Measuring multipoles of small-aperture magnets by Rotated Vibrating Wire (RVW)

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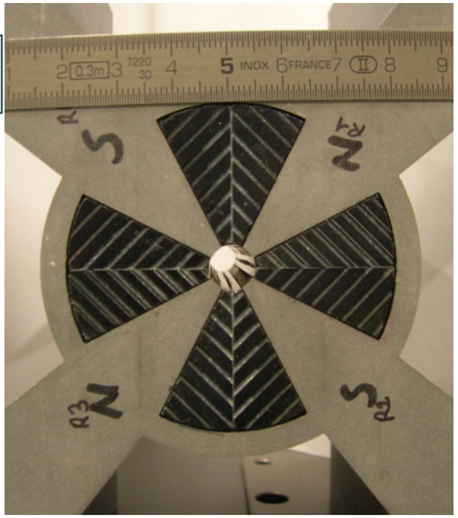
Outline

- Requirements
- Rotated Vibrating Wire method (RVW)
  - Basic idea
  - Mathematical model
  - Measurement procedure
- Experimental proof demonstration
- Conclusions

Requirements

~ Ø 8 mm



To measure multipoles:

1. in magnets with very ***small*** *aperture (~mm) critical for coils*

2. for different magnets at ***different radii*** *(flexibility)*

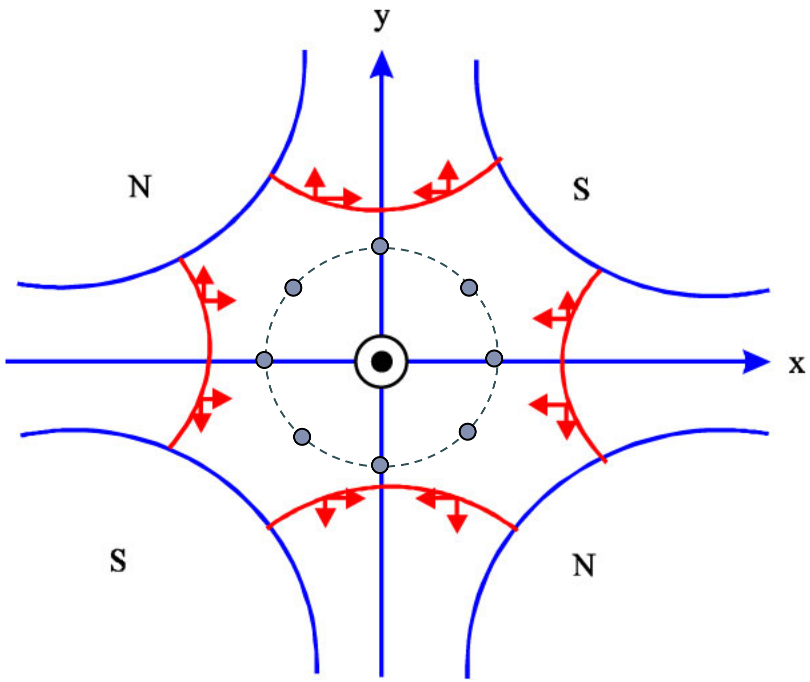
Rotated Vibrating Wire (RVW)

Basic idea

Measure multipoles:

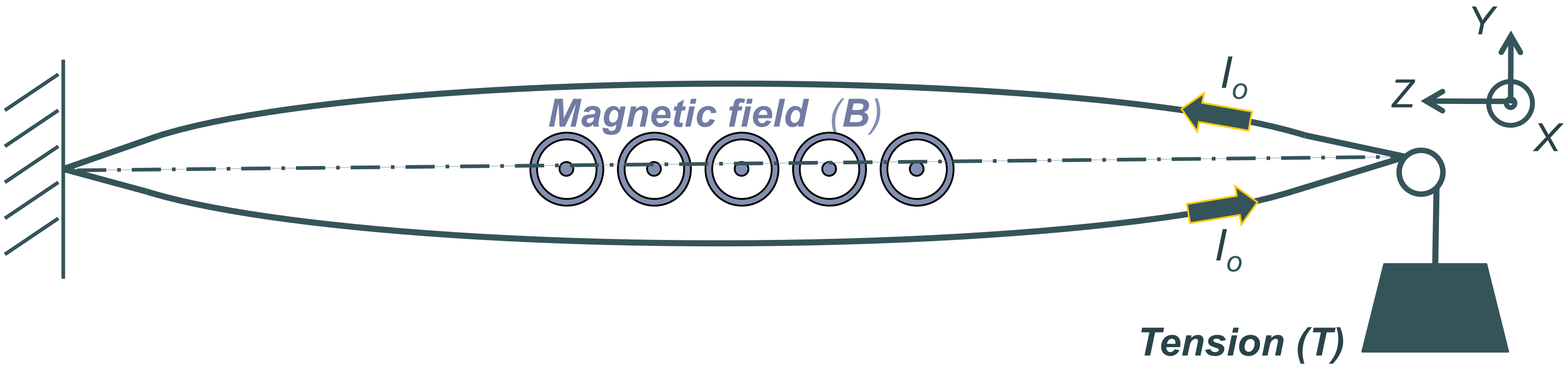
1. *by means of a vibrating wire*
2. *by measuring in different positions on a circle*

through a simple mathematical model relating oscillation and field components



Rotated Vibrating Wire method

How to measure the multipoles by vibrating wire?



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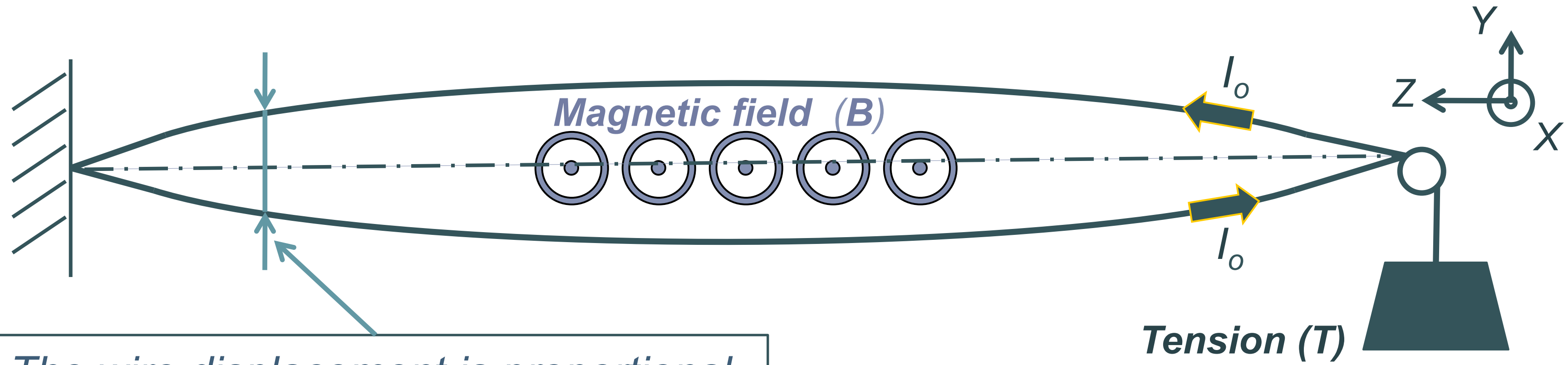
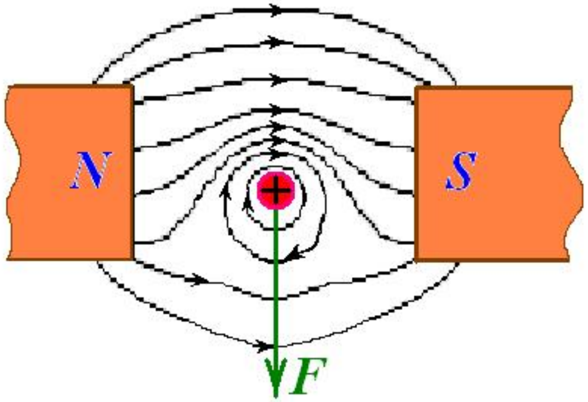


The wire displacement is proportional to the strength of the magnetic field



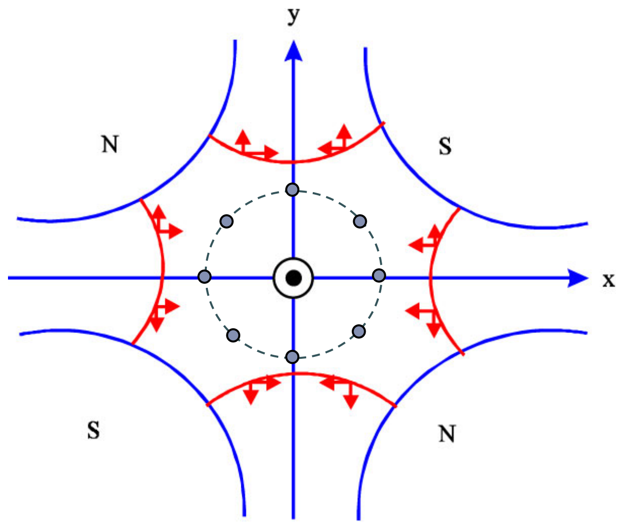
$$\vec{F} = q\left(\vec{v} \times \vec{B}\right)$$

Rotated Vibrating Wire method

Mathematical model

The wire displacement components are proportional to the magnetic field components

$$A_x \propto B_y \qquad A_y \propto B_x$$



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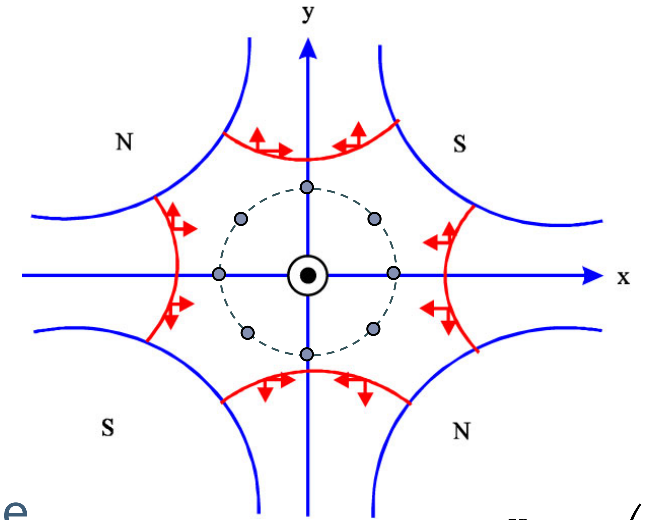

The amplitude **A** can be represented in the complex plane as the magnetic field:

$$\mathbf{A}(z) = A_x + iA_y = \sum_{n=1}^{\infty} \mathbf{V}_n \left(\frac{\mathbf{z}}{R_{ref}} \right)^{n-1}$$

R_{ref}*:reference radius*

Rotated Vibrating Wire method

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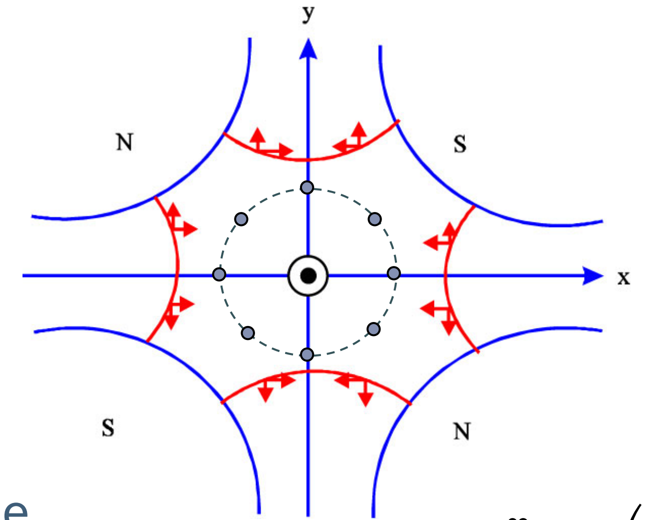

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R_{ref}*:reference radius*

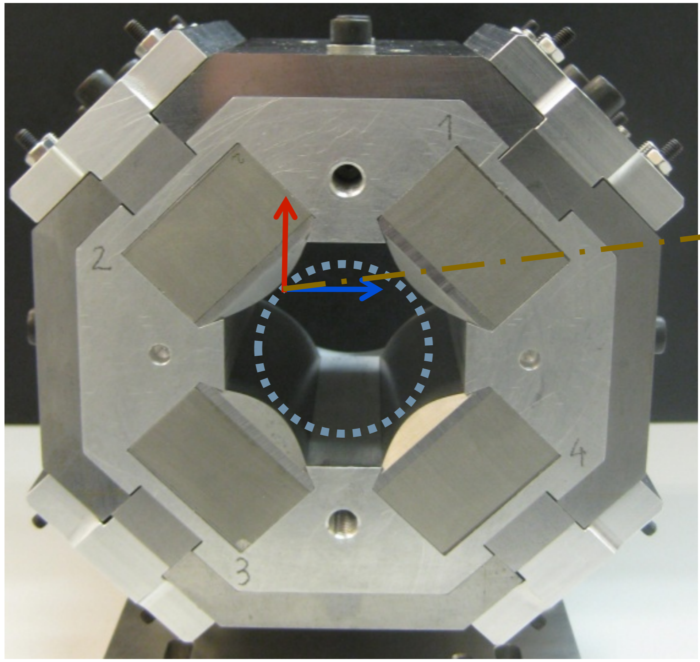
The relative multipoles, scaled on the main component in units, are:

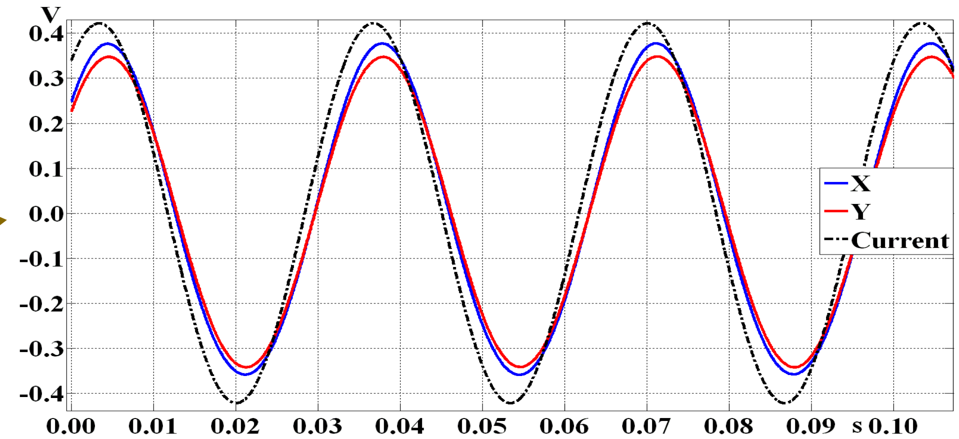
$$\mathbf{V}_n = P_n + iQ_n \rightarrow \mathbf{c}_n = 10^4 \frac{\mathbf{V}_n}{P_{main}} = 10^4 \left(\frac{P_n}{P_{main}} + i \frac{Q_n}{P_{main}} \right) = \boxed{b_n + ia_n}$$

Rotated Vibrating Wire procedure

How to measure multipoles by vibrating wire?

On each position there are two components of the wire displacement



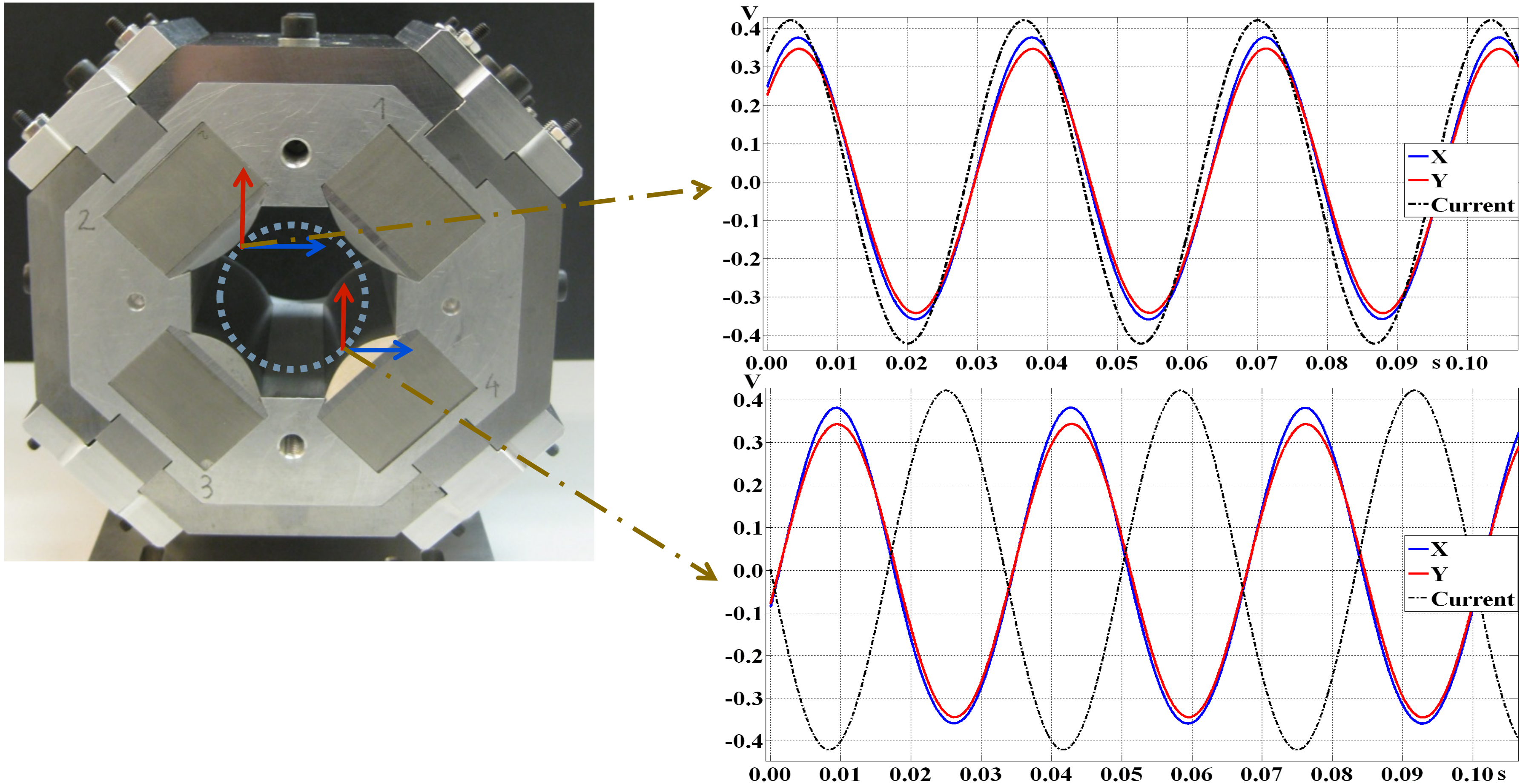


Moving a wire on a circle
fed by a sinusoidal current (in order to increase the measurement significativity)

Rotated Vibrating Wire procedure

How to measure multipoles by vibrating wire?

On each position there are two components of the wire displacement



Rotated Vibrating Wire procedure

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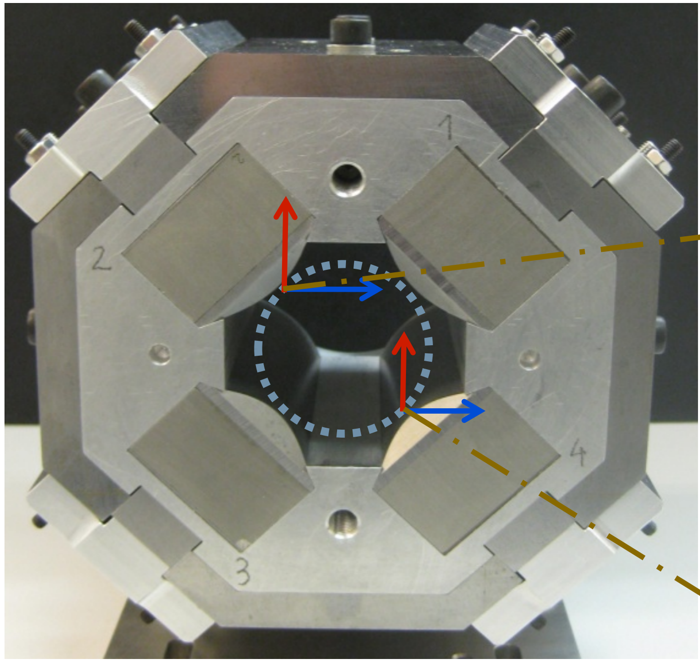
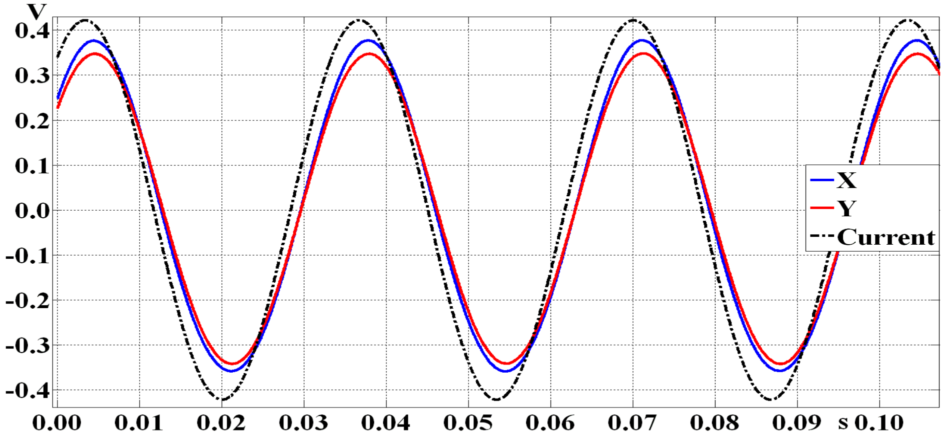
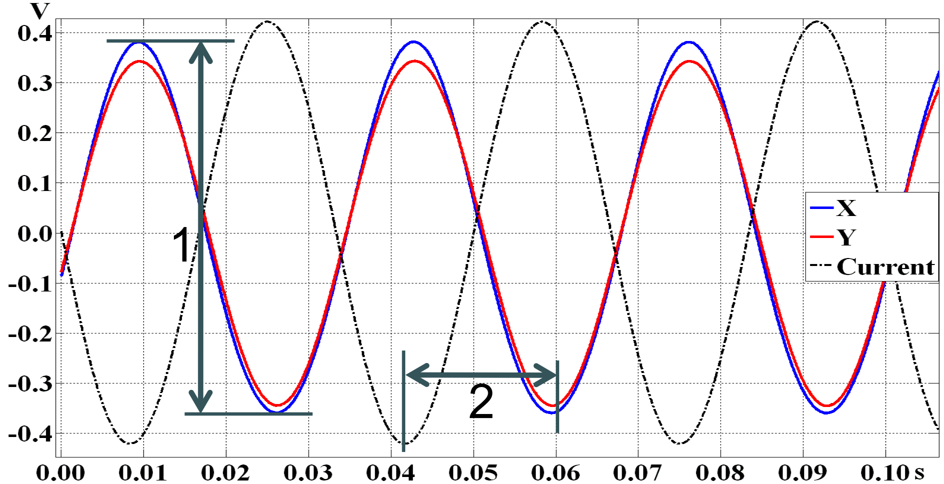


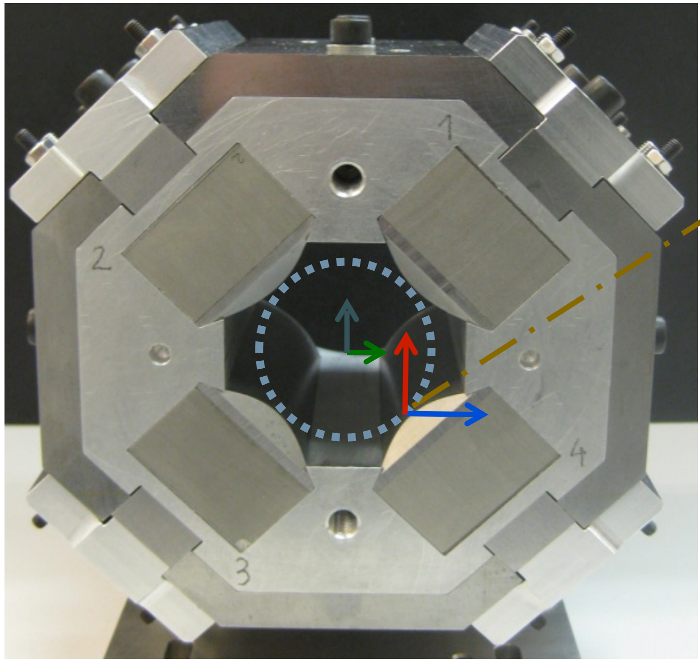


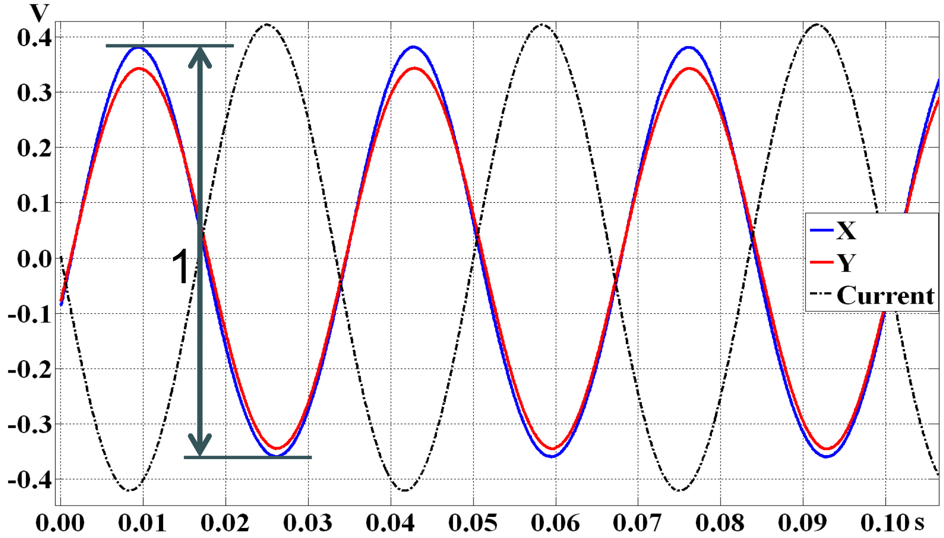


1. *The **amplitude** components are proportional to the magnetic field*
2. *The **phase** differences among current and displacements give the sign of the reconstructed signal*

Rotated Vibrating Wire procedure

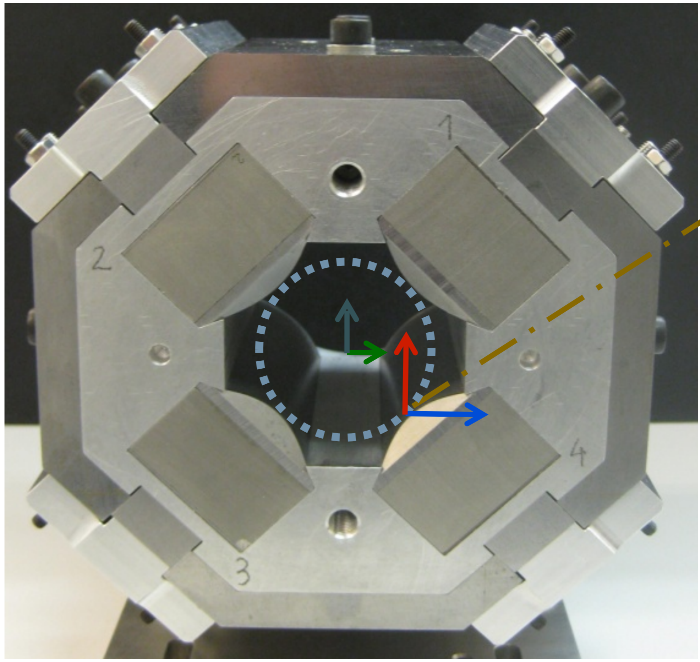
How to measure multipoles by vibrating wire?

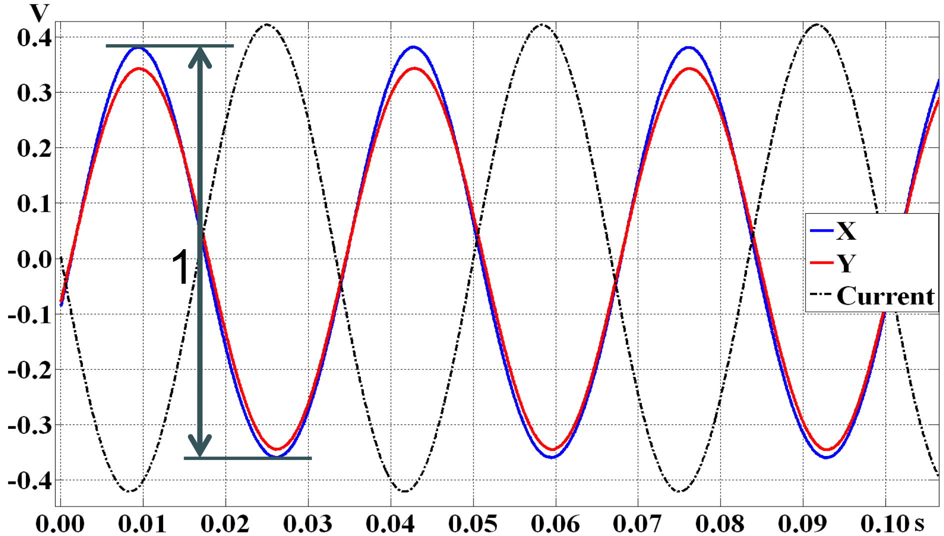


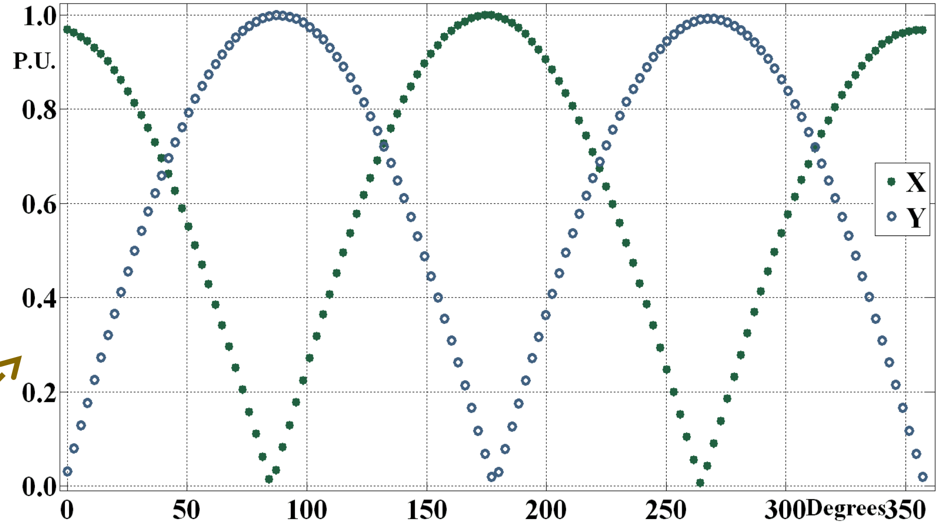


Rotated Vibrating Wire procedure

How to measure multipoles by vibrating wire?



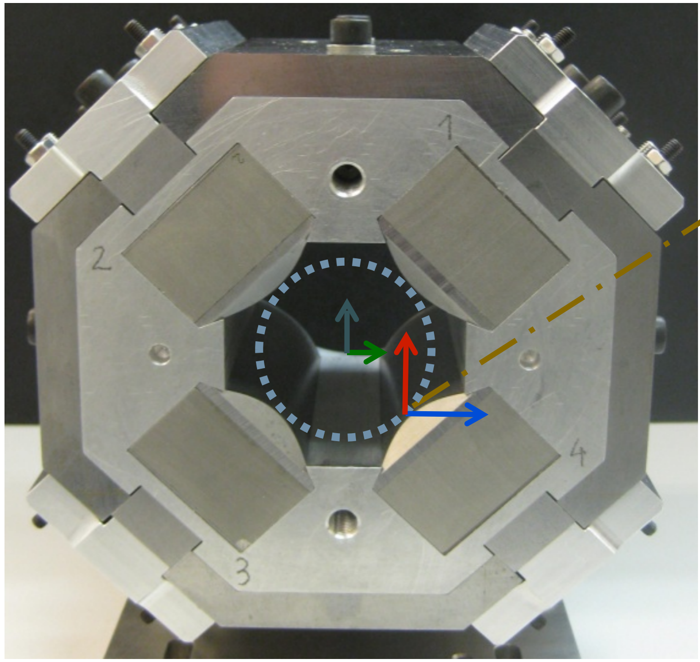


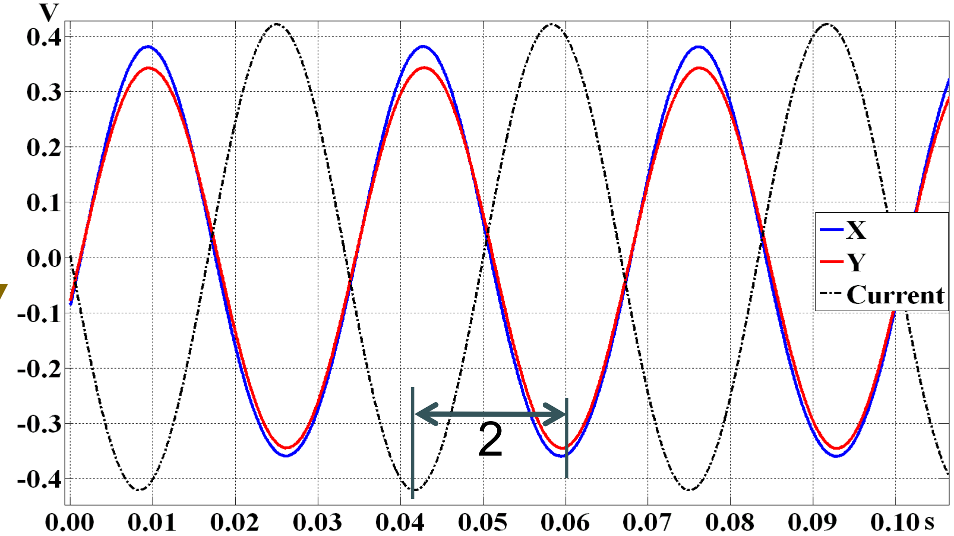


The wire amplitude displacement on a number of points into a circle are collected

Rotated Vibrating Wire procedure

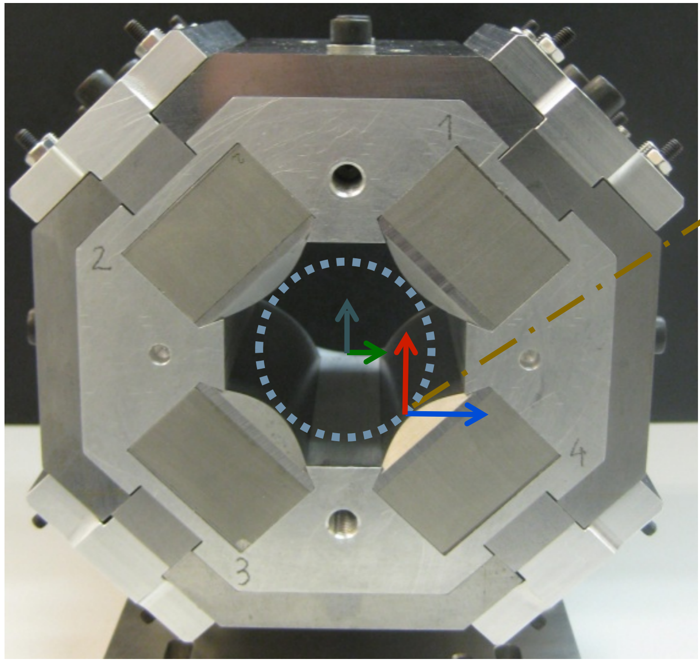
How to measure multipoles by vibrating wire?

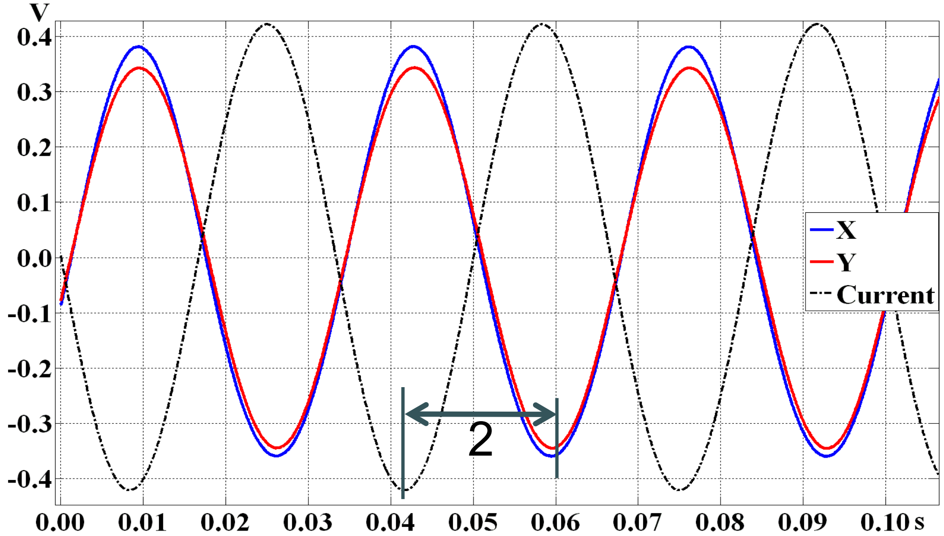


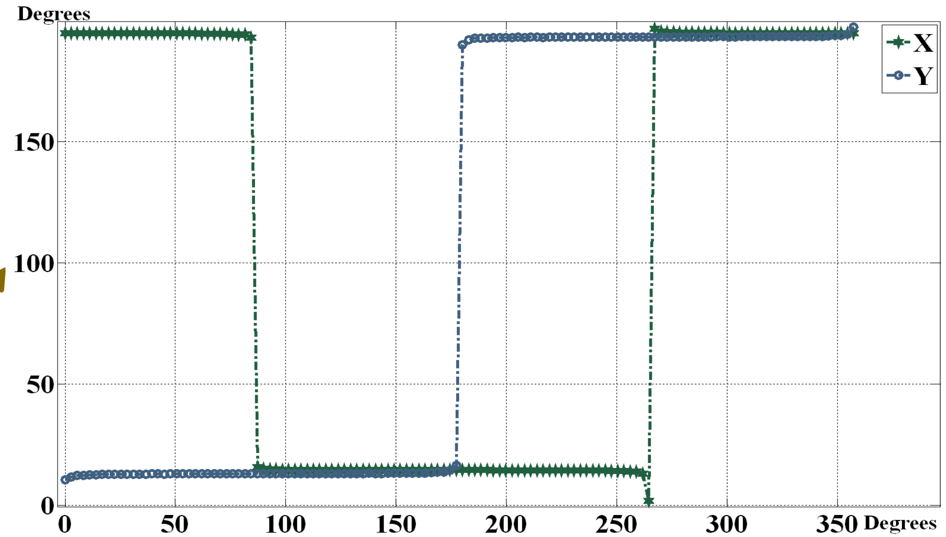


Rotated Vibrating Wire procedure

How to measure multipoles by vibrating wire?



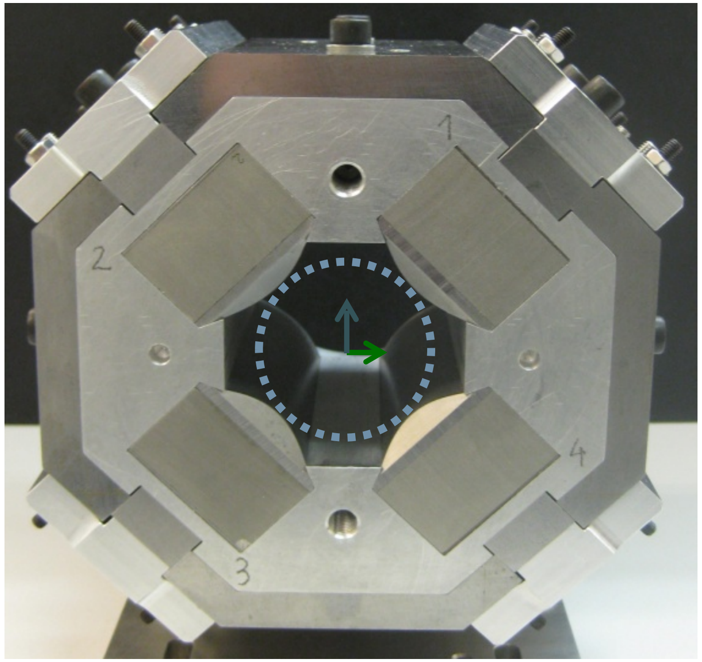


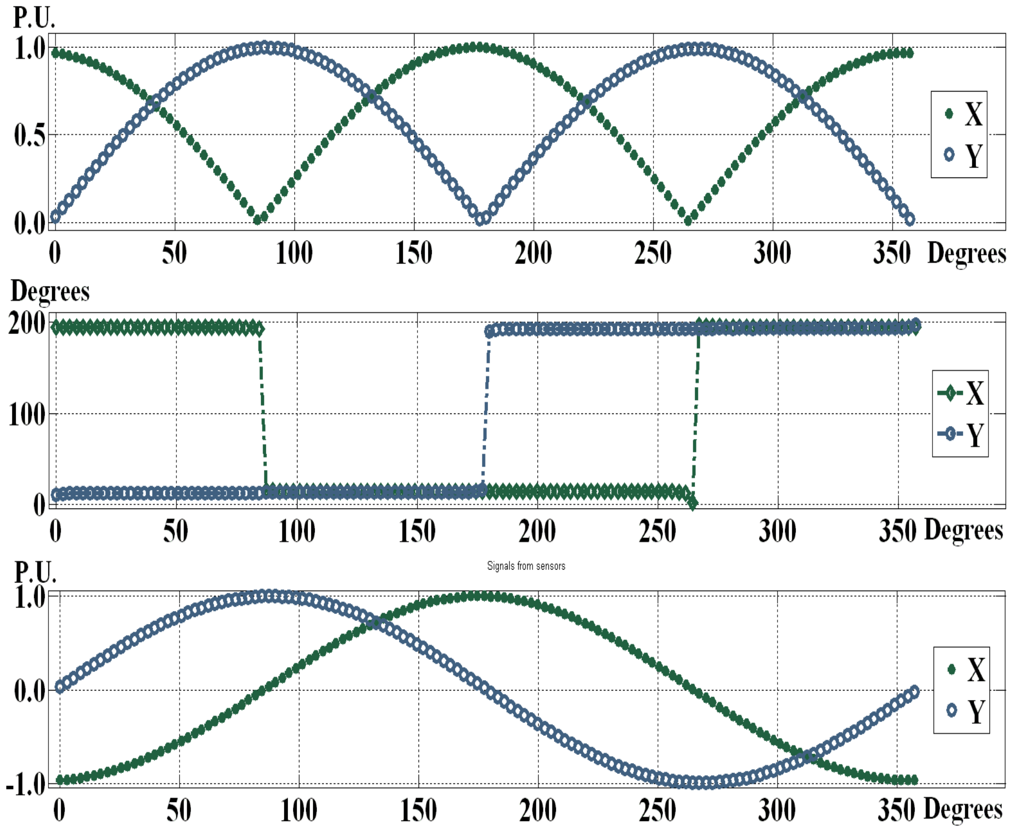


On each point on a circle there are differences among current and wire displacements

Rotated Vibrating Wire procedure

How to measure multipoles by vibrating wire?

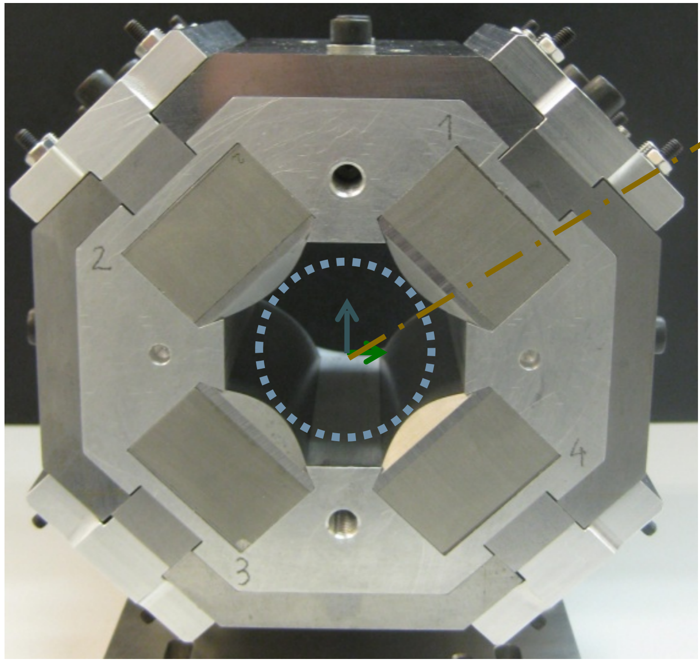


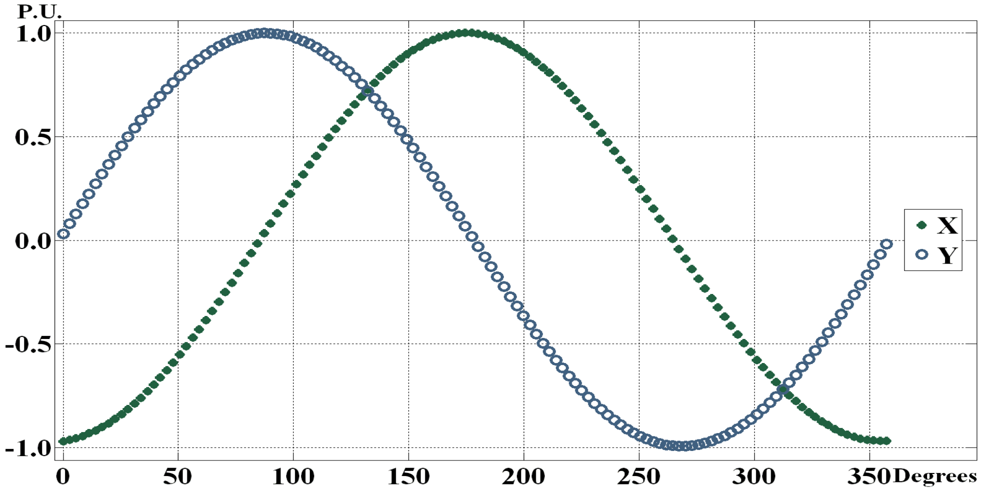


The phase differences among current and displacements give sign information

Rotated Vibrating Wire procedure

How to measure multipoles by vibrating wire?



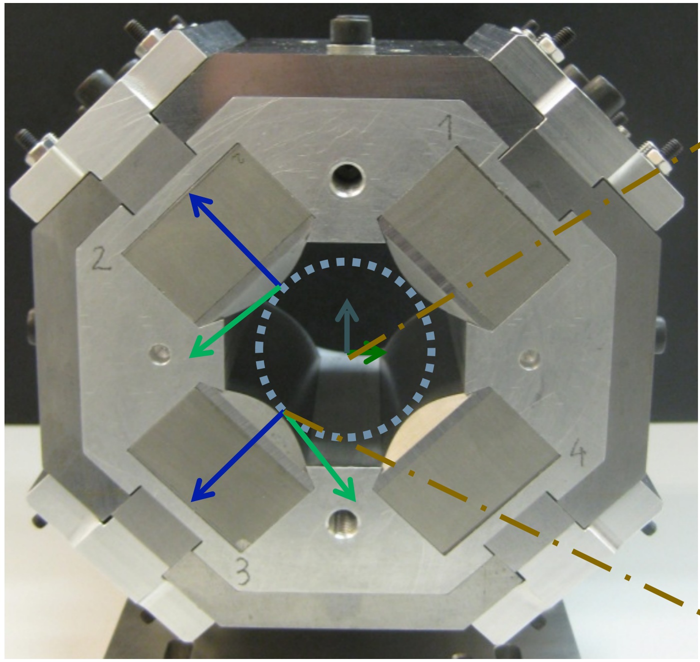


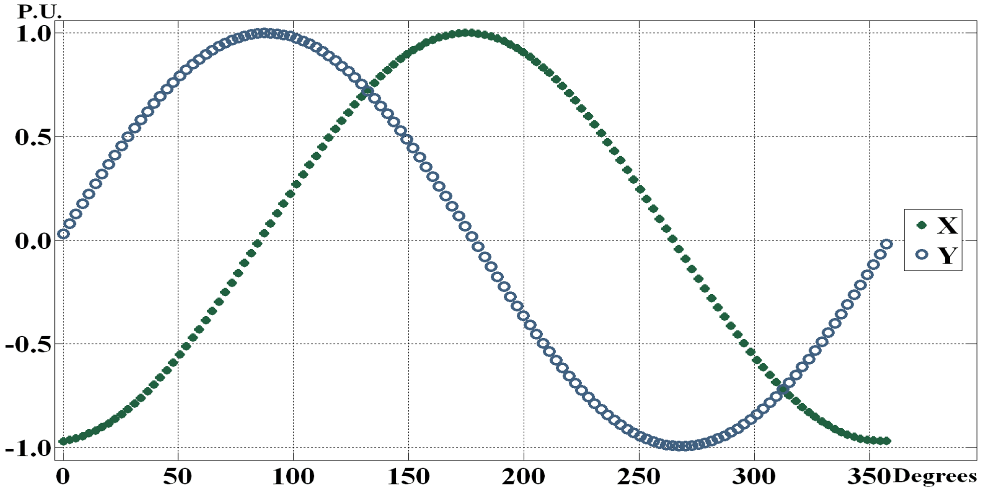
Rotated Vibrating Wire procedure

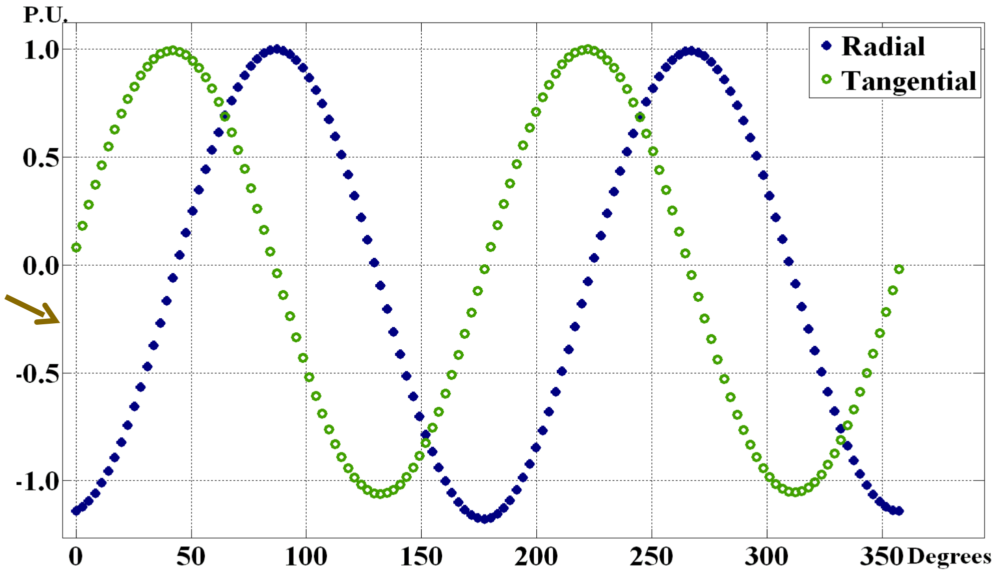
How to measure multipoles by vibrating wire?

$$x_{Rad} = (x + R\cdot\cos\vartheta)\cdot\cos\vartheta + (y + R\cdot sin\vartheta)\cdot sin\vartheta$$

$$y_{Tan} = -(x + R\cdot\cos\vartheta)\cdot sin\vartheta + (y + R\cdot sin\vartheta)\cdot\cos\vartheta$$



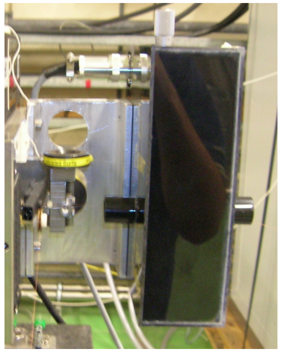




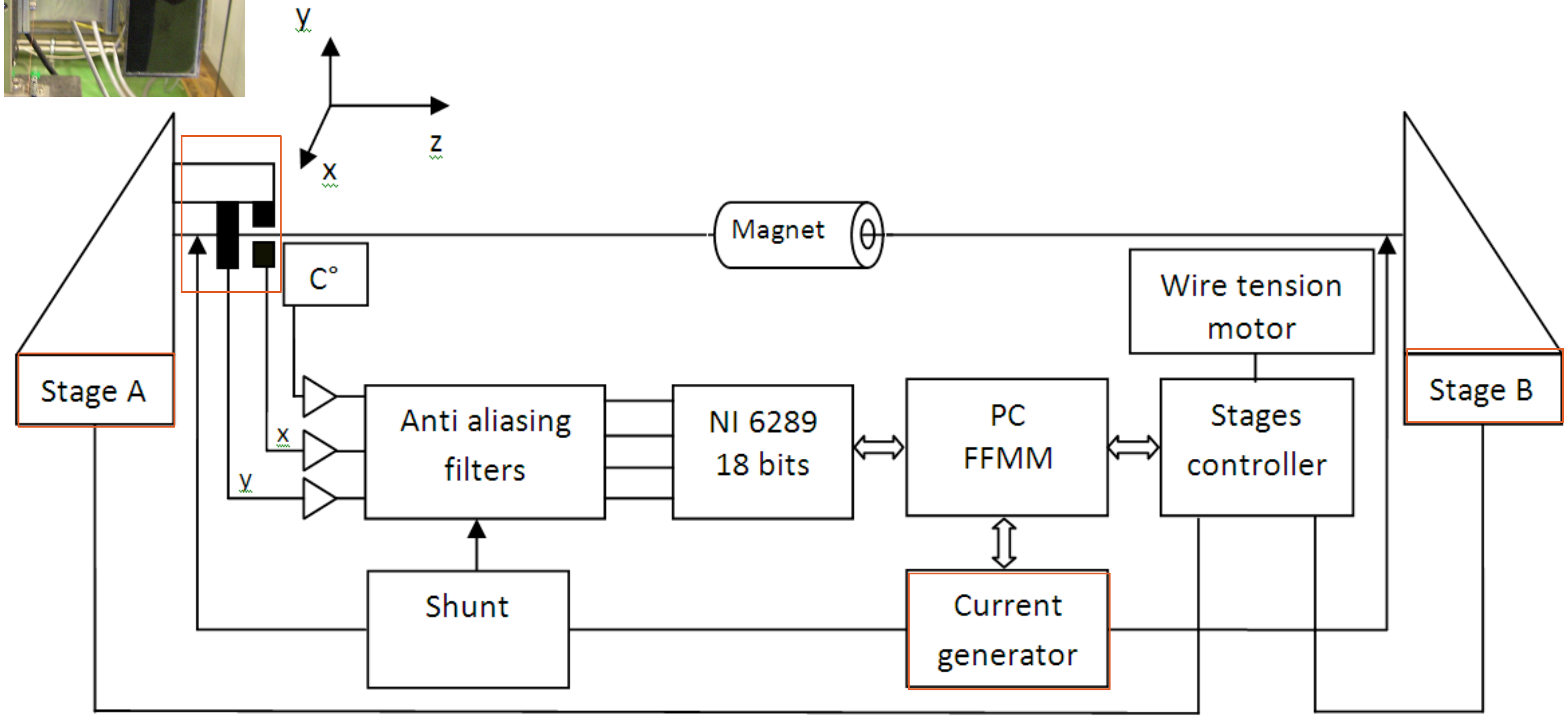
The radial and tangential relative field components can be calculated by rotation of the reference system

Experimental proof demonstration

Measurement setup architecture

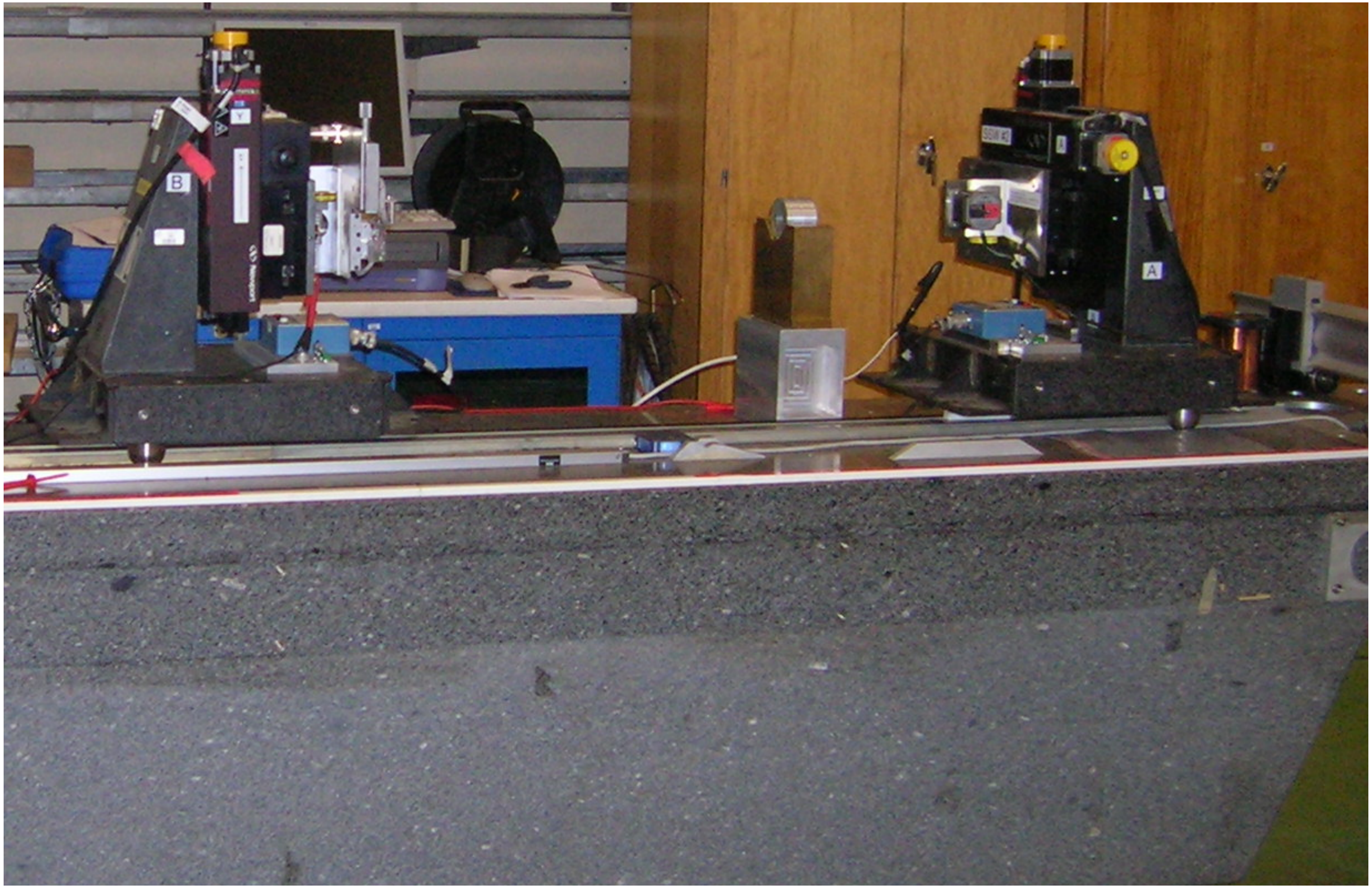


- ***Sensors***: *phototransistor* Sharp GP1S094HCZ0F
- ***Current generator***: *Keithley 6351*
- ***Unique marble*** *support for magnets and stages*



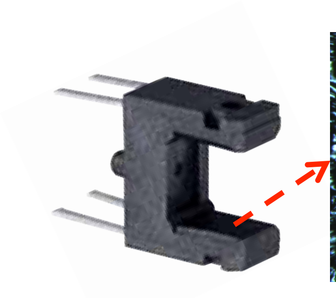
Experimental proof demonstration

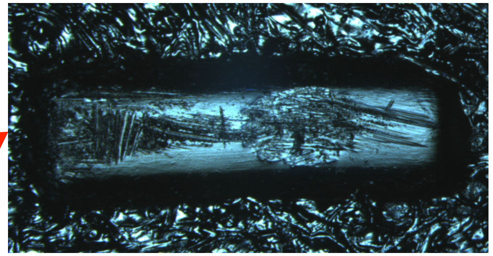
Measurement setup



Optical sensor linearization

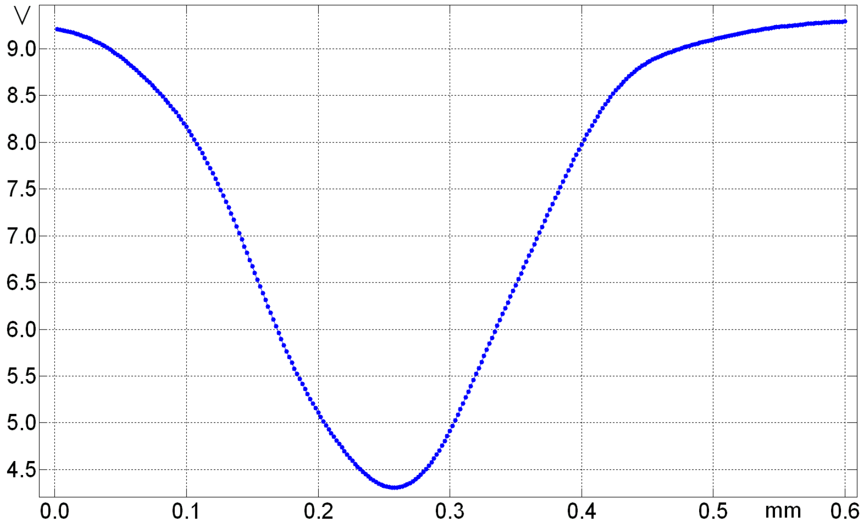
Measurement setup

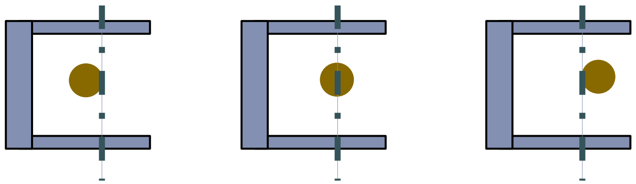




GAP 3 mm, Slit 0.3 mm

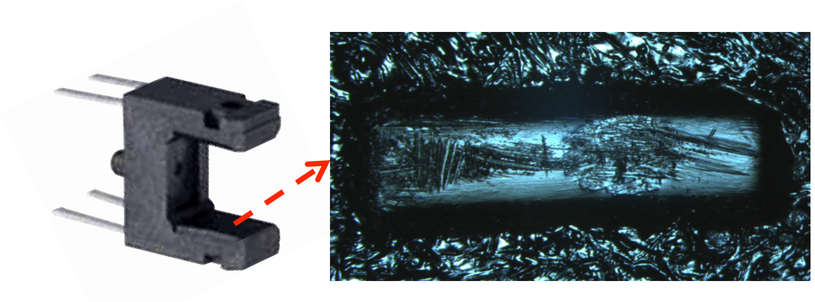
Scratched surface: nonlinear response





Optical sensor linearization

Measurement setup



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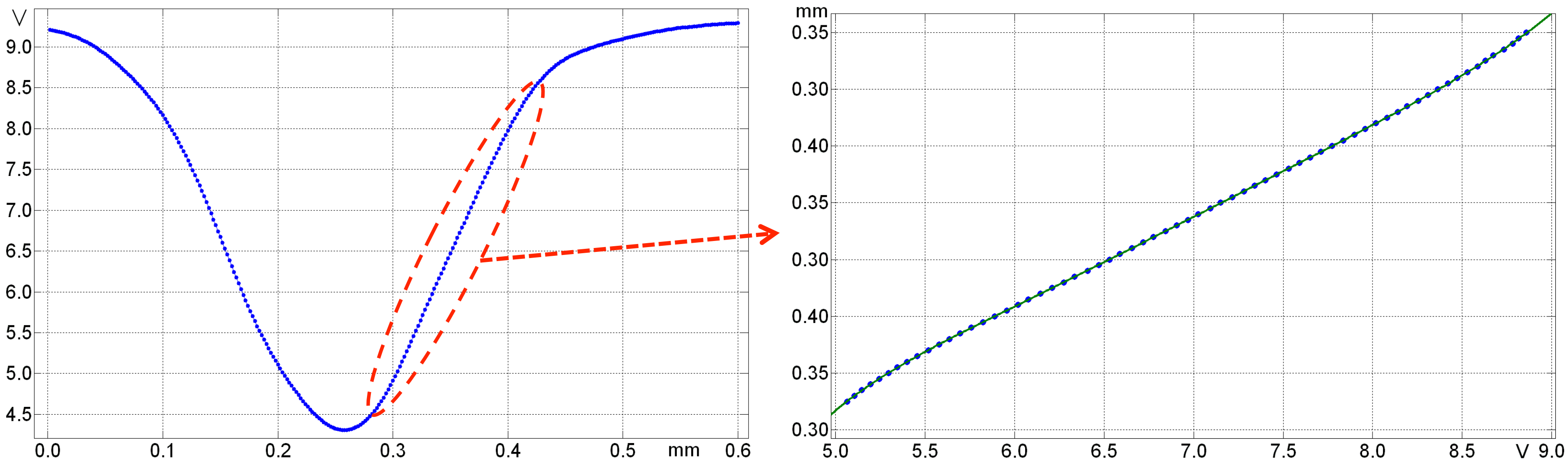
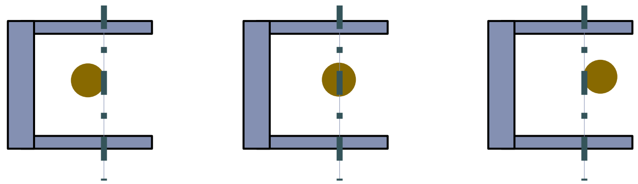
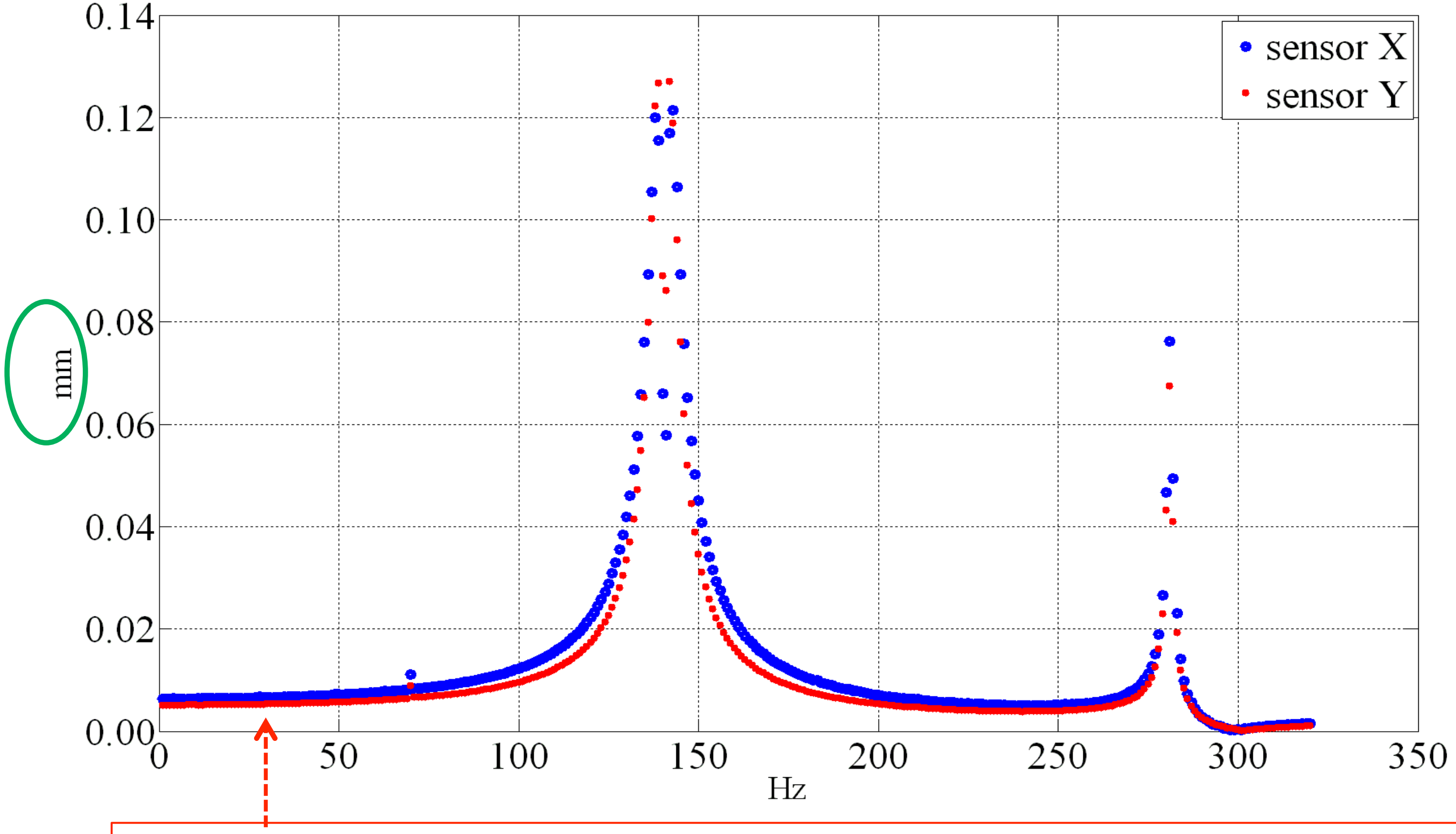




Sensor linearization

What parameters to use?

What current frequency?



I = 105 mA

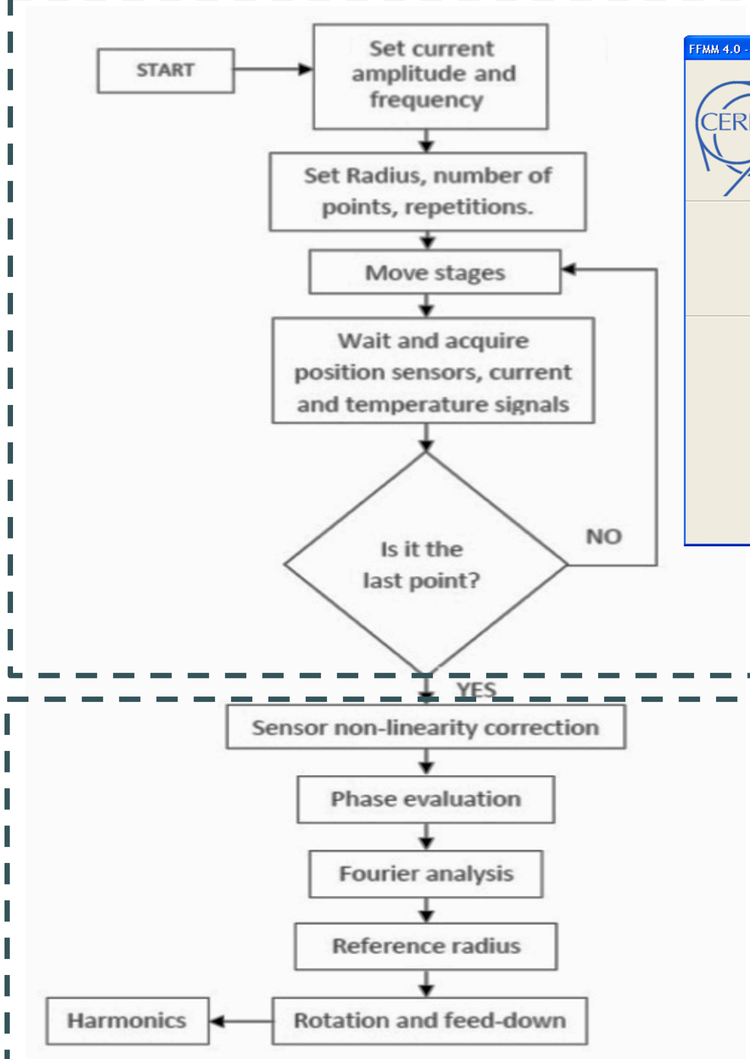
T = 950 g

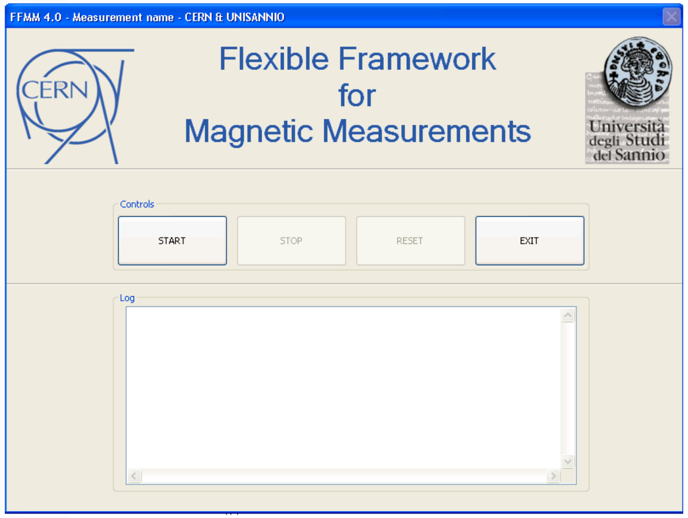
L = 1.86 m

***Frequency**: small enough to assume almost static movement of the wire*

Test protocol

Measurement setup





Framework domain

FFMM-**F**lexible **F**ramework for **M**agnetic **M**easurements* drives all measurement system

*Lucio Fiscarelli IMMW16

Matlab domain

Data analysis off line done by using Matlab^R

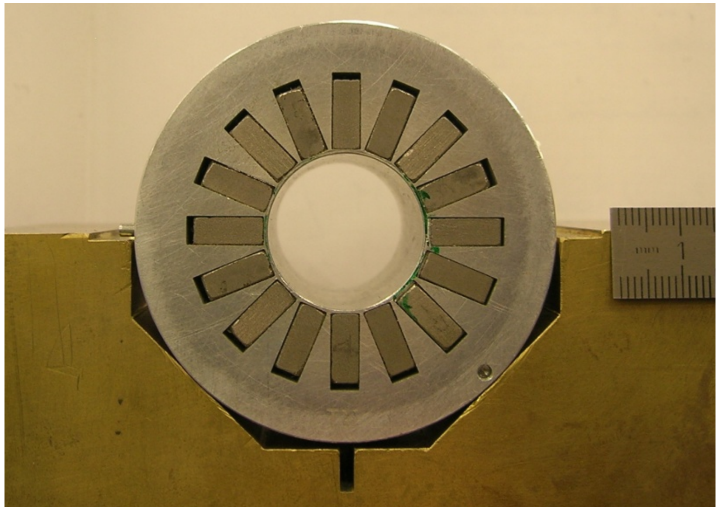
Experimental results

Magnet Linac4

The first case study exploits magnet Linac4-R1:

Diameter: 22 mm

Length: 45 mm



Several measurements using different radius and different configuration are carried out.

Experimental results

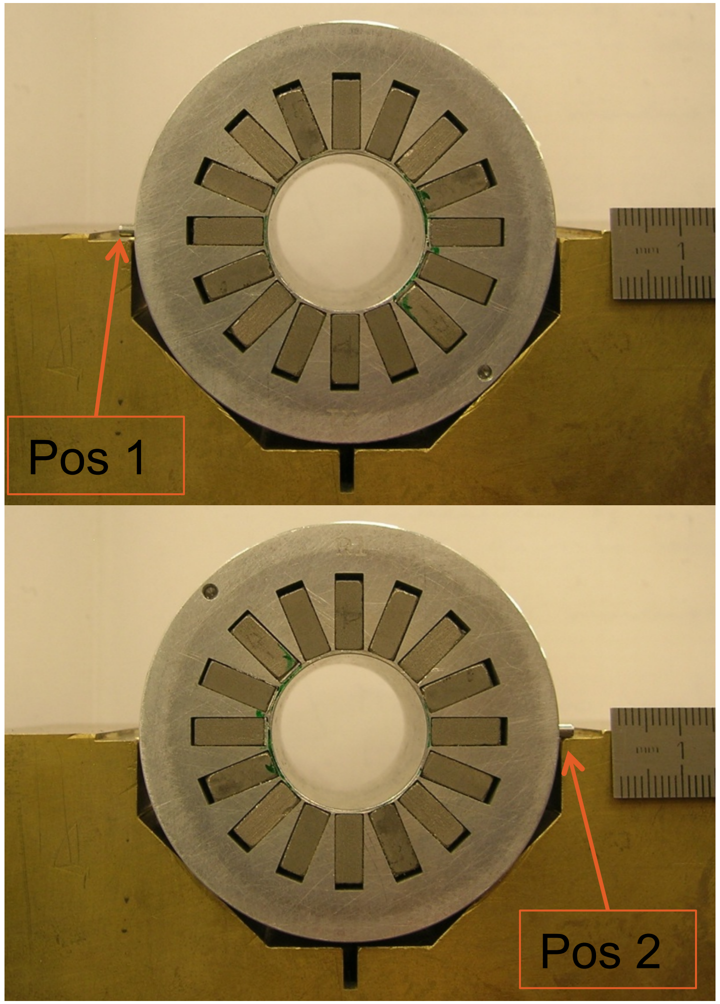
The first case study exploits magnet Linac4-R1:

Diameter: 22 mm

Length: 45 mm

Several measurements using different radius and different configuration are carried out.

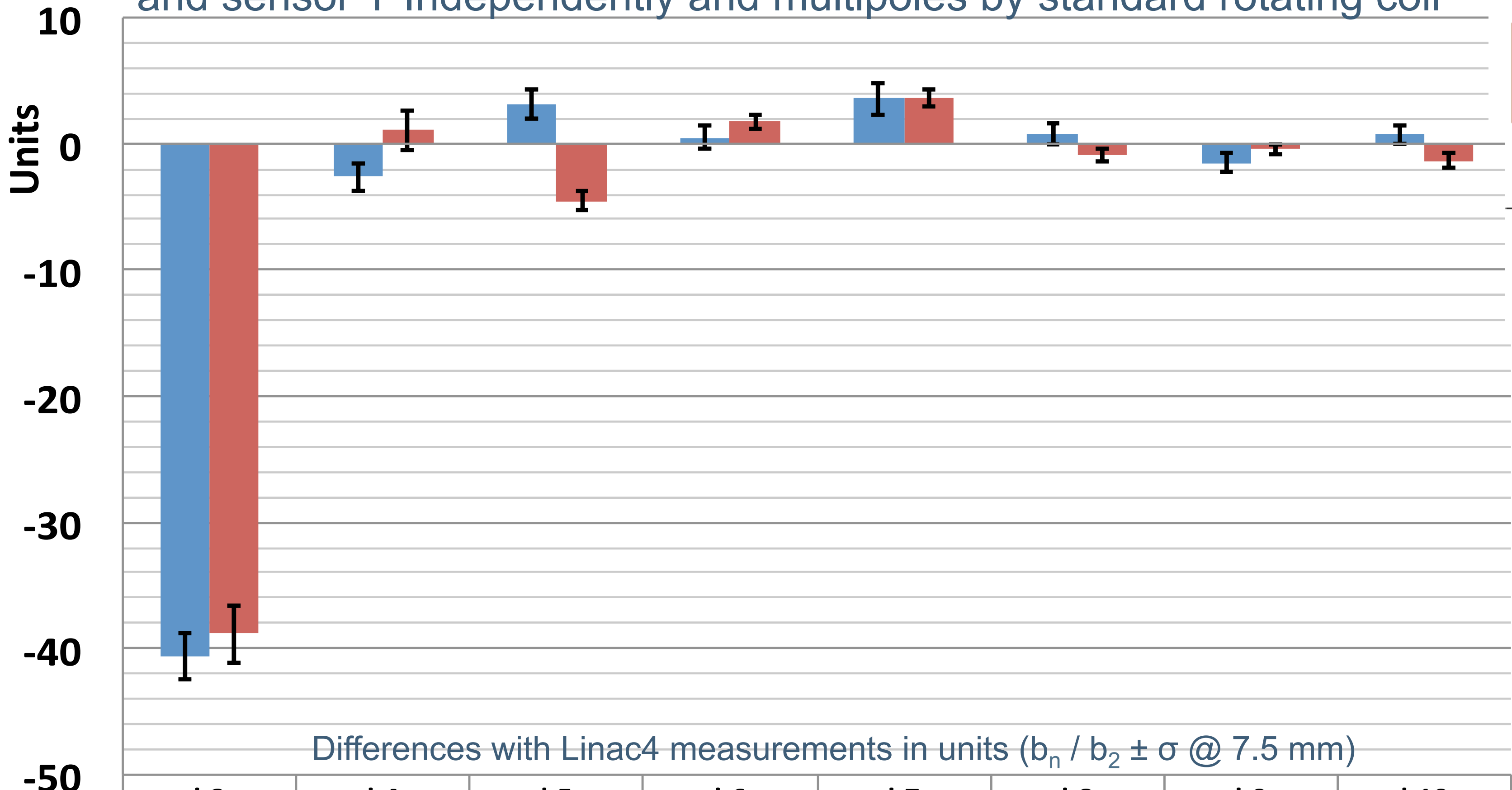
The magnet is rotated in order to investigate deterministic errors



Experimental results

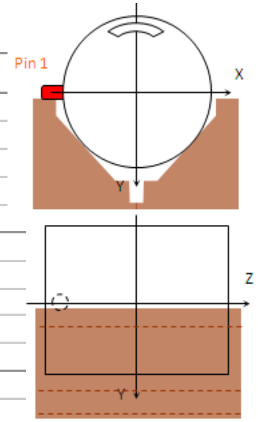
Magnet Linac4 R1 - Reference radius: 7.5 mm - b_n

Differences among multipoles achieved from sensor X and sensor Y Independently and multipoles by standard rotating coil



Differences with Linac4 measurements in units (b_n / b_2 ± σ @ 7.5 mm)

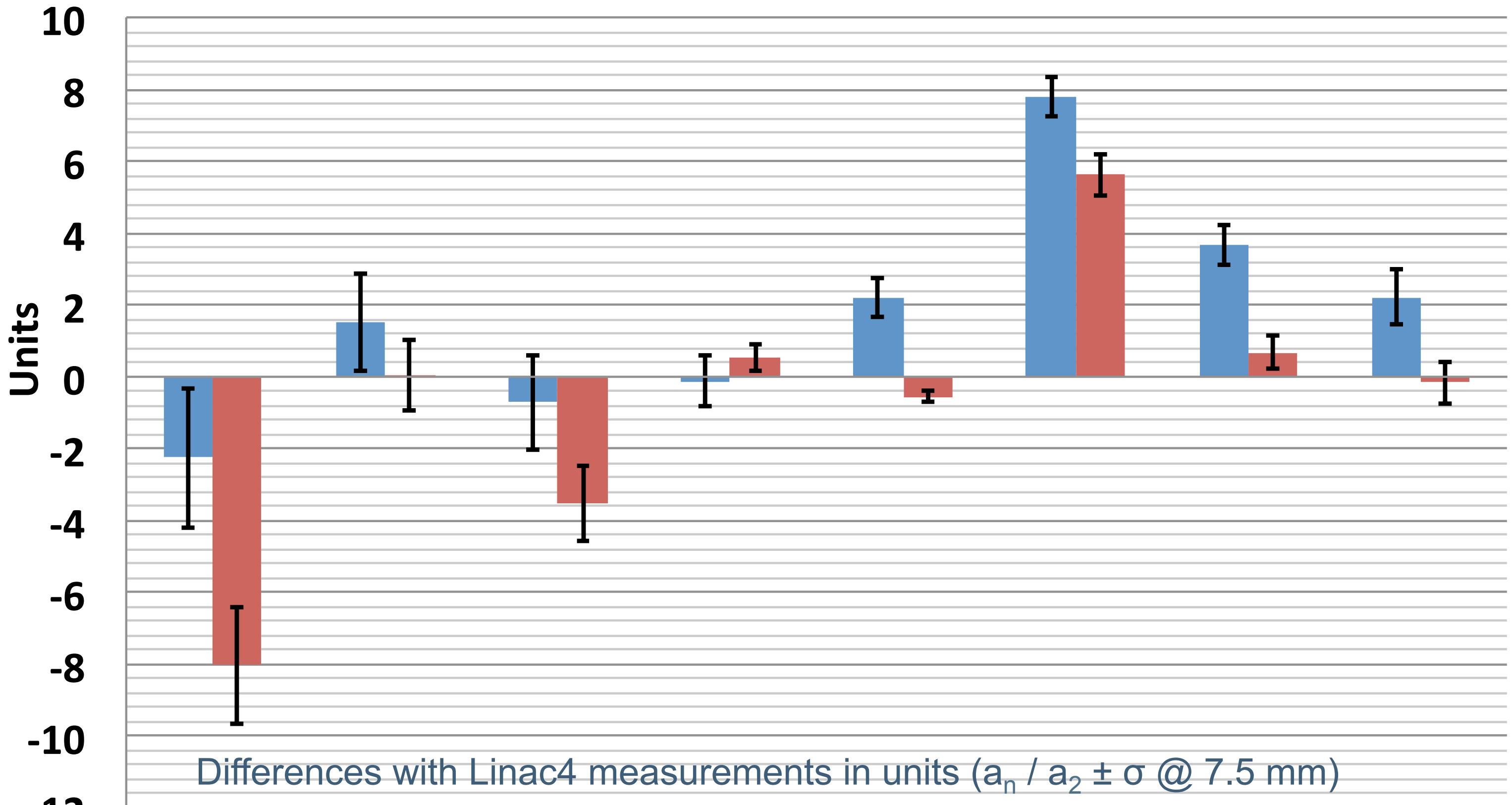
	b3	b4	b5	b6	b7	b8	b9	b10
X-Ref	-41	-3	3	1	4	1	-2	1
Y-Ref	-39	1	-5	2	4	-1	0	-1



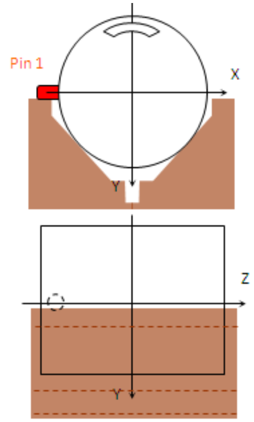
Position 1

Experimental results

Magnet Linac4 R1 - Reference radius: 7.5 mm - a_n



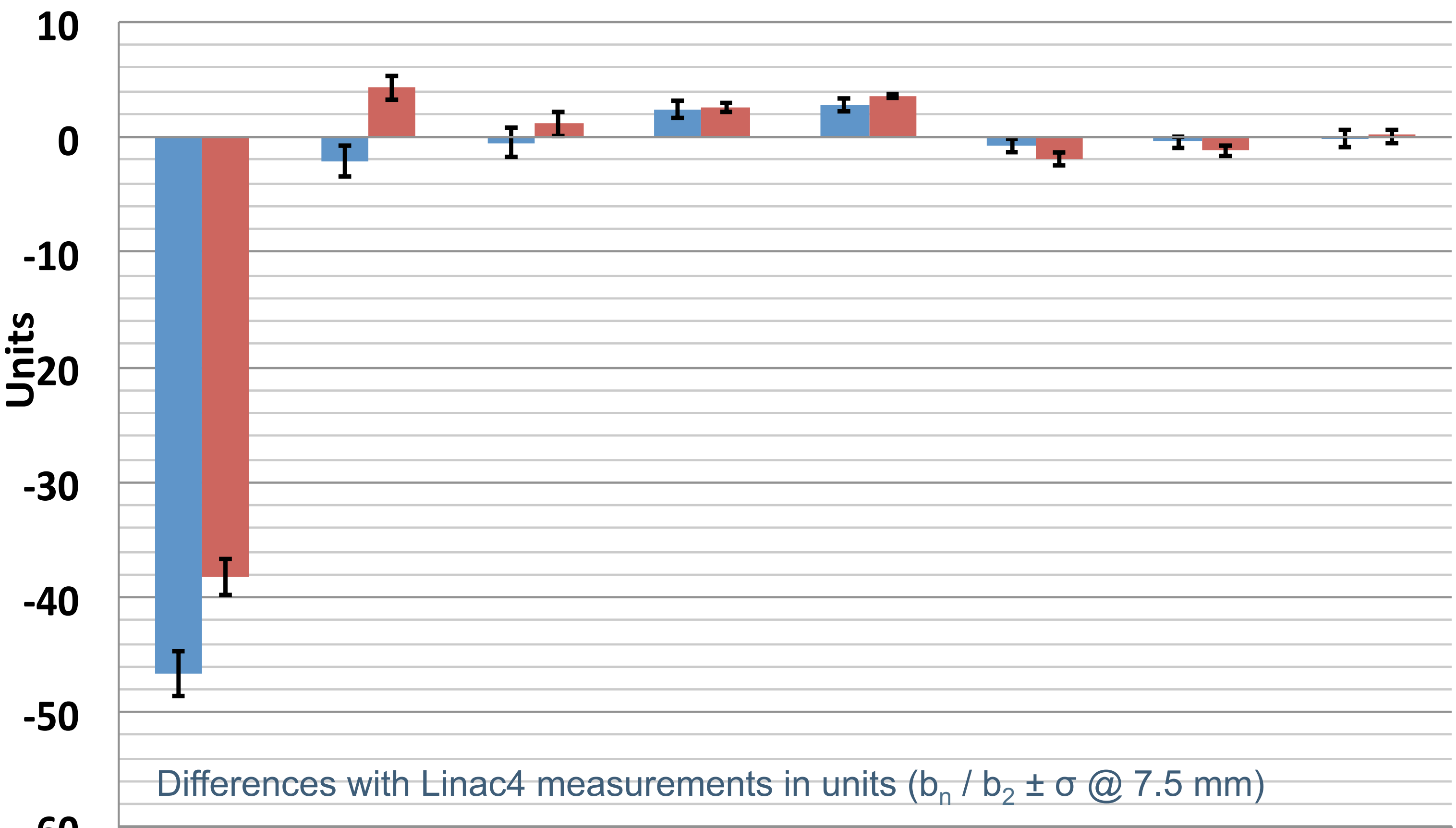
	a3	a4	a5	a6	a7	a8	a9	a10
X-Ref	-2	2	-1	0	2	8	4	2
Y-Ref	-8	0	-4	1	-1	6	1	0



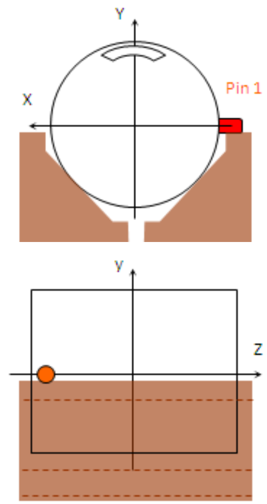
Position 1

Experimental results

Magnet Linac4 R1 - Reference radius: 7.5 mm - b_n



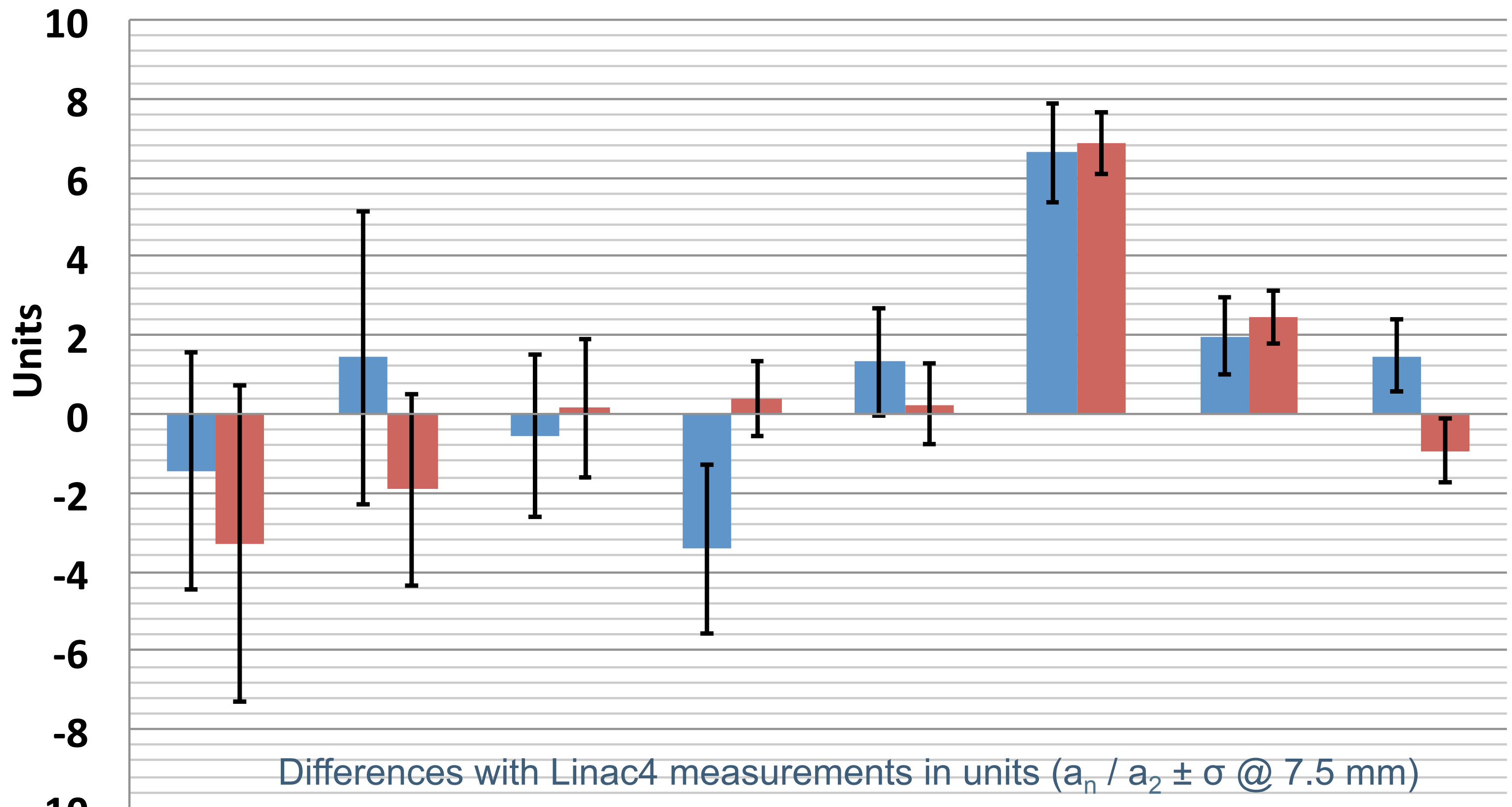
	b3	b4	b5	b6	b7	b8	b9	b10
X-Ref	-47	-2	0	2	3	-1	0	0
Y-Ref	-38	4	1	3	4	-2	-1	0



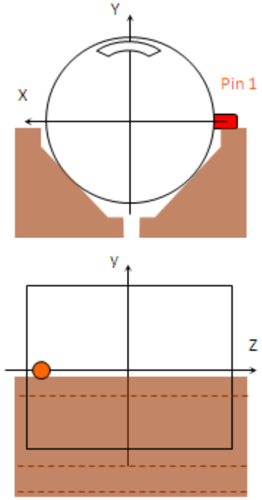
Position 2

Experimental results

Magnet Linac4 R1 - Reference radius: 7.5 mm - a_n



	a3	a4	a5	a6	a7	a8	a9	a10
X-Ref	-1	1	-1	-3	1	7	2	1
Y-Ref	-3	-2	0	0	0	7	2	-1

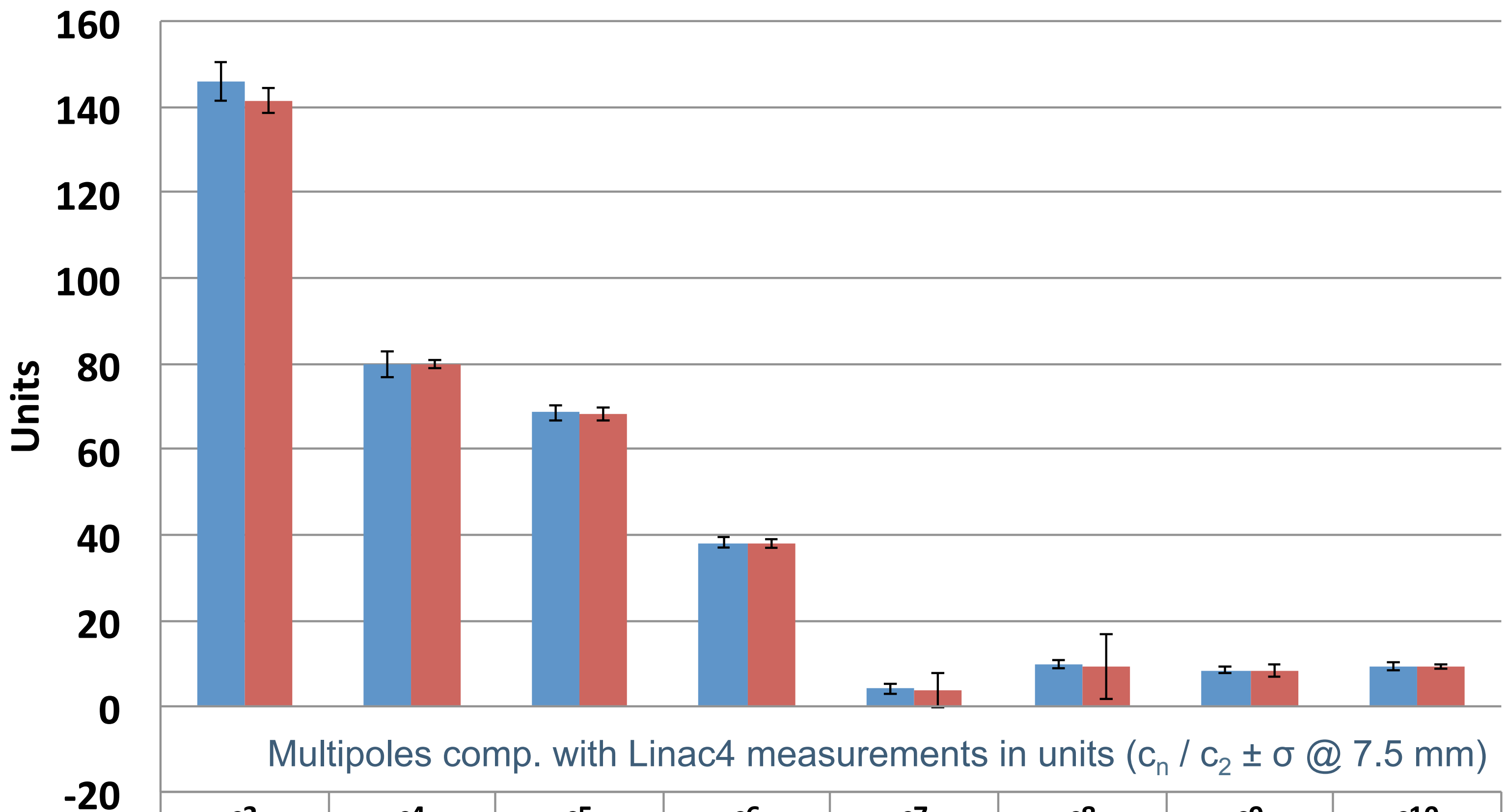


Position 2

Experimental results

Magnet Linac4 R1 - Reference radius: 7.5 mm - c_n

Using the magnet **rotation** the systematic effect is corrected and also b3 is comparable with rotating coil results



	c3	c4	c5	c6	c7	c8	c9	c10
wire	146	80	69	38	4	10	8	9
coil	141	80	68	38	4	9	8	9

Other case studies will be presented by J. García at this workshop

Conclusions

- multipoles are measured by an original method based on vibrating wire
- Method very flexible (easy to change measurement's radius and magnet)
- By rotating magnet is possible to correct deterministic effects

- Further ongoing investigations to:
  - optimize the setup's parameters
  - correct deterministic effects

Future…

- Refer the magnetic axis to the local point into the magnet
- Measure multipoles not only on a circle but on ellipse and …

I would like to thank

Dominique Cote, Lucio Fiscarelli, Peter Galbraith, David Giloteaux,

Giancarlo Golluccio, Fernando Mateo Jimenez.

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Thank you for your attention