Single-Stretched and Vibrating-Wire Measurements at CERN

P. Arpaia, A. Beaumont, G. Deferne, J. Garcia-Perez, C. Petrone,
S. Russenschuck, L. Walckiers

IMMW18, Brookhaven, June 2013

Overview

- Introduction
- Stretched-Wire systems at CERN
  - Upgrade plans
  - Copper-Niobium wire test
- Recent measurements with the vibrating and oscillating wire methods
  - Harmonics correction on quadrupole $\int$Gdl measurement
  - Solenoid axis measurement
- Conclusion

Introduction

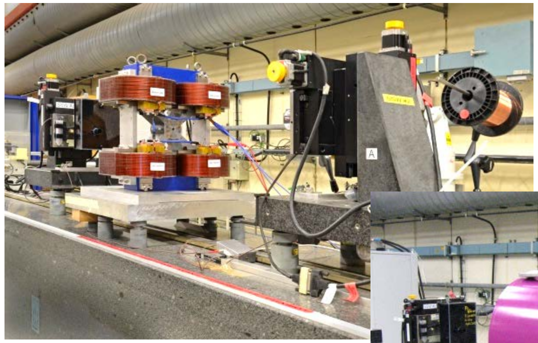
3 Single Stretched Wire (SSW) systems at CERN :

Featuring:

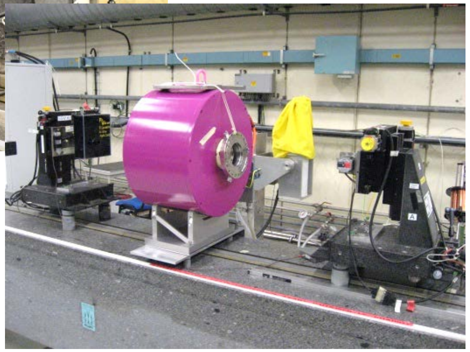
- **Integrated strength** accuracy few units
- **Magnetic axis** including survey <50 µm
- **Roll angle** < 100 µrad
- Warm (**AC**) and cold (**DC**) measurements
- **Wire length up to 20 m**

SSW system installed on a LHC SSS

- **For 10 years**: LHC reference for strength, axis, and angle measurement
- **Since end of LHC series tests**: heavily used for many different projects and experiments
- **Add-ons**
  - More accurate axis positioning with the **V**ibrating **W**ire (**VW**) method (working at wire resonance)
  - Relative harmonics measurement with the **O**scillating **W**ire (**OW**) method (forced oscillation out of resonance), *see C.Petrone presentation @ IMMW17*



CLIC hybrid quad prototype – aperture diam. 8.25 [mm]



Low energy solenoid for MedAustron and LINAC4

SSW at CERN: upgrade plans

Approaching end of life-time: no spare parts, no repair possible on several of the components

Already one system broke down: and then there were two…

➢ **urgent need for new systems**

Our philosophy:

1. To built new SSW **based on FNAL's systems**, with at least the same accuracy but … using our own software (FFMM – **F**lexible **F**ramework for **M**agnetic **M**easurement) and our own integrator (FDI – **F**ast **D**igital **I**ntegrator, *see L. Fiscarelli presentation @IMMW18*)
2. Add vibrating wire features to increase the measurement capabilities in terms of field axis and harmonics measurement

SSW at CERN: upgrade plans

Approaching end of life-time: no spare parts, no repair possible on several of the components

Already one system broke down: and then there were two…

➢**urgent need for new systems**

Our philosophy:

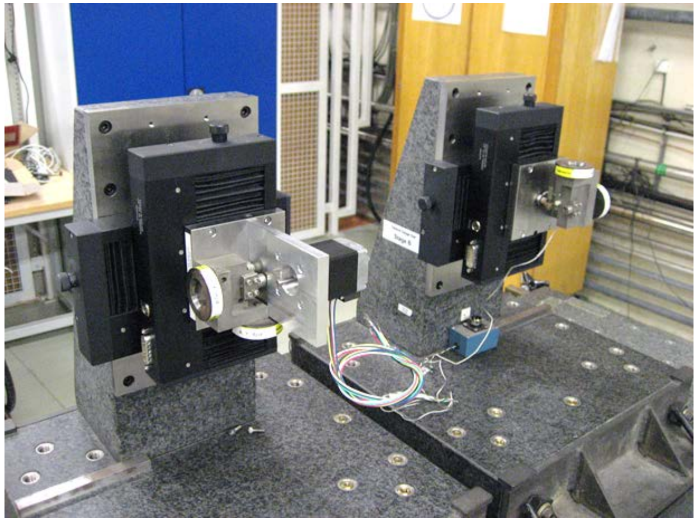
1. To built new SSW **based on FNAL's systems**, with at least the same accuracy but … using our own software (FFMM – **F**lexible **F**ramework for **M**agnetic **M**easurement) and our own integrator (FDI – **F**ast **D**igital **I**ntegrator, *see L. Fiscarelli presentation @IMMW18*)
2. Add vibrating wire features to increase the measurement capabilities in terms of field axis and harmonics measurement

Our wish: an "all-in-one" system…

SSW at CERN: upgrade plans (2)

Purchase of new stages:

- For old systems replacement (2013-2014): 2 assemblies with 150-200 mm range, 1 µm overall accuracy
  - **In discussion with the PI (Physik Instrumente) company**
  - **Between 75 and 100 kUSD each system (two granite units with X/Y stages + tension + controller)**
- For large-aperture magnets (2014): 1 system with range of 500 mm and accuracy of 10 µm
- For small magnets (2014): 1 system with range of 10 mm, accuracy <1 µm
  - Need for a dedicated fixed bench, including temperature regulation, accurate fiducialization, vibration monitoring, …



Meanwhile: PI M-605.2DD, range: 50 mm, accuracy 1 µm for development

Being assembled in the metrology lab at CERN (goal: 25 µrad of orthogonality) on granite supports of the broken system

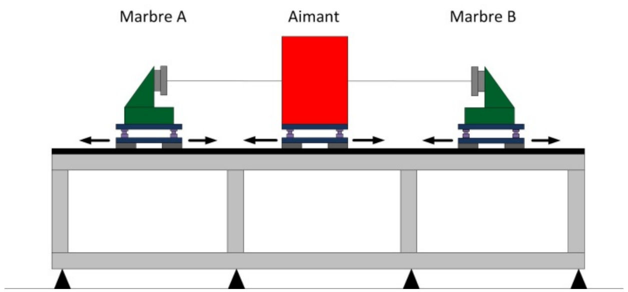
Only 2 kg push-pull force: the original wire supports had to be adapted to these stages (weight reduction)

First measurements foreseen summer 2013

SSW at CERN: upgrade plans (3)

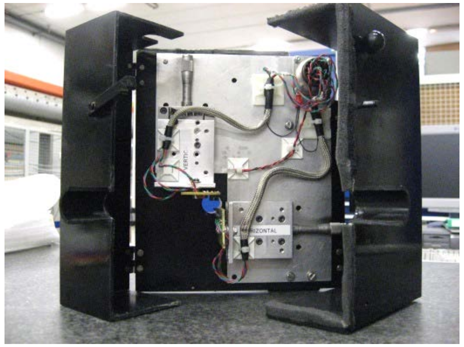
Stages alignment

- Parallel stages is important for oscillating wire (0.1mrad gives 20 units of b3!)
  - Bench equipped with rails
  - Interferometer for stand-alone installation?



Vibrating wire optimization

1. Measurement methodology
2. Optical sensors units
   - **Size and weight reduction**



Second prototype of optical sensors unit – 25x20 cm/2 kg

New wire supports

1. Constant tension issues for vibrating wire and variable tension for $\int$Gdl & sag measurement: not trivial!
2. Old request from the operation point of view: facilitate the wire installation

Switching device

1. Adding switching capability from SSW to VW/OW methods

SSW at CERN: upgrade plans (4)

Upgrade plan: not exhaustive!

What	Operation mode	Hardware	Step #	Work description	Status
Replacing the existing SSW	SSW - DC mode operation	FFMM + FDI with existing stages and DMM	1.1.1.1	ESP 7000 motor controller integration in FFMM	Done
			1.1.1.2	FDI integration in FFMM (replacing Metrolab PDI-5035)	Done
			1.1.1.3	Implementation in FFMM script: wire tensioning and tension reading	Done
			1.1.1.4	Implementation in FFMM script: rudimental GUI	Done
			1.1.1.5	Implementation in FFMM script: moving the wire in x and y with tension acquisition from the FDI	Done
			1.1.1.6	Implementation in FFMM script: data analysis to get field strength in Tesla + stdev	Done
			1.1.1.7	Implementation in FFMM script: storage of raw and computed data in a folder with current date and time	Done
			1.1.1.8	Implementation in FFMM script: roll angle measurement (measure x @ different y)	To be done
			1.1.1.10	Full test of the new implementations: magnet measurement	To be done
		+ new PI stages and new tension motor with existing wire support + new ADC	1.1.2.1	Implementation of the PI stages commands in FFMM	To be done
			1.1.2.2	Verification of the syncronization of the movement between stages	To be done
			1.1.2.3	Trigger feedback from the controllers	To be done
			1.1.2.4	Tension motor with new controller implementation in FFMM	To be done
			1.1.2.5	Implementation of a N.I. ADC card (replacement of the HP 3457A)	To be done
			1.1.2.6	Full test of the new implementations: magnet measurement	To be done
	SSW - AC mode operation	+ waveform generator	1.2.1.1	Trigger signal implementation	To be done
			1.2.1.2	Waveform generator implementation in FFMM	To be done
			1.2.1.3	AC data analysis implementation in FFMM	To be done
			1.2.1.4	Fault detection improvement	To be done
Implementing new features	Vibrating Wire (OW)	+ optical X&Y detectors	2.1.1.1	Implementation of a optical unit on stage B of SSW2	Done
			2.1.1.2	Labview vi: simple reading of the voltage given by the two sensors and FFT	Done
			2.1.1.3	Labview vi: possibility to manually minimize the signals, move the stages and find the magnetic center	Done
			2.1.1.4	Script able to move and acquire the signal from the sensors at resonance mode	Done
	Oscillating Wire (OW)	+ optical X&Y detectors	2.2.1.1	Relative hamonics measurement in automatic mode	Done
			2.2.1.2	Data analysis implementation in the script	To be done
			2.2.1.3	Extrapolation of the amplitude to infinite tension	To be done
			2.2.1.4	Improvement of the fault dectection in FFMM	To be done
			2.2.1.5	GUI improvement	To be done
	SSW general	New wire supports/fixation	2.3.1.1	New tension motor support for easier operation on the wire	To be done
			2.3.1.2	Constant wire tension for OW	To be done

SSW at CERN: upgrade plans (4)

High priority: replacing existing systems (same capabilities)

What	Operation mode	Hardware	Step #	Work description	Status
Replacing the existing SSW	SSW - DC mode operation	FFMM + FDI with existing stages and DMM	1.1.1.1	ESP 7000 motor controller integration in FFMM	Done
			1.1.1.2	FDI integration in FFMM (replacing Metrolab PDI-5035)	Done
			1.1.1.3	Implementation in FFMM script: wire tensioning and tension reading	Done
			1.1.1.4	Implementation in FFMM script: rudimental GUI	Done
			1.1.1.5	Implementation in FFMM script: moving the wire in x and y with tension acquisition from the FDI	Done
			1.1.1.6	Implementation in FFMM script: data analysis to get field strength in Tesla + stdev	Done
			1.1.1.7	Implementation in FFMM script: storage of raw and computed data in a folder with current date and time	Done
			1.1.1.8	Implementation in FFMM script: roll angle measurement (measure x @ different y)	To be done
			1.1.1.10	Full test of the new implementations: magnet measurement	To be done
		+ new PI stages and new tension motor with existing wire support + new ADC	1.1.2.1	Implementation of the PI stages commands in FFMM	To be done
			1.1.2.2	Verification of the syncronization of the movement between stages	To be done
			1.1.2.3	Trigger feedback from the controllers	To be done
			1.1.2.4	Tension motor with new controller implementation in FFMM	To be done
			1.1.2.5	Implementation of a N.I. ADC card (replacement of the HP 3457A)	To be done
			1.1.2.6	Full test of the new implementations: magnet measurement	To be done
	SSW - AC mode operation	+ waveform generator	1.2.1.1	Trigger signal implementation	To be done
			1.2.1.2	Waveform generator implementation in FFMM	To be done
			1.2.1.3	AC data analysis implementation in FFMM	To be done
			1.2.1.4	Fault detection improvement	To be done
Implementing new features	Vibrating Wire (OW)	+ optical X&Y detectors	2.1.1.1	Implementation of a optical unit on stage B of SSW2	Done
			2.1.1.2	Labview vi: simple reading of the voltage given by the two sensors and FFT	Done
			2.1.1.3	Labview vi: possibility to manually minimize the signals, move the stages and find the magnetic center	Done
			2.1.1.4	Script able to move and acquire the signal from the sensors at resonance mode	Done
	Oscillating Wire (OW)	+ optical X&Y detectors	2.2.1.1	Relative hamonics measurement in automatic mode	Done
			2.2.1.2	Data analysis implementation in the script	To be done
			2.2.1.3	Extrapolation of the amplitude to infinite tension	To be done
			2.2.1.4	Improvement of the fault dectection in FFMM	To be done
			2.2.1.5	GUI improvement	To be done
	SSW general	New wire supports/fixation	2.3.1.1	New tension motor support for easier operation on the wire	To be done
			2.3.1.2	Constant wire tension for OW	To be done

SSW at CERN: upgrade plans (5)

Lower priority: implementing vibrating (VW) and oscillating wire (OW) features

What	Operation mode	Hardware	Step #	Work description	Status
Replacing the existing SSW	SSW - DC mode operation	FFMM + FDI with existing stages and DMM	1.1.1.1	ESP 7000 motor controller integration in FFMM	Done
			1.1.1.2	FDI integration in FFMM (replacing Metrolab PDI-5035)	Done
			1.1.1.3	Implementation in FFMM script: wire tensioning and tension reading	Done
			1.1.1.4	Implementation in FFMM script: rudimental GUI	Done
			1.1.1.5	Implementation in FFMM script: moving the wire in x and y with tension acquisition from the FDI	Done
			1.1.1.6	Implementation in FFMM script: data analysis to get field strength in Tesla + stdev	Done
			1.1.1.7	Implementation in FFMM script: storage of raw and computed data in a folder with current date and time	Done
			1.1.1.8	Implementation in FFMM script: roll angle measurement (measure x @ different y)	To be done
			1.1.1.10	Full test of the new implementations: magnet measurement	To be done
		+ new PI stages and new tension motor with existing wire support + new ADC	1.1.2.1	Implementation of the PI stages commands in FFMM	To be done
			1.1.2.2	Verification of the syncronization of the movement between stages	To be done
			1.1.2.3	Trigger feedback from the controllers	To be done
			1.1.2.4	Tension motor with new controller implementation in FFMM	To be done
			1.1.2.5	Implementation of a N.I. ADC card (replacement of the HP 3457A)	To be done
			1.1.2.6	Full test of the new implementations: magnet measurement	To be done
	SSW - AC mode operation	+ waveform generator	1.2.1.1	Trigger signal implementation	To be done
			1.2.1.2	Waveform generator implementation in FFMM	To be done
			1.2.1.3	AC data analysis implementation in FFMM	To be done
			1.2.1.4	Fault detection improvement	To be done
Implementing new features	Vibrating Wire (OW)	+ optical X&Y detectors	2.1.1.1	Implementation of a optical unit on stage B of SSW2	Done
			2.1.1.2	Labview vi: simple reading of the voltage given by the two sensors and FFT	Done
			2.1.1.3	Labview vi: possibility to manually minimize the signals, move the stages and find the magnetic center	Done
			2.1.1.4	Script able to move and acquire the signal from the sensors at resonance mode	Done
	Oscillating Wire (OW)	+ optical X&Y detectors	2.2.1.1	Relative hamonics measurement in automatic mode	Done
			2.2.1.2	Data analysis implementation in the script	To be done
			2.2.1.3	Extrapolation of the amplitude to infinite tension	To be done
			2.2.1.4	Improvement of the fault dectection in FFMM	To be done
			2.2.1.5	GUI improvement	To be done
	SSW general	New wire supports/fixation	2.3.1.1	New tension motor support for easier operation on the wire	To be done
			2.3.1.2	Constant wire tension for OW	To be done

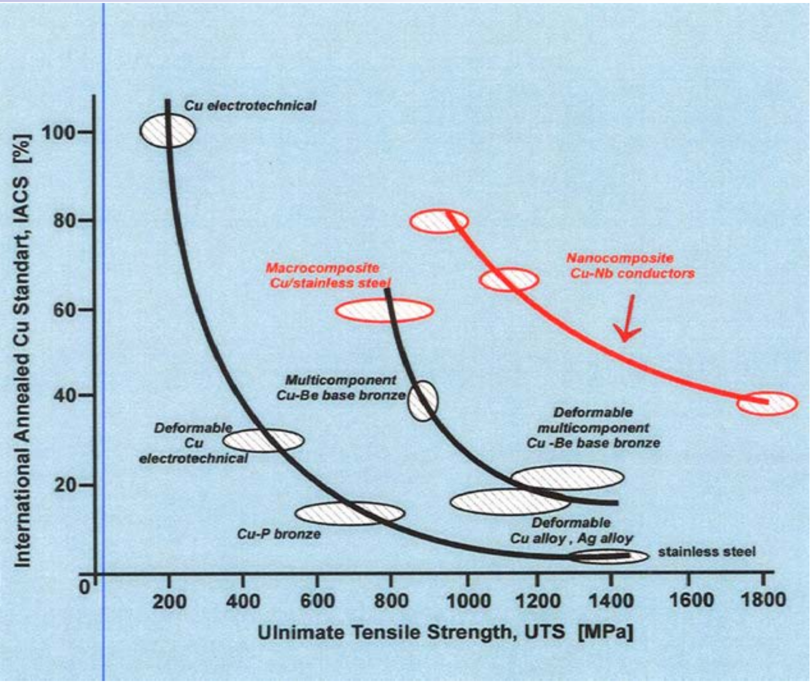
SSW at CERN: Copper-Niobium wire test

Copper – Niobium thin wires available on the market!

- Cu82-Nb18 UTS = **1900** MPa
- Cu98-Be2 UTS ≅ max 1500 MPa

→ Perfect to use as stretched wire!

- Purchase of a 500 m sample CuNb (0.1 mm diam., UTS 1900 MPa, IACS 55 %) wire by Alphysica, Germany.
- Wire manufactured in Russia by Nanoelectro Ltd, (Moscow, Russia).



Data : Nanoelectro Ltd

Comparison with two different CuBe samples

	Material	Manufacturer	Wire Diameter	Tensile strength - manufacturer data	Tensile Strength - CERN test	Max. Wire Tension	Aprox. sag with 2m wire at max. tension	Aprox. sag with 12m wire at max. tension
			[mm]	[Mpa]	[Mpa]	[N]	[um]	[um]
	CuBe	CalFineWire	0.1	1520	1533	12.0	28	1016
Used @ CERN→	CuBe	GoodFellow	0.125	500-1300	1145	14.0	38	1360
	CuNb	Nanoelectro	0.1	1900	1692	13.3	26	928

Gain on sag: 10%

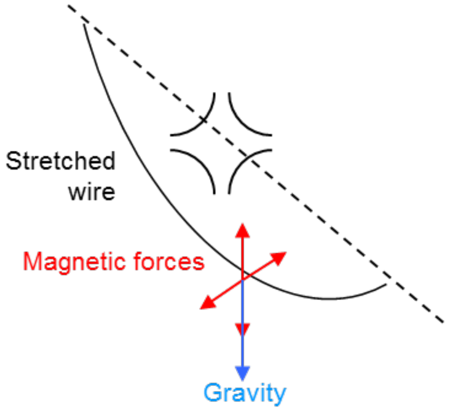
- For big wire length (> 2 m), errors on wire offset corrected to more than 99 % by measuring at different wire tensions and extrapolating to infinite.

→ Copper – Niobium might be interesting when sag can be neglected (short wires)!

SSW at CERN: Copper-Niobium wire test (2)

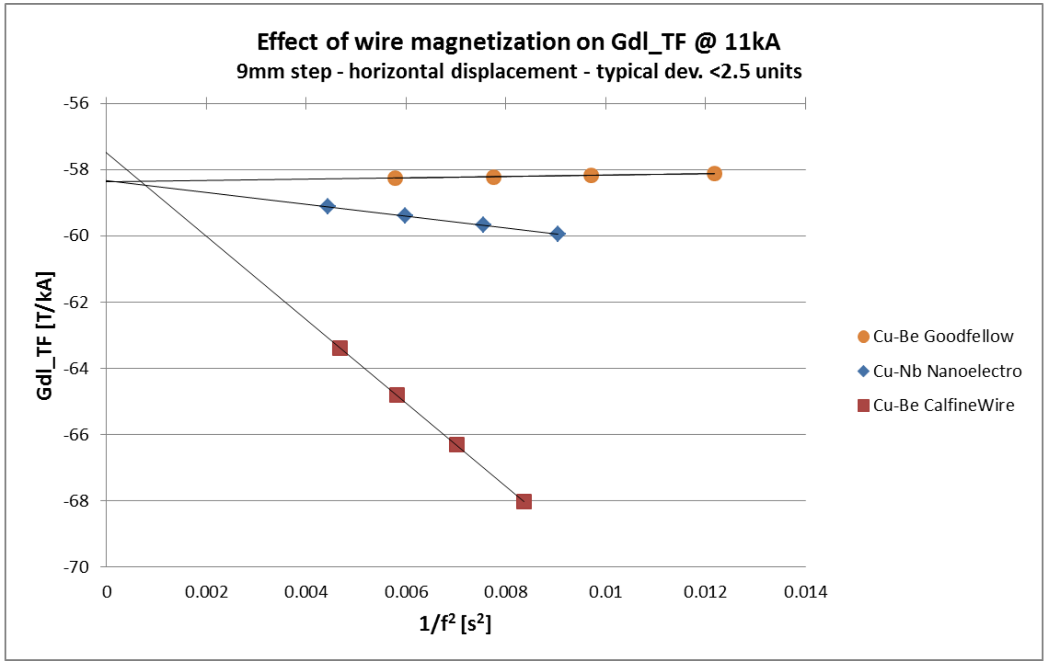
What about wire magnetization effects on $\int$Gdl?

(see «Enhancement of Single Stretched Wire measurements" - IMMW14)



Position of the wire influenced by magnetic forces:

$$Y_{mag} or X_{mag} \propto -\frac{G^2 D^2 \chi}{2\mu_0 T}\rho(z)$$



Gdl dependence to wire tension measured at cold on an LHC MQ (SSS535), Imagnet = 11 kA

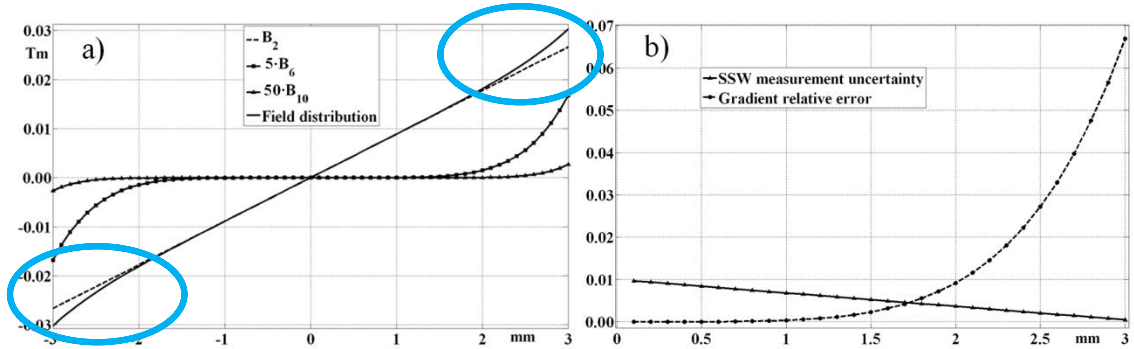
Extrapolated integrated gradient deviation w/r to Goodfellow Cu-Be as a function of integrated field strength

Wire:	CuBe Goodfellow	CuNb Nanoelectro	CuBe CalFineWires
Slope [T/kA/s^2]:	19.379	-181.04	-1259.7
	[units]	[units]	[units]
dev @58T	0	3.3	10.0
dev @175T	0	2.9	28.9
dev @292T	0	5.1	49.1
dev @409T	0	5.3	55.8
dev @526T	0	6.8	84.6
dev @642T	0	7.4	148.2

- When measuring strong fields, wire susceptibility does matter!
- Copper – niobium not better or worse than copper-beryllium in term of susceptibility: strongly depending on the extrusion matrix pollution
- Only systematic measurements of a new wire would give information on its magnetic quality; never trust manufacturer data!

- **$\int$Gdl measured with SSW: "pollution" due to field harmonics**

  - Small wire steps around the magnetic axis = low signal, low sensitivity
  - Increasing wire steps = influence of higher-order harmonics



(a) Magnetic field distribution as the superposition of a quadrupole main component B_2 and two higher-order multipoles (B_6 and B_{10})

(b) the corresponding measurement error (-.-) and operative usual uncertainty (-) that decrease with the wire displacement

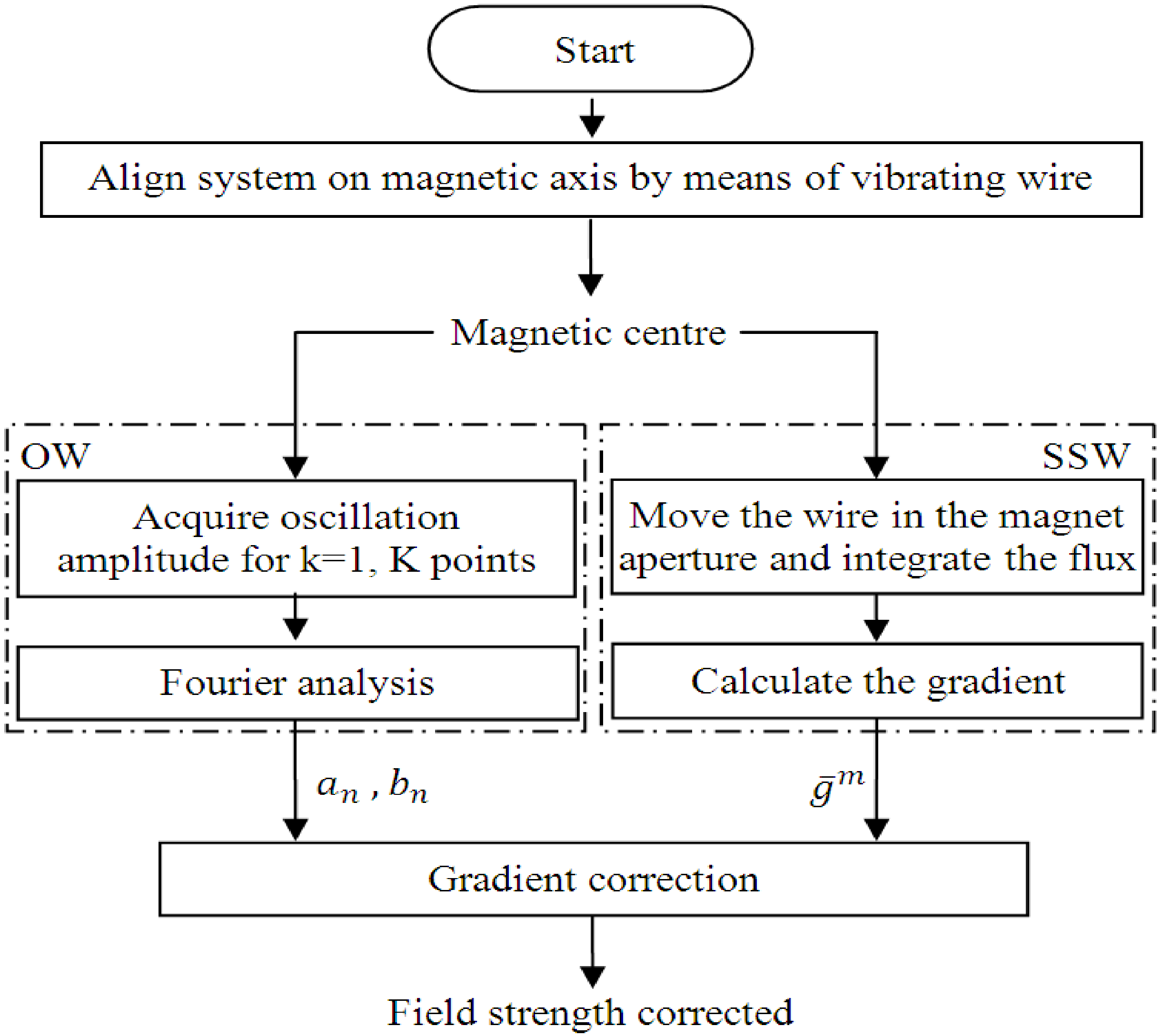
- **$\int$Gdl correction possible with higher-order multipolar components** ***(see theory in S. Russenschuck's talk)***

Using both stretched and oscillating wire method:

- Same measurement bench setup
- Possibility to measure relative harmonics at different reference radii for magnets with different aperture sizes

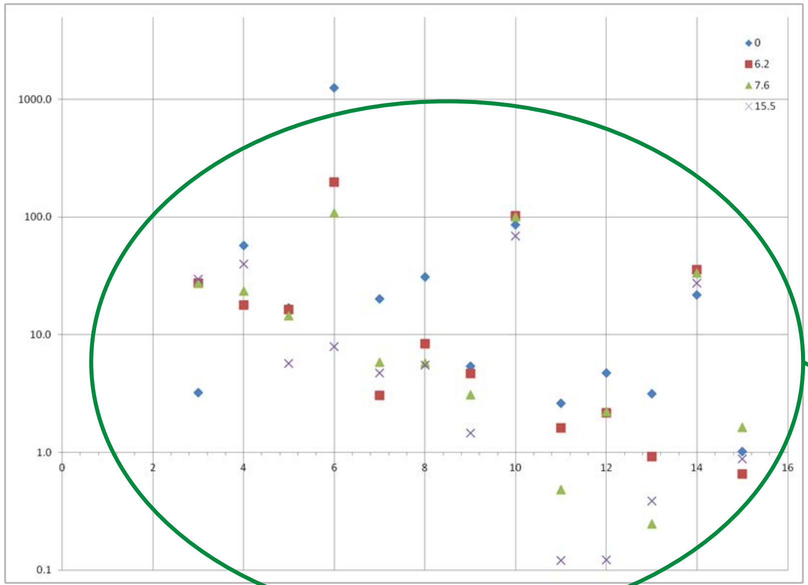
Recent measurements using the vibrating and oscillating wire method: quadrupole integrated strength correction with harmonics (2)

Procedure:

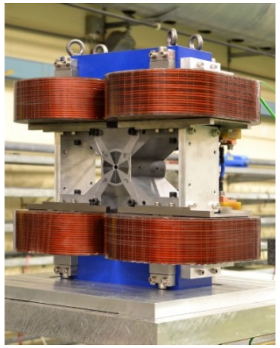


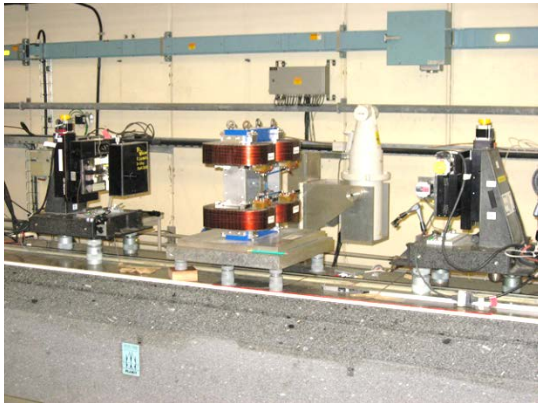
Recent measurements using the vibrating and oscillating wire method: quadrupole integrated strength correction with harmonics (3)

Practical application: integrated gradient correction on a high-gradient hybrid quadrupole for the final-focus transport line of the Compact Linear Collider (CLIC) at CERN



Normal relative Multipoles (b_n, in 10^{-4} units) in log scale as a function of current at r_0 = 3 mm. Measurement averaged on 30 measurement repetition between x and y phototransistor.





Yoke length: 100 [mm]
Aperture width: **8.3** [mm]
Permanent magnet blocks gradient: 85.6 [T/m]
Integrated permanent gradient: about 9 [T]
The gradient can be increased to 509 [T/m] when the magnet is excited to 18.6 [A]

Relative multipoles measured with the oscillating wire (OW) at r_0=3 mm

Gdl_x correction:

$$g^c = g^m\left(1 + \frac{b_4}{2}\left(\frac{x}{r_0}\right)^2 + \frac{b_6}{3}\left(\frac{x}{r_0}\right)^4 + \frac{b_8}{4}\left(\frac{x}{r_0}\right)^6 + \cdots\right)^{-1}$$

Gdl_y correction:

$$g^c = g^m\left(1 - \frac{b_4}{2}\left(\frac{y}{r_0}\right)^2 + \frac{b_6}{3}\left(\frac{y}{r_0}\right)^4 - \frac{b_8}{4}\left(\frac{y}{r_0}\right)^6 + \cdots\right)^{-1}$$

Where

- g^m is the integrated gradient measured with the stretched wire (SSW) method
- g^c the corrected gradient using multipoles up to order 10
- x and y the horizontal resp. vertical wire measuring step equal to the oscillating wire measurement radius (OW)
- r_0 the arbitrary reference radius = 3 mm

Recent measurements using the vibrating and oscillating wire method: quadrupole integrated strength correction with harmonics (4)

Results:

Comparison between integrated gradients before and after correction, versus the excitation current

I (A)	$L\,\bar{g}^{\mathrm{m}}(-x,x)$ (T)	$L\,\bar{g}^{\mathrm{m}}(-y,y)$ (T)	R^{m}	$L\,\bar{g}^{\mathrm{c}}(-x,x)$ (T)	$L\,\bar{g}^{\mathrm{c}}(-y,y)$ (T)	R^{c}
0.0	9.245	-9.327	0.009	8.886	-8.907	0.002
6.2	32.686	-32.786	0.003	32.557	-32.618	0.002
7.6	39.174	-39.274	0.003	39.144	-39.177	0.001
15.5	51.358	-51.462	0.002	51.504	-51.430	0.001
7.6	39.523	-39.618	0.002	39.498	-39.530	0.001
6.2	33.077	-33.164	0.003	32.959	-33.002	0.001
0.0	9.238	-9.307	0.007	8.880	-8.883	0.000

- Relative difference reduced by a factor around 2 (high field) to 7 (low field)
- Residual inaccuracy of the order of 0.1% w/r to main field. To be qualified

Where R^m is the relative difference between $\int$Gdl measurements along horizontal (x) and vertical (y) axis

$$R^m = \frac{\left||g^{\mathrm{m}}(-x,x)| - |g^{\mathrm{m}}(-y,y)|\right|}{|g^{\mathrm{m}}(-x,x)|}$$

R^c is the relative difference between $\int$Gdl measurements along horizontal (x) and vertical (y) axis AFTER correction

$$R^c = \frac{\left||g^{\mathrm{c}}(-x,x)| - |g^{\mathrm{c}}(-y,y)|\right|}{|g^{\mathrm{c}}(-x,x)|}$$

Relative difference between horizontal and vertical gradient helps to avoid sign errors on correction: both should converge!

Recent measurements using the vibrating and oscillating wire method: axis measurement of solenoids

Manufacturer:	Danfysik, DK
Aperture	140.0 mm
Iron Length	340.0 mm
Total Length	340.0 mm
RMS current	122.0 A
Resistance 20C	215.0 mΩ
Inductance	56.0 mH

LINAC4 (new linear accelerator at CERN):

- 4 solenoids for the accelerator + test stand.

The MedAustron accelerator (Hadrons therapy facility)

- 3 solenoids

- Field quality measured in industry – crosscheck mapping at CERN
- Magnetic axis fiducialization done at CERN
  - Requirements: **±0.1 mm**

Note: due to low transverse field the standard stretched wire counter-directional method is insensitive

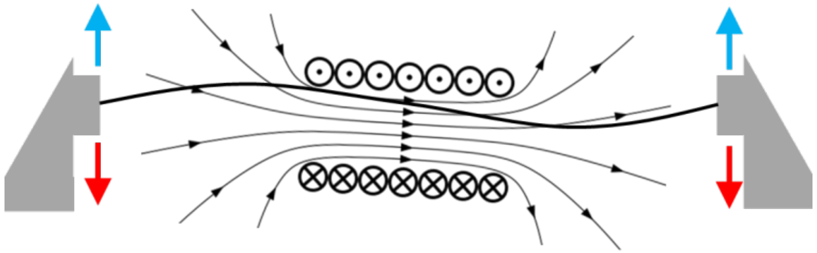
→ **The vibrating wire method is more appropriated**

(see as well A. Temnykh's "Application of the Vibrating Wire Technique for Solenoid magnetic center finding", IMMW14 and J. DiMarco "Solenoid Magnet Alignment at Fermilab", IMMW16)

Recent measurements using the vibrating and oscillating wire method: axis measurement of solenoids (2)

First step: average axis

1. Wire excited at the frequency of the **second fundamental** harmonic
2. Stages move **co-directional** along horizontal or vertical axis to minimize the amplitude of the wire



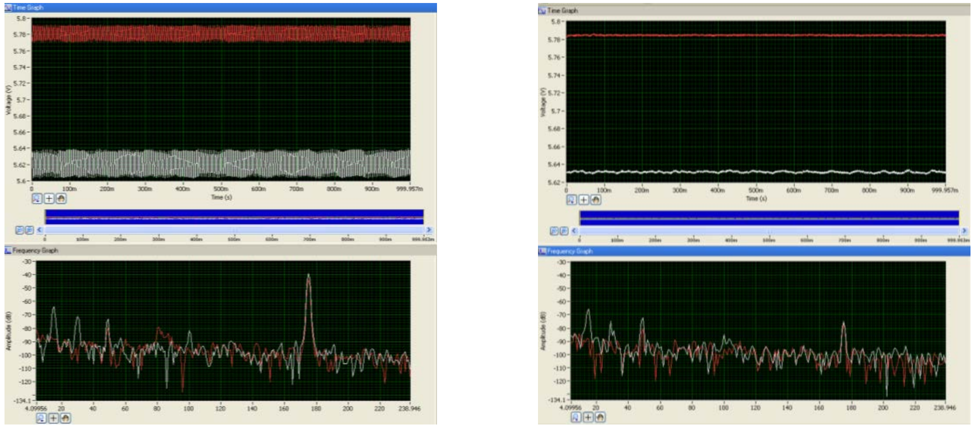
Hardware:

- Optical sensors: Sharp GP1S094HCZ0F
- Acquisition: NI 6289
- Waveform generator: Keithley 6221
- Display: LabView Signal Express

Bench setup:

- Wire: CuBe, 0.125 mm
- Wire tension: ≅ 875 g
- Wire length: ≅ 1700 mm
- Second resonance frequency: ≅ 160 Hz
- Sinusoidal wire current current: = 21 mAp-p

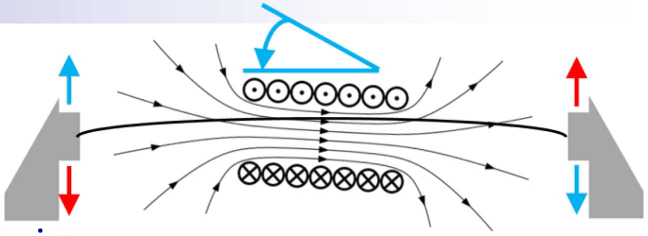
Horizontal (white) and vertical (red) wire amplitude display in time domain (top) and frequency domain (bottom)



Before correction (left) and after correction (right)

- **Typical resolution obtained for the average axis on the 4 tested magnets: 10 µm**
- **Final fiducialization: <50 µm (LTD 500 laser tracker overall accuracy)**

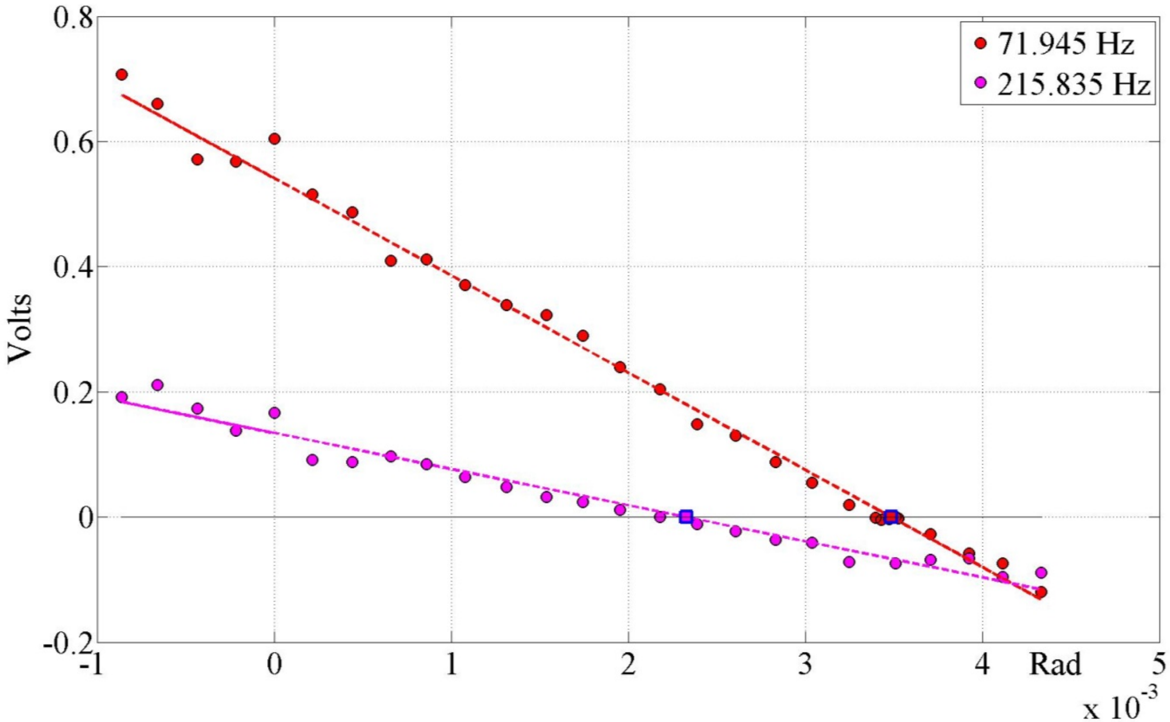
Second step: true axis



1. Wire is excited at the frequency of the **fundamental** or **third** harmonic
2. **Counter-directional** movement of the stages to minimize the amplitude of the wire

Problem: wire touches the optical sensors (stages dx or dy >5 [mm]) and wire tension changes (fixed tension wire).
Solution: **magnet** is moved instead (in this case, for practical reasons in yaw only)

Voltage amplitude from the optical sensor as a function of the magnet yaw angle



Wire excited at fundamental frequency

Magnet angle to adjust:

ψ = 3.5 mrad stdev = 0.37 mrad

Wire excited at 3rd harmonic frequency

Magnet angle to adjust:

ψ = 2.3 mrad stdev = 1.4 mrad

Conclusion

- SSW systems @ CERN:
  - **FNAL's SSW systems still are a reference** – difficult to do better!
  - **Integration of wire technique into FFMM + FDI** well advanced. First full test in DC mode with PI- 50 mm range stages expected summer 2013
  - **Purchase of new 150-200 mm range stages** to replace old systems in study – **foreseen 2013**
- New Cu-Nb wire
  - UTS data from manufacturer **not matching** measured value.
  - **Gain on sag <10 %** w/r to CalFineWire Cu-Be sample
  - Susceptibility of this sample giving errors up to 10 units w/r to Goodfellow Cu-Be (**not predictable!**)
  - 500m spool Cu – Nb, diam. 0.1[mm]: **$4150.-** (Feb2012) and Cu – Be **$275.-** (Feb. 2013)
- Quadrupole gradient correction with harmonics
  - **Simple analytical method for gradient correction** of quadrupole magnets using unique setup and hardware, adaptable to the magnet aperture size
  - **Residual inaccuracy estimated to 0.1% w/r to main field**: more measurements required!
  - **Correction factor higher at low field than high field**: more measurements required !
- Solenoid axis alignment
  - **Vibration wire** measurement technique allowed **10 µm average axis** and **0.4 mrad true axis** alignment
  - Angle difference between 1st and 3rd harmonic wire excitation current ≅ 0.83 mrad: systematic?
  - Magnet movement instead of stages displacements avoids errors due to wire/sensor contact and tension change, but this **requires a proper adjustable support…**

…like this?

PI hexapod h-845

- Load capacity to 1000 kg
- Velocity to 20 mm/s
- Repeatability to ±2 μm
- Travel ranges to 220 mm / 60°

…like this?

PI hexapod h-845

- ❑Load capacity to 1000 kg
- ❑Velocity to 20 mm/s
- ❑Repeatability to ±2 μm
- ❑Travel ranges to 220 mm / 60˚

Price ≅ 200 k$

THANK YOU!