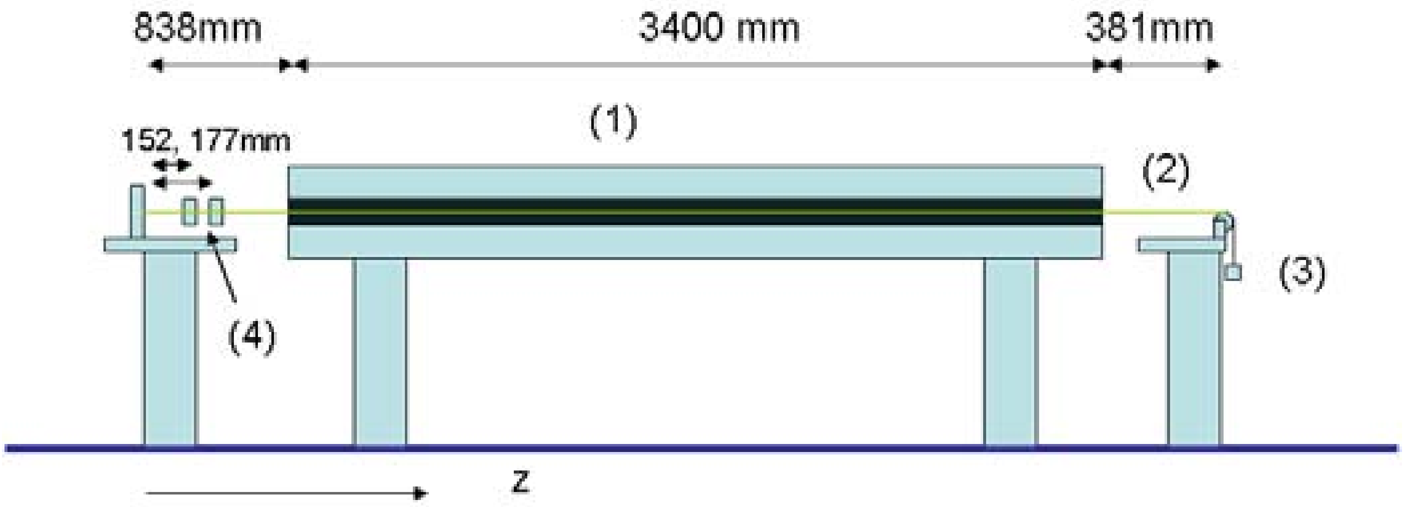
$$B_y(z) = \sum_{n=1}^{\infty} B_n \sin\left(\frac{\pi n}{L}z\right)$$

$n \neq 2Nk \quad k = 1,2,\ldots.$



n	a(n)
1	6.76E+02
2	9.08E+02
3	-8.08E+02
4	-2.25E+03
5	-8.94E+02
6	1.82E+03
7	1.98E+03
8	-1.16E+02
9	-1.79E+03
10	-7.66E+02
11	4.83E+02
12	7.13E+02
13	7.62E+01

Experiment setup

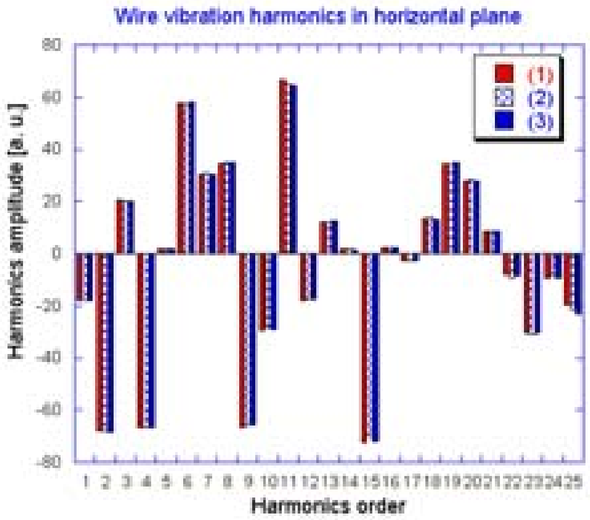


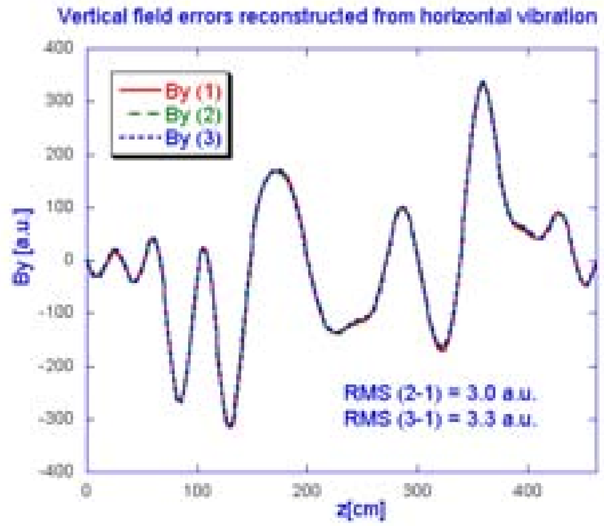
1- LCLS undulator S/N 01, 2 – 100 µm copper-beryllium wire, 3 – load, 4 – LED phototransistor assemblies

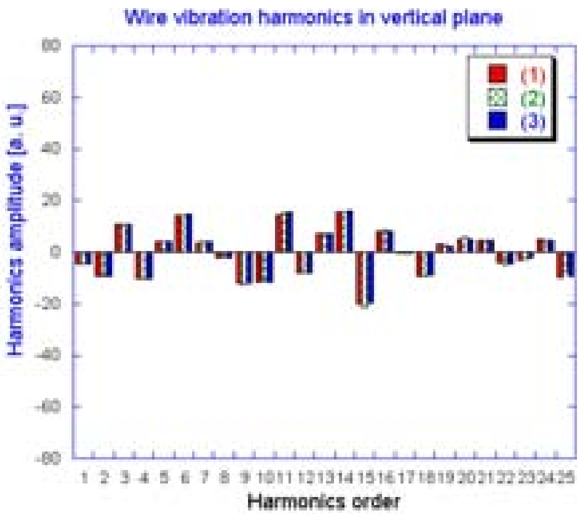
Gap = 6.8mm
Period = 3.0 cm
Number of periods N = 113
Average peak field = 1.25T

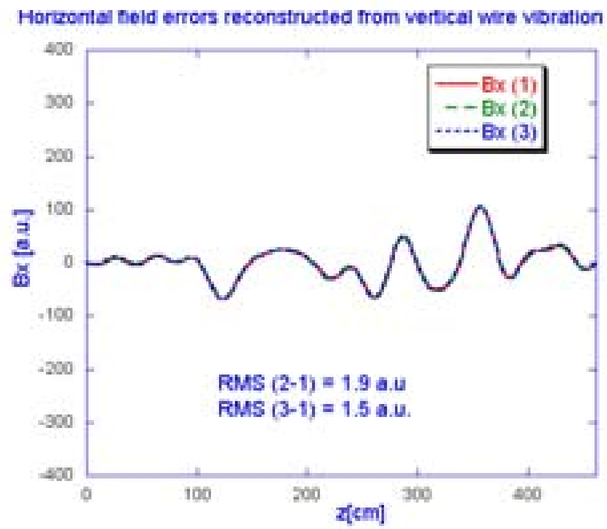
The current amplitude =100mA, driven directly by a wave form generator HP33120A
Signal recording by NI DAQcard – 6024E
Signals processed with LabView and MatLab programs
First vibration mode resonance frequency ~ 30Hz
Number of first modes scanned = 25

Repeatability test









1 and 2 measured within 1 hour,
3 – next day

25 harmonics used,
Shortest wavelength ~ 18cm or 6 periods

3 a.u ≈ 0.1G
≈ 10^{-5} of peak field

Field Integrals:

I1y = 114 ± 2 G · cm
I1x = 2 ± 1.2 G · cm

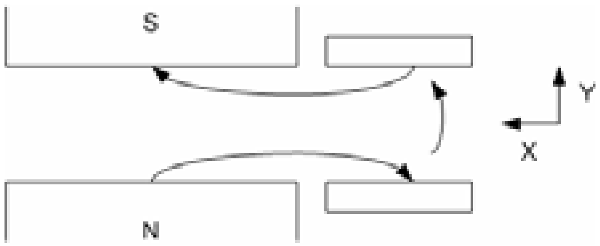
Measurement of localized field distortion. Shims

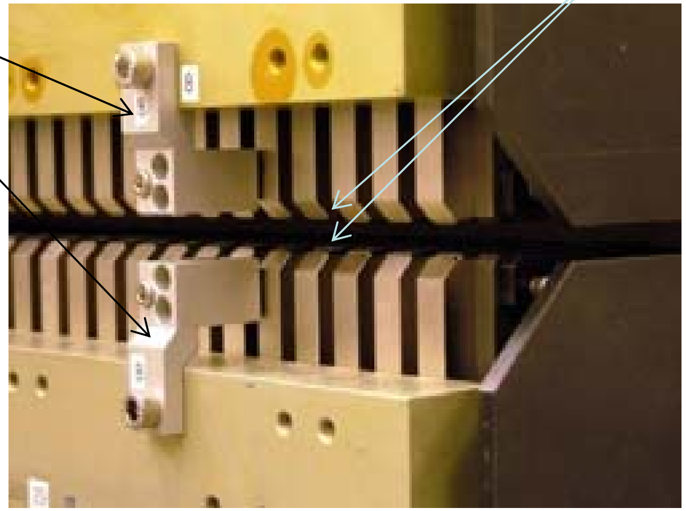
Y-field shims

Field integral from shim = 340 G·cm

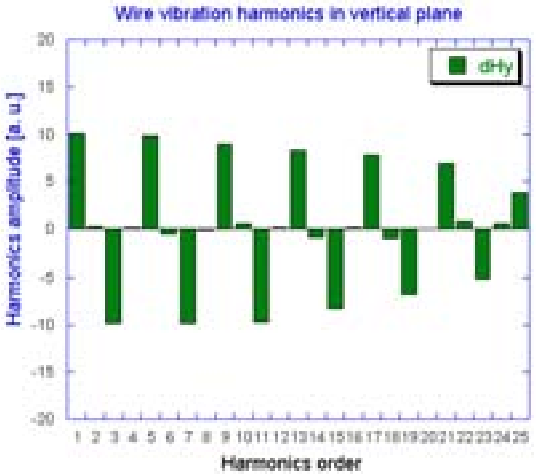
X-field shims

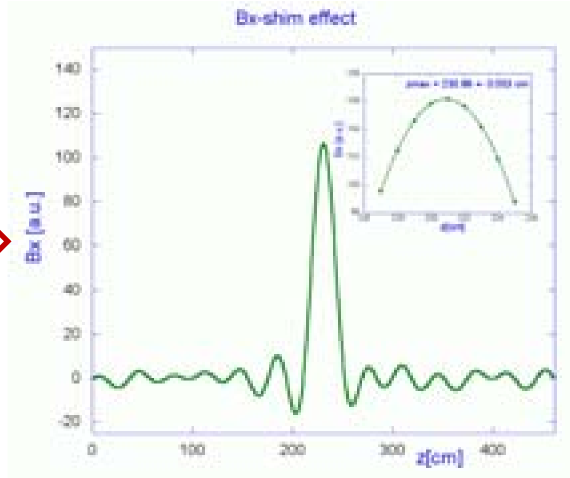
Field integral from shim = 30 G·cm.





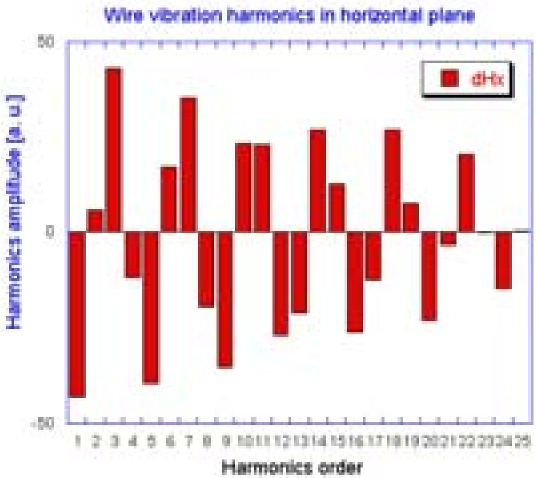
Single shim measurement

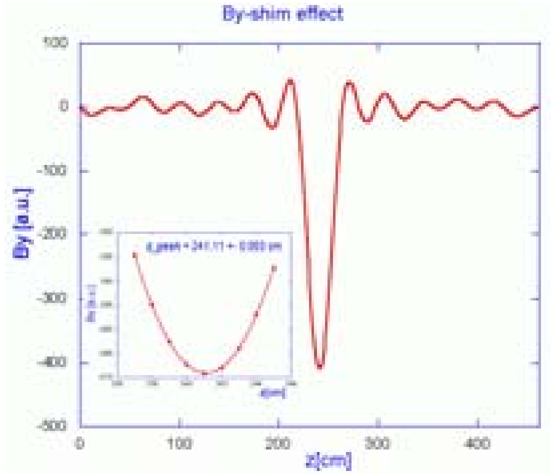




Signal Calibration
Peak area = 906 [a.u.·cm]
Field integral = 30 G·cm.
1 a.u. = 0.033 G

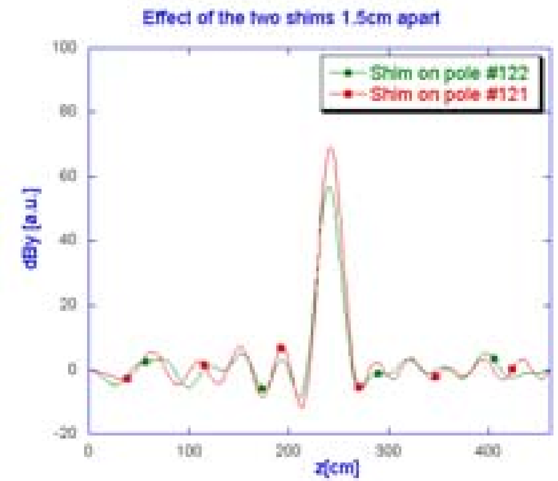
Shim location z = 231cm
Measured z = 230.89cm

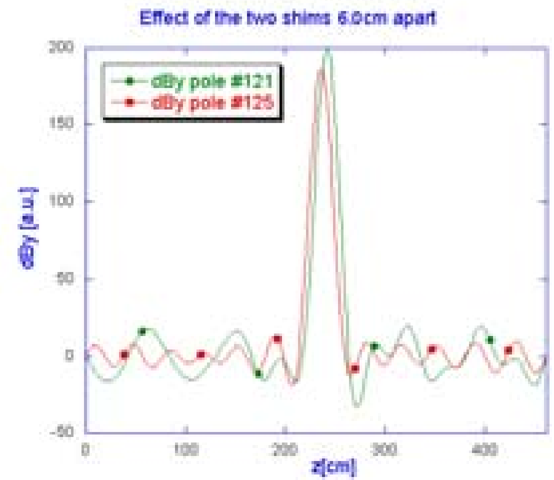


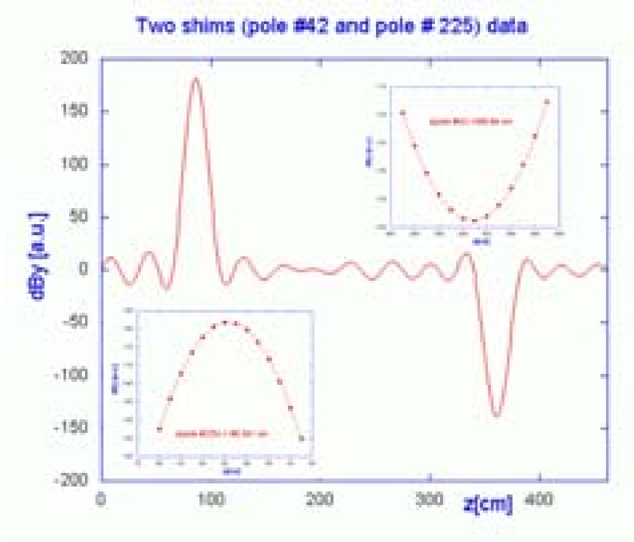


Shim location z = 241cm
Measured z = 241.11cm

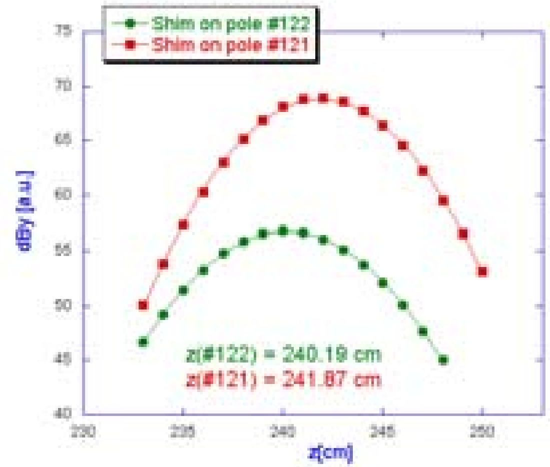
Two shims measurement



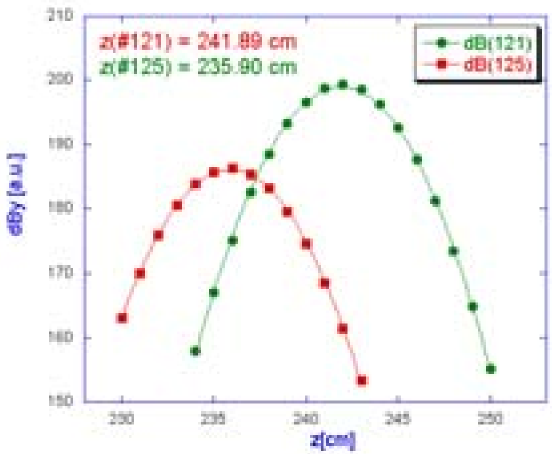




2 shims 274.5 cm apart
Δz = 274.49 cm between peaks



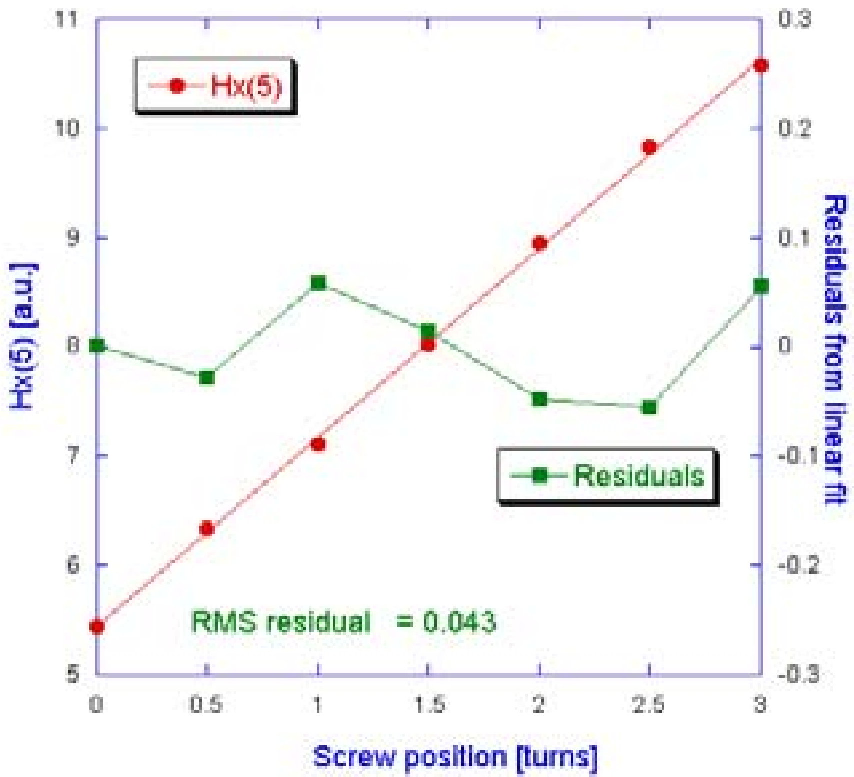
2 shims 1.5 cm apart Δz = 1.7cm



2 shims 6.0 cm apart Δz = 6.01 cm

Sensitivity test

We varied strength of By shim and measured amplitude of the 5-th mode of wire vibration.



Calibration

From measurements of localized field distortion (see slide 8):

Field integral from shim = 340 G·cm

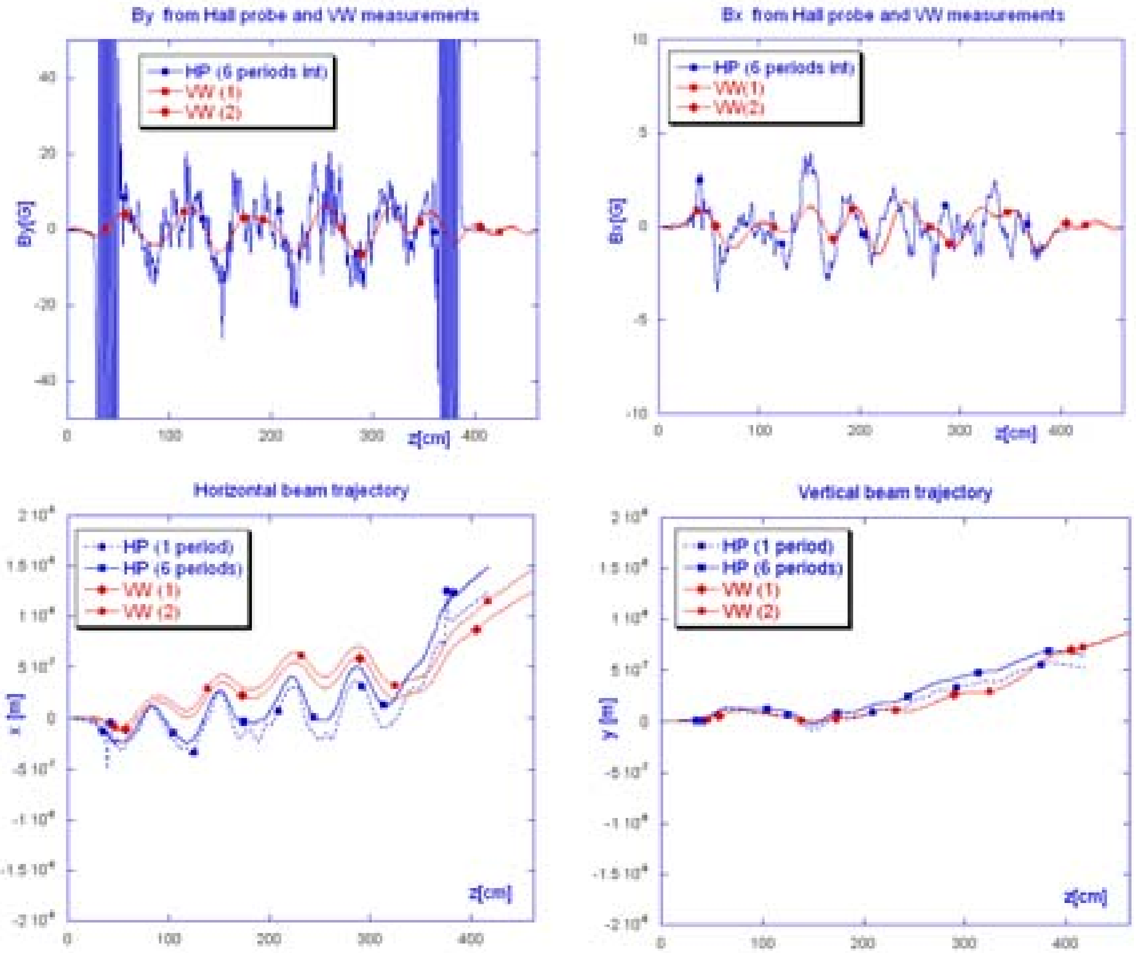
5 – th harmonic amplitude = 39 a.u.

1 a.u. = 340/39 ≈ 9 G·cm

Sensitivity (to local field change)

0.043 a.u. = 0.4 G·cm

Vibrating wire vs. Hall probe



Field Integrals
(Undulator S/N 13)

	I_y (G·cm)	I_x (G·cm)
VW	18 ± 3	15 ± 1
Hall Probe	21.0	18.0
Coil	6.0	21.0

Conclusion

The VW technique could be practical for:

- characterization of small gaps (bores) undulators and devices with limited access to the tested field region because of small sensor size.

- field integrals and beam trajectory tuning because of good space resolution (~1 mm), exceptional sensitivity to the local field integrals (~0.37 G cm) and acceptable accuracy of measuring field integrals over total magnet length (~ 6 G cm).

- adjustable phase and elliptical undulators tuning because of VW is free from effects analogous to the planar Hall effect.

The VW technique should be considered as a supplement to the Hall probe measurement because it cannot be used for the measurement and tuning of undulator parameter ‘‘K’’.