Follow-Up and Checkpoints of Harmonics in Collared Coils and Cold Masses

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AT-MAS-MA

Contents

- What do we control
  - Field quality in the dipole specification
  - Warm magnetic measurements
- How we control
  - The holding point
  - The holding point tools
- Results obtained so far
  - Overview
  - Data validation: Measurement problems
  - Data analysis: Quality control
- Conclusions

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Field Quality in the Dipole Specification

- The philosophy of the specification:
  - A magnet can be refused if we can prove that the assembly procedure has not been followed correctly
  - The firms are not responsible for the field quality required for beam dynamics, but CERN will indicate the corrective actions
  - Statistical control important in holding the point procedure also to detect assembly problems

Magnetic measurements to monitor production

- Measurements carried out in the firms by CERN/Firm personnel
- Magnetic measurements at 300 K
  - 0.75 m rotating coils, 20 positions along the longitudinal axis

- Quality control of the magnet - early detection of problems
  - Not all problems can be detected (1005, cold welds in sc cables)
  - Many of them can be detected (2002, 1027 - faulty assembly, 1021 doubts on assembly procedure)
- Steering field quality towards beam dynamics limits (using correlations to measurements at 1.9 K, at CERN)

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How do we control: The Holding Points

- Two Holding Points for magnetic field:
  - Collared coil assembly, before proceeding to cold mass assembly
  - Cold mass assembly, before shipping to CERN
- Results of Holding Point:
  - OK: approval
  - OK-W: approval, but a warning on specific problems is given to project engineers, technicians, and to the firm
  - OK-c.a.: approval, but a corrective action will be taken on the cold mass (collared coil only)
  - HOLD: not approved, collared coil or cold mass hold for analysis

How do we control: The Holding Hoints (2)

- How is the holding point managed ?
  - Measurements carried out in the firms by CERN/Firm personnel
  - Analysis at CERN - answer to the manufacturer through AT-MAS-MD (ok necessary for CERN invoicing to firm)
  - In case of problems, an informal "unit of crisis" (project engineers and technicians, analysts) is immediately activated
- How is the analysis done ?
  - A macro using information based on statistical analysis of previous magnets sets alarms for multipoles and positions
  - Green (ok), yellow alarm (warning), red alarm (special care)
  - Control limits are not related to beam dynamics specifications: this is a check of production homogeneity

Alarm Classification

Green:

Up to 3.5 standard deviation of a Gaussian Distribution which corresponds to *1 alarm on the whole production*

Yellow:

From 3.5 to 7 standard deviation of a Gaussian Distribution

Red:

From 7 standard deviation of a Gaussian Distribution

We have more alarms which means that the distribution is not Gaussian

The holding point analysis

- For a "normal" magnet we need to:
  - Download measurements file (mail)
  - Analyze the data: data validation, macro results, interpretation, comparison with previous cases
  - Store file in repository and upload to Oracle
  - Update graphs that make comparison to beam dynamics ranges
  - Put them on the web
  - Write answer to AT-MAS-MD
  - At maximum production speed:

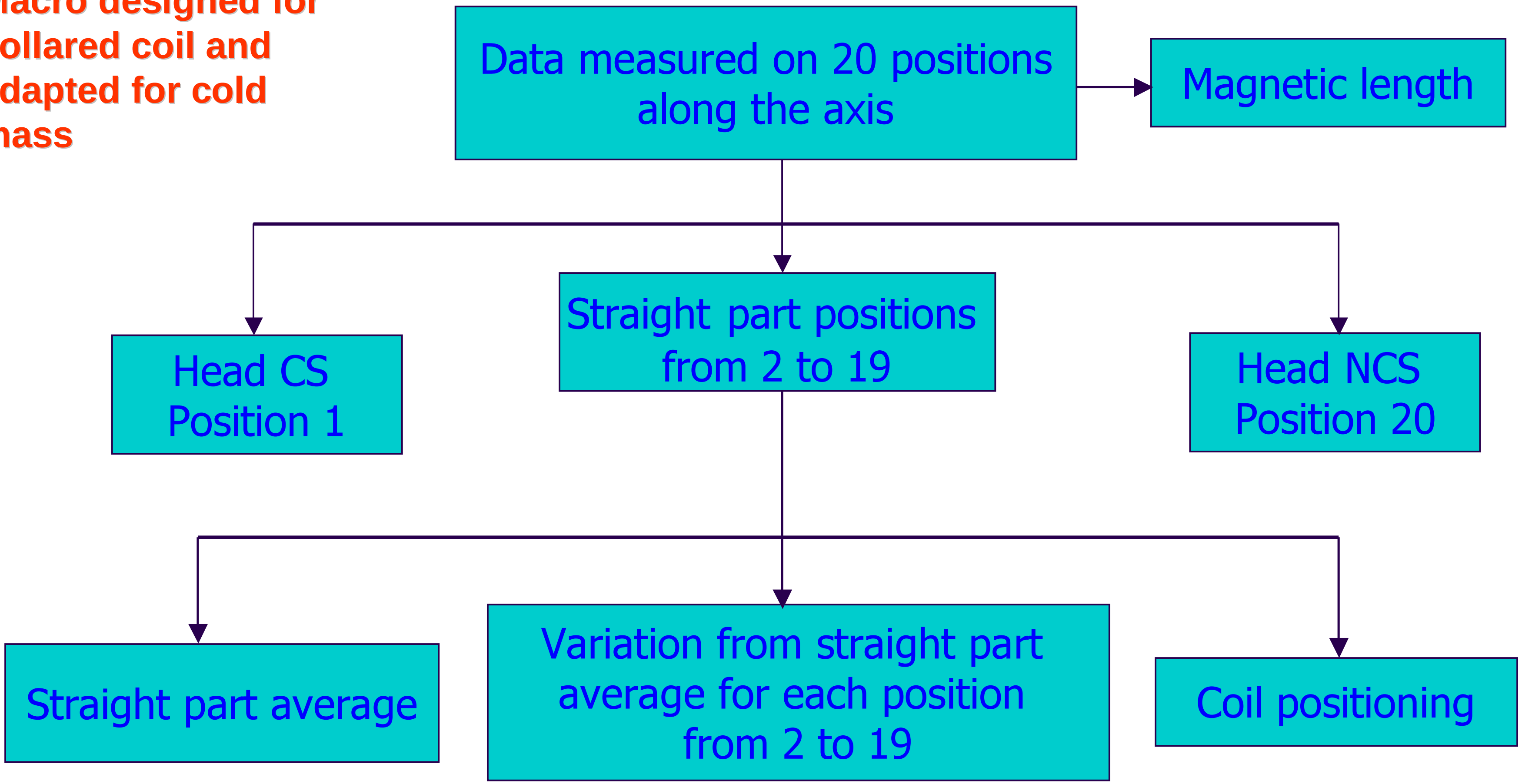
> - 8 cold masses per week
> - 16 measurements per week (cc and cm, 100% or more tested)

The holding point data storage

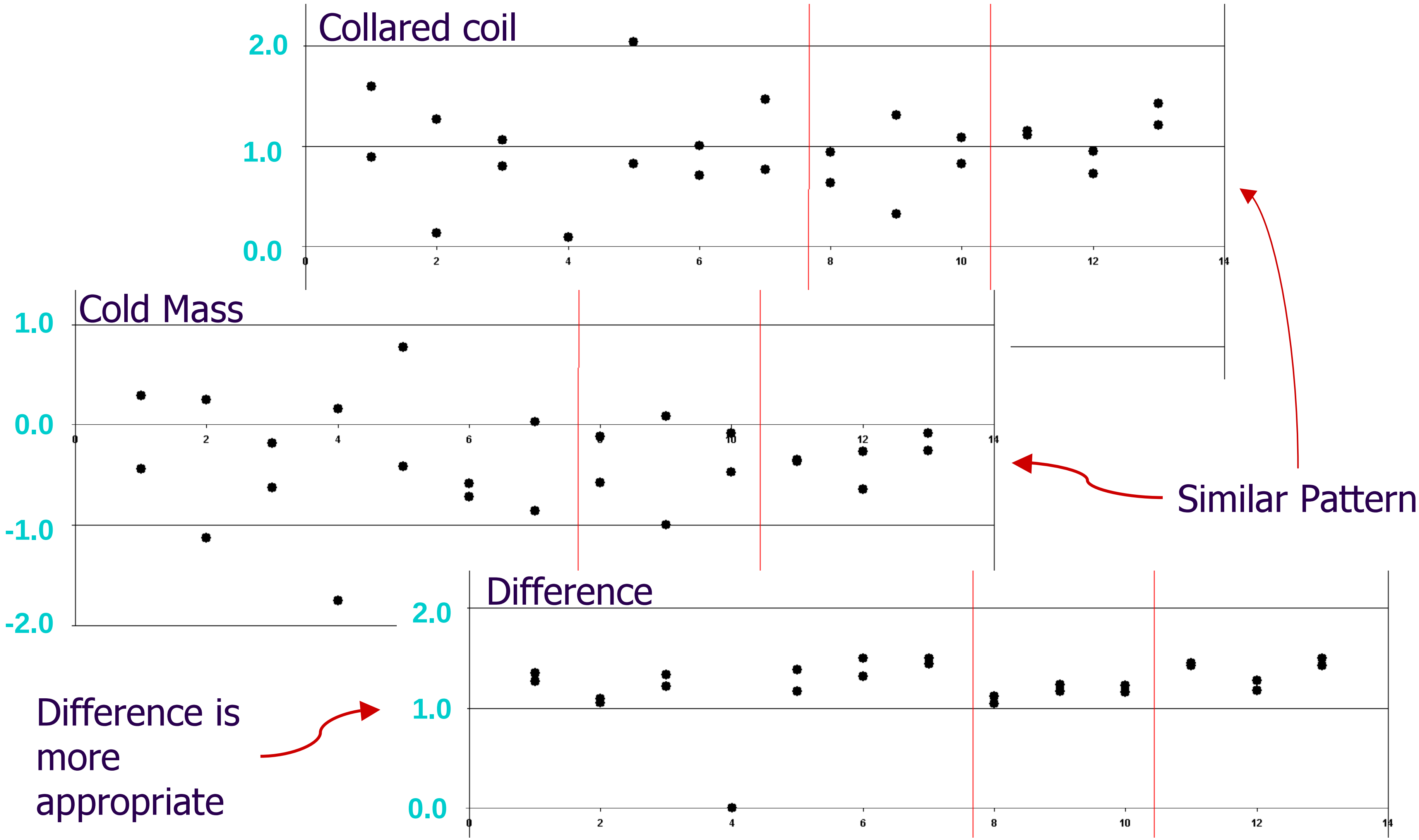
- Measurement data: immediate email (.txt, .xls)
- The Oracle Database (J.Beauquis) is filled with all measurements
- Data of each dipole: Repository on the web (Excel)
- Plots of multipoles: Field Quality Observatory on the web (Excel)
- When Dipole shipped: Analyzed data in MTF

The statistical filters, philosophy

Macro designed for collared coil and adapted for cold mass



Cold mass analysis example: b_2



Holding Point: Analysis of collared coil & cold mass

	Bound Parameters																			
	Mean	Sigma	Ybound	Rbound			Mean	Sigma	Ybound	Rbound										
Magnetic Length (mm)	-0.058	0.008	3.5	7	Field Colinearity		0	0.28	3.5	7										
dB/B Heads CS+NCS (u)	-4070	100	3.5	7																
	Mean Value (3:18) (mT/kA)				dB/B Inner Positions 3 to 18 (u)				dB/B Head CS (u)				dB/B Head NCS (u)				dB/B Horn positions 2 and 19 (u)			
	Mean	Sigma	Ybound	Rbound	Mean	Sigma	Ybound	Rbound	Mean	Sigma	Ybound	Rbound	Mean	Sigma	Ybound	Rbound	Mean	Sigma	Ybound	Rbound
Main Field Component	108.30	0.38	4	8	0.34	1.52	4	8	-4140	380	3.5	7	-4022	211	3.5	7	-2.1	2.02	3.5	7
	Mean Value (2:19)				er Positions 2 to 19 minus mean v				Head CS				Head NCS							
	Mean	Sigma	Ybound	Rbound	Mean	Sigma	Ybound	Rbound	Mean	Sigma	Ybound	Rbound	Mean	Sigma	Ybound	Rbound				
Delta Angle (mrad)	0	0	3.5	7	-0.16	0.9600	4	8	3.29	0.88	3.5	7	1.08	1.77	3.5	7				
b2 (u)	1.30	0.15	3.5	7	0	0.5085	4	8	32	9	3.5	7	30	8	3.5	7				
b3 (u)	4.60	0.16	3.5	7	0	0.5085	4	8	1.44	5.50	3.5	7	7.55	1.64	3.5	7				
b4 (u)																				
b5 (u)																				
b6 (u)																				
b7 (u)																				
b8 (u)																				
b9 (u)																				
b10 (u)																				
b11 (u)																				
b12 (u)																				
b13 (u)																				
b14 (u)																				
b15 (u)																				
a2 (u)																				
a3 (u)																				
a4 (u)																				
a5 (u)																				
a6 (u)																				
a7 (u)																				
a8 (u)																				
a9 (u)																				
a10 (u)																				
a11 (u)																				
a12 (u)																				
a13 (u)																				
a14 (u)																				
a15 (u)																				

	Bound Limits																			
	Inf. Y limit	Sup. Y limi	Inf. R lim	Sup. R lim			Inf. Y lim	Sup. Y lim	Inf. R lim	Sup. R limit										
Magnetic Length (mm)	-0.086	-0.030	-0.114	-0.002	Field Colinearity		-0.98	0.98	-1.96	1.96										
dB/B Heads CS+NCS (u)	-4420	-3720	-4770	-3370																
	Mean Value (3:18) (mT/kA)				dB/B Inner Positions 3 to 18 (u)				dB/B Head CS (u)				dB/B Head NCS (u)				dB/B Horn positions 2 and 19 (u)			
	Inf. Y limit	Sup. Y limi	Inf. R limi	Sup. R lim	Inf. Y lim	Sup. Y limi	Inf. R lim	Sup. R lim	Inf. Y lim	Sup. Y lim	Inf. R lim	Sup. R lim	Inf. Y lim	Sup. Y limi	Inf. R lim	Sup. R lim	Inf. Y lim	Sup. Y lim	Inf. R lim	Sup. R limi
Main Field Component	106.7800	109.8200	105.2600	111.3400	-5.7400	6.4200	-11.8200	12.5000	-5470	-2810	-6800	-1480	-4761	-3284	-5499	-2545	-9.1700	4.9700	-16.2400	12.0400
	Mean Value (2:19)				er Positions 2 to 19 minus mean v				Head CS				Head NCS							
	Inf. Y limit	Sup. Y limi	Inf. R limi	Sup. R lim	Inf. Y lim	Sup. Y limi	Inf. R lim	Sup. R lim	Inf. Y lim	Sup. Y lim	Inf. R lim	Sup. R lim	Inf. Y lim	Sup. Y limi	Inf. R lim	Sup. R limit				
Delta Angle (mrad)	0.0000	0.0000	0.0000	0.0000	-4.0000	3.6800	-7.8400	7.5200	0.2100	6.3700	-2.8700	9.4500	-5.1150	7.2750	-11.3100	13.4700				
b2 (u)	0.7750	1.8250	0.2500	2.3500	-2.0339	2.0339	-4.0678	4.0678	0.5000	63.5000	-31.0000	95.0000	2.0000	58.0000	-26.0000	86.0000				
b3 (u)	4.0400	5.1600	3.4800	5.7200	-2.0339	2.0339	-4.0678	4.0678	-17.8100	20.6900	-37.0600	39.9400	1.8100	13.2900	-3.9300	19.0300				
b4 (u)	-0.0590	0.1790	-0.1780	0.2980	-0.5424	0.5424	-1.0847	1.0847	-1.7700	2.8500	-4.0800	5.1600	-1.8000	2.9600	-4.1800	5.3400				
b5 (u)	-0.0440	0.1240	-0.1280	0.2080	-0.5424	0.5424	-1.0847	1.0847	-3.5700	2.1700	-6.4400	5.0400	-0.8050	0.8050	-1.6100	1.6100				
b6 (u)	-0.0387	-0.0008	-0.0577	0.0182	-0.2373	0.2373	-0.4746	0.4746	-0.9900	1.1100	-2.0400	2.1600	-0.2450	0.2450	-0.4900	0.4900				
b7 (u)	-0.0458	0.0242	-0.0808	0.0592	-0.1831	0.1831	-0.3661	0.3661	-1.4250	1.1650	-2.7200	2.4600	-0.1050	0.1050	-0.2100	0.2100				
b8 (u)	-0.0151	0.0089	-0.0272	0.0209	-0.1153	0.1153	-0.2305	0.2305	-0.1960	0.1960	-0.3920	0.3920	-0.1330	0.1330	-0.2660	0.2660				
b9 (u)	-0.0392	0.0588	-0.0882	0.1078	-0.0678	0.0678	-0.1356	0.1356	-0.2235	0.2875	-0.4790	0.5430	-0.0585	0.1165	-0.1460	0.2040				
b10 (u)	-0.0064	0.0067	-0.0129	0.0132	-0.1356	0.1356	-0.2712	0.2712	-0.3150	0.3150	-0.6300	0.6300	-0.3665	0.3125	-0.7060	0.6520				
b11 (u)	-0.0735	0.0735	-0.1470	0.1470	-0.0200	0.0200	-0.0400	0.0400	-0.0960	0.1280	-0.2080	0.2400	-0.0155	0.0475	-0.0470	0.0790				
b12 (u)	-0.0035	0.0035	-0.0070	0.0070	-0.0207	0.0207	-0.0414	0.0414	-0.0525	0.0525	-0.1050	0.1050	-0.0350	0.0350	-0.0700	0.0700				
b13 (u)	-0.0083	0.0083	-0.0165	0.0165	-0.0085	0.0085	-0.0169	0.0169	-0.0214	0.0248	-0.0445	0.0479	-0.0109	0.0109	-0.0217	0.0217				
b14 (u)	-0.0222	0.0212	-0.0439	0.0429	-0.0115	0.0115	-0.0231	0.0231	-0.0182	0.0182	-0.0364	0.0364	-0.0172	0.0172	-0.0343	0.0343				
b15 (u)	-0.0127	0.0147	-0.0263	0.0283	-0.0092	0.0092	-0.0183	0.0183	-0.0196	0.0092	-0.0339	0.0235	-0.0275	0.0195	-0.0509	0.0429				
a2 (u)	-0.4150	0.3550	-0.8000	0.7400	-3.7288	3.7288	-7.4576	7.4576	-8.4000	7.0000	-16.1000	14.7000	-2.5700	1.7700	-4.7400	3.9400				
a3 (u)	-0.2905	0.2905	-0.5810	0.5810	-1.1864	1.1864	-2.3729	2.3729	-8.1200	1.8200	-13.0900	6.7900	-0.7000	0.7000	-1.4000	1.4000				
a4 (u)	-0.0630	0.0630	-0.1260	0.1260	-0.9153	0.9153	-1.8305	1.8305	-2.4800	1.7200	-4.5800	3.8200	-1.2300	0.5900	-2.1400	1.5000				
a5 (u)	-0.1575	0.1575	-0.3150	0.3150	-0.4068	0.4068	-0.8136	0.8136	0.3100	2.8300	-0.9500	4.0900	-0.5600	0.5600	-1.1200	1.1200				
a6 (u)	-0.0172	0.0172	-0.0343	0.0343	-0.2305	0.2305	-0.4610	0.4610	-1.1500	0.9500	-2.2000	2.0000	-0.2250	0.2650	-0.4700	0.5100				
a7 (u)	-0.0910	0.0910	-0.1820	0.1820	-0.1898	0.1898	-0.3797	0.3797	1.0800	1.9200	0.6600	2.3400	-0.0665	0.0665	-0.1330	0.1330				
a8 (u)	-0.0067	0.0087	-0.0144	0.0164	-0.0847	0.0847	-0.1695	0.1695	-0.2275	0.2275	-0.4550	0.4550	-0.1035	0.1555	-0.2330	0.2850				
a9 (u)	-0.0630	0.0630	-0.1260	0.1260	-0.0712	0.0712	-0.1424	0.1424	-0.3445	-0.0435	-0.4950	0.1070	-0.1205	0.0965	-0.2290	0.2050				
a10 (u)	-0.0033	0.0033	-0.0067	0.0066	-0.1153	0.1153	-0.2305	0.2305	-0.3500	0.3500	-0.7000	0.7000	-0.3205	0.3445	-0.6530	0.6770				
a11 (u)	-0.1285	0.1445	-0.2650	0.2810	-0.0305	0.0305	-0.0610	0.0610	0.0395	0.3405	-0.1110	0.4910	-0.1200	0.1460	-0.2530	0.2790				
a12 (u)	-0.0028	0.0028	-0.0056	0.0056	-0.0190	0.0190	-0.0380	0.0380	-0.0700	0.0700	-0.1400	0.1400	-0.0340	0.0340	-0.0679	0.0679				
a13 (u)	-0.0174	0.0204	-0.0363	0.0393	-0.0075	0.0075	-0.0149	0.0149	-0.0245	0.0245	-0.0490	0.0490	-0.0174	0.0204	-0.0363	0.0393				
a14 (u)	-0.0202	0.0044	-0.0324	0.0166	-0.0102	0.0102	-0.0203	0.0203	-0.0195	0.0219	-0.0401	0.0425	-0.0167	0.0121	-0.0310	0.0264				
a15 (u)	-0.0262	0.0200	-0.0493	0.0431	-0.0102	0.0102	-0.0203	0.0203	-0.0226	0.0300	-0.0488	0.0562	-0.0315	0.0315	-0.0630	0.0630				
Coil positioning	0.000	0.010	0.000	0.020																

Blue: test on cold mass
Black: test on cm-collared coil

- **Excel Program with Macro for computation of alarm limits**
- **Similar analysis for collared coil and cold mass -> similar Excel macro**
- **BUT for the cold mass the difference between collared coil and cm is analysed-> use cold mass or difference according to smallest standard deviation**
- **For cold mass: additional yoke laminations taken into account for the tests of magnetic length**

Macro/Analysis by E.Todesco, S. Pauletta, E.Wildner

The holding point result

	A	B	C	D	E	F	G	H	I	J
1	**File name**	HCMBBRA001-01000009_cm.xls								
2	**Component ID**	HCMBBRA001				**Serial Number**	1000009			
3	**Date of test Ap 1**	20.09.2002				**Date of test Ap 2**	20.09.2002			
4		**Aperture 1**					**Aperture 2**			
5	**Magnetic length**	status ok				**Magnetic length**	status ok			
6		**Average straight**	**Variation straight**	**Heads CS**	**Heads NCS**		**Average straight**	**Variation straight**	**Heads CS**	**Heads NCS**
7		positions 2 to 19	positions 2 to 19	position 1	position 20		positions 2 to 19	positions 2 to 19	position 1	position 20
8	**Main field**	status ok	status ok	status ok	status ok	**Main field**	status ok	status ok	status ok	status ok
9	**Angle**		status ok	status ok	status ok	**Angle**		status ok	status ok	status ok
10	**b2**	status ok	status ok	status ok	status ok	**b2**	status ok	status ok	status ok	status ok
11	**b3**	status ok	status ok	status ok	status ok	**b3**	status ok	status ok	status ok	status ok
12	**b4**	status ok	status ok	status ok	status ok	**b4**	status ok	status ok	status ok	status ok
13	**b5**	status ok	status ok	status ok	status ok	**b5**	status ok	status ok	status ok	status ok
14	**b6**	status ok	status ok	status ok	status ok	**b6**	status ok	status ok	status ok	status ok
15	**b7**	status ok	status ok	status ok	status ok	**b7**	status ok	status ok	status ok	status ok
16	**b8**	status ok	status ok	status ok	status ok	**b8**	status ok	status ok	status ok	status ok
17	**b9**	status ok	status ok	status ok	status ok	**b9**	status ok	status ok	status ok	status ok
18	**b10**					**b10**				
19	**b11**	status ok	status ok	status ok	status ok	**b11**	status ok	status ok	status ok	status ok
20	**b12**	status ok	status ok	status ok	status ok	**b12**	status ok	status ok	status ok	status ok
21	**b13**	status ok	status ok	status ok	status ok	**b13**	status ok	status ok	status ok	status ok
22	**b14**	status ok	status ok	status ok	status ok	**b14**	status ok	status ok	status ok	status ok
23	**b15**	status ok	status ok	status ok	status ok	**b15**	status ok	status ok	status ok	status ok
24	**a2**	status ok	status ok	status ok	status ok	**a2**	status ok	status ok	status ok	status ok
25	**a3**	status ok	status ok	status ok	status ok	**a3**	status ok	status ok	status ok	status ok
26	**a4**	status ok	status ok	status ok	status ok	**a4**	status ok	status ok	status ok	status ok
27	**a5**	status ok	status ok	status ok	status ok	**a5**	status ok	status ok	status ok	status ok
28	**a6**	status ok	status ok	status ok	status ok	**a6**	status ok	status ok	status ok	status ok
29	**a7**	status ok	status ok	status ok	status ok	**a7**	status ok	status ok	status ok	status ok
30	**a8**	status ok	status ok	status ok	status ok	**a8**	status ok	status ok	status ok	status ok
31	**a9**	status ok	status ok	status ok	status ok	**a9**	status ok	status ok	status ok	status ok
32	**a10**					**a10**				
33	**a11**	status ok	status ok	status ok	status ok	**a11**	status ok	status ok	status ok	status ok
34	**a12**	status ok	status ok	status ok	status ok	**a12**	status ok	status ok	status ok	status ok
35	**a13**	status ok	status ok	status ok	status ok	**a13**	status ok	status ok	status ok	status ok
36	**a14**	status ok	status ok	status ok	status ok	**a14**	status ok	status ok	status ok	status ok
37	**a15**	status ok	status ok	status ok	status ok	**a15**	status ok	status ok	status ok	status ok
38	**Coil Positioning**	status ok				**Coil Positioning**	status ok			
39	**Field Colinearity**	status ok								

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Quality Control

- Data validation:
  - Measurement problems (calibration, signs, problems with measurement device etc.)
  - Data format (units, delimiters, etc)
- Analysis of measurement results (1200 parameters per collared coil or cold mass):
  - Statistical evaluation to detect elements out of statistics and to detect trends
  - The analysis should permit to detect problems in assembly

Quality Control: Summary

- 81/81 collared coil measured [100%]
  - 14 cases of multiple measurement [17%]
    - 4 faulty measurements,
    - 2 measurements confirmed field anomalies
    - 8 special measurements asked
  - 2 decollarings asked: 2 assembly problems found [2%]
  - 21 warnings given to firms [25%]
    - 13 warnings for large multipole variations (curing mould at Firm 1)
    - 9 warnings for anomalies in multipoles
  - 4 corrective actions: additional laminations to correct low B [5%]
- 43/44 cold masses measured [98%]
  - 3 cases of faulty measurements [7%]
  - 1 unwelding for high variations of field direction [2%]

Measurement problems

- Sign of multipoles:
  - 1018, 1023 cold mass: cabling of measurement coil inversed
- Data points inversed:
  - 1023 collared coil and 1015 cold mass : data sent with connection side replacing non connection side and vice versa: wrong measurement procedure
- Field colinearity:
  - If different measurement coils are used for the two apertures the colinearity cannot be measured (missing software for calibration of field direction, no manpower)
- 1 mm off on x and y
  - 2016 collared coil: one position had a bad mole positioning in the tube
- Higher normal multipoles out of statistics:
  - 2020 cold mass: Inversed calibration of the two measurement coils

Assembly collared coil 2002

Faulty assembly (see [R. Gupta et al., MT-15] for experience at RHIC)

2002 had big spikes in c_1 (40 u.), b_2 (24 u.), and anomalies in b3.

	A	B	C	D	E
4		**Aperture 1**			
5	**Magnetic length**	status ok			
6		**Average straight**	**Variation straight**	**Heads CS**	**Heads NCS**
7		positions 2 to 19	positions 2 to 19	position 1	position 20
8	**Main field**	status ok	red alarm	status ok	status ok
9	**Angle**		status ok	status ok	status ok
10	**b2**	yellow alarm	red alarm	status ok	status ok
11	**b3**	status ok	yellow alarm	status ok	status ok
12	**b4**	status ok	status ok	status ok	status ok
13	**b5**	status ok	status ok	status ok	status ok
14	**b6**	status ok	status ok	status ok	status ok
15	**b7**	status ok	status ok	status ok	status ok

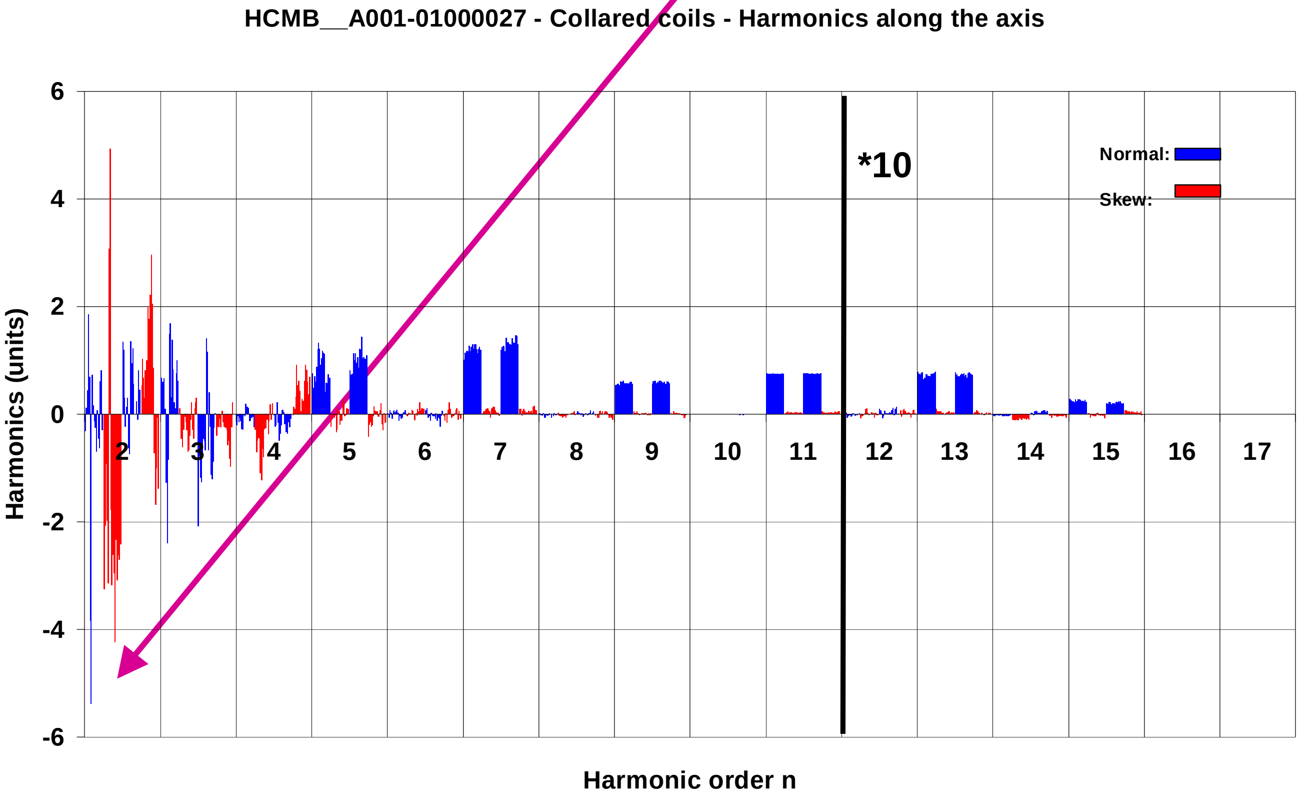
Decollared, it has been found that it was erroneously assembled with two coil protection sheets (0.5 mm more !) on a 1-m section

This case showed that control limits for the production and beam dynamics limits are and must be independent (the magnet field quality was ok for beam dynamics)

Assembly collared coil 1027

Faulty assembly (see also [R. Gupta et al., MT-15])

1027 had a spike in b_2 (5.5 u.), and anomalies in b_3 and a_2.

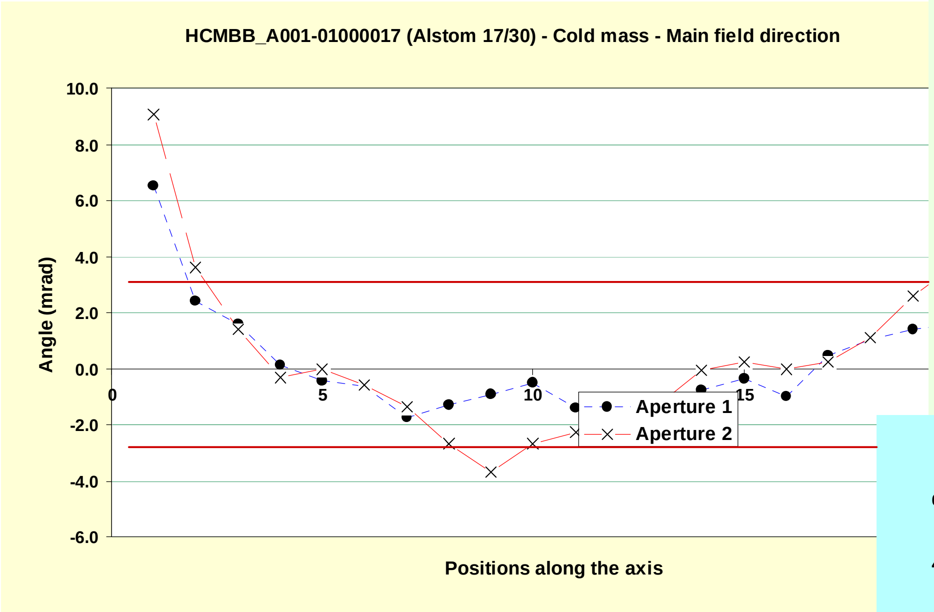


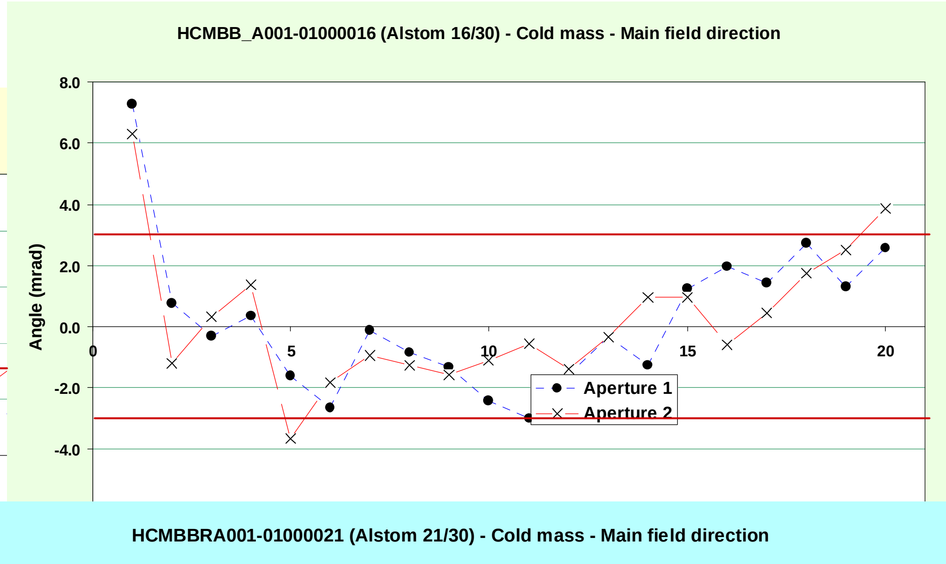
	Measure	Model
c1	-6.7	-7.5
angle	18.4	22.0
b2	-5.5	-7.6
b3	-3.0	-3.2
b4	-0.3	-0.5
a2	7.5	8.2
a3	0.1	0.5
a4	-1.0	-0.8

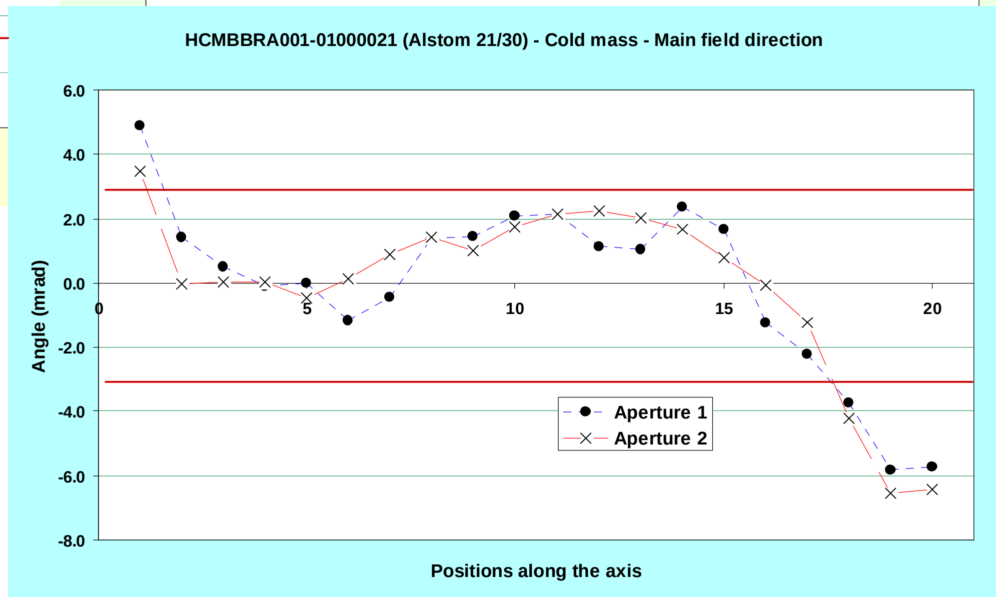
Strong numerical evidence of a missing shim (0.8 mm) along 1 m

Decollared, a missing shim was found in the foreseen position

Twist of cold mass



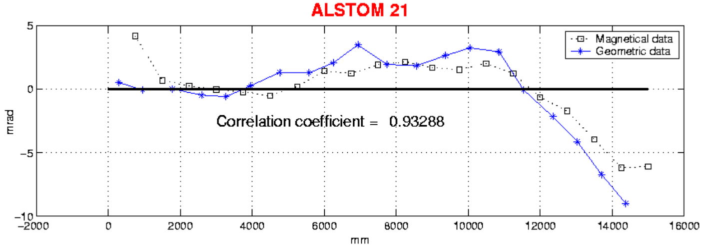


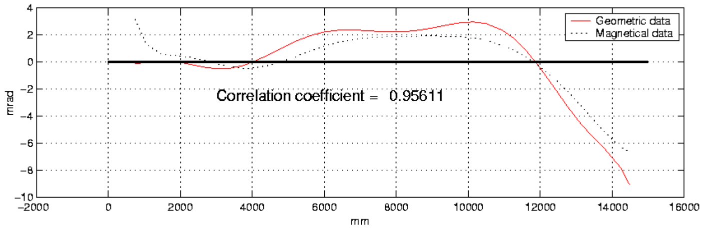


Trend of twist of cold mass main field vector

$$\int_0^{Length} \Theta(s)(Length - s)ds < 0.18 \quad ?$$

Twist of cold mass: relation to geometry



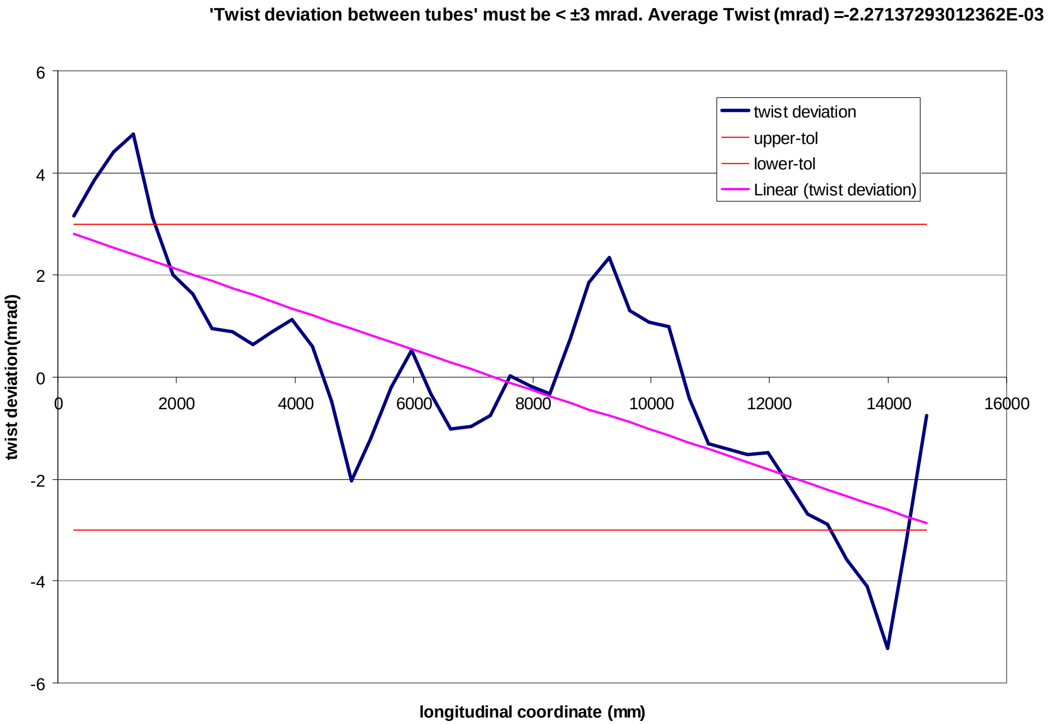


G.Gubello

Check of correlation between geometric and magnetic twist:

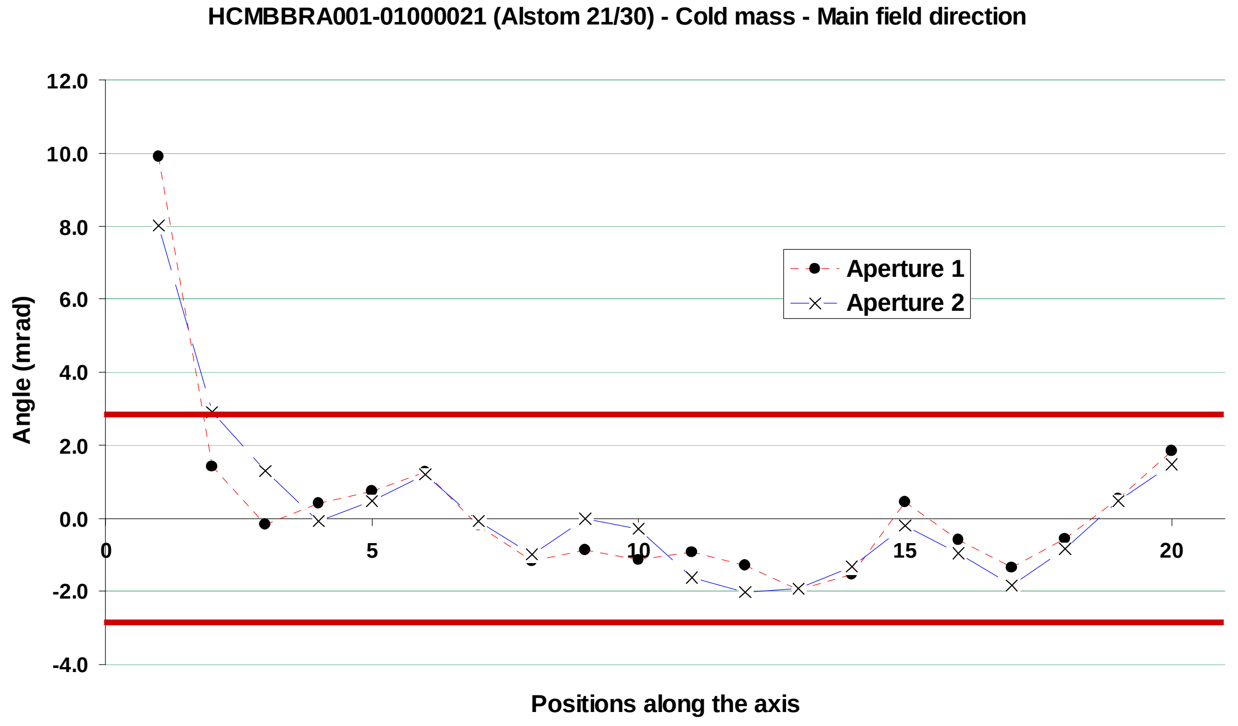
Large twist large correlation

- Magnet 1021 unwelded: problems with welding press
- Magnet remeasured after reweld: Result ok!
- Trend stopped



M.Bajko

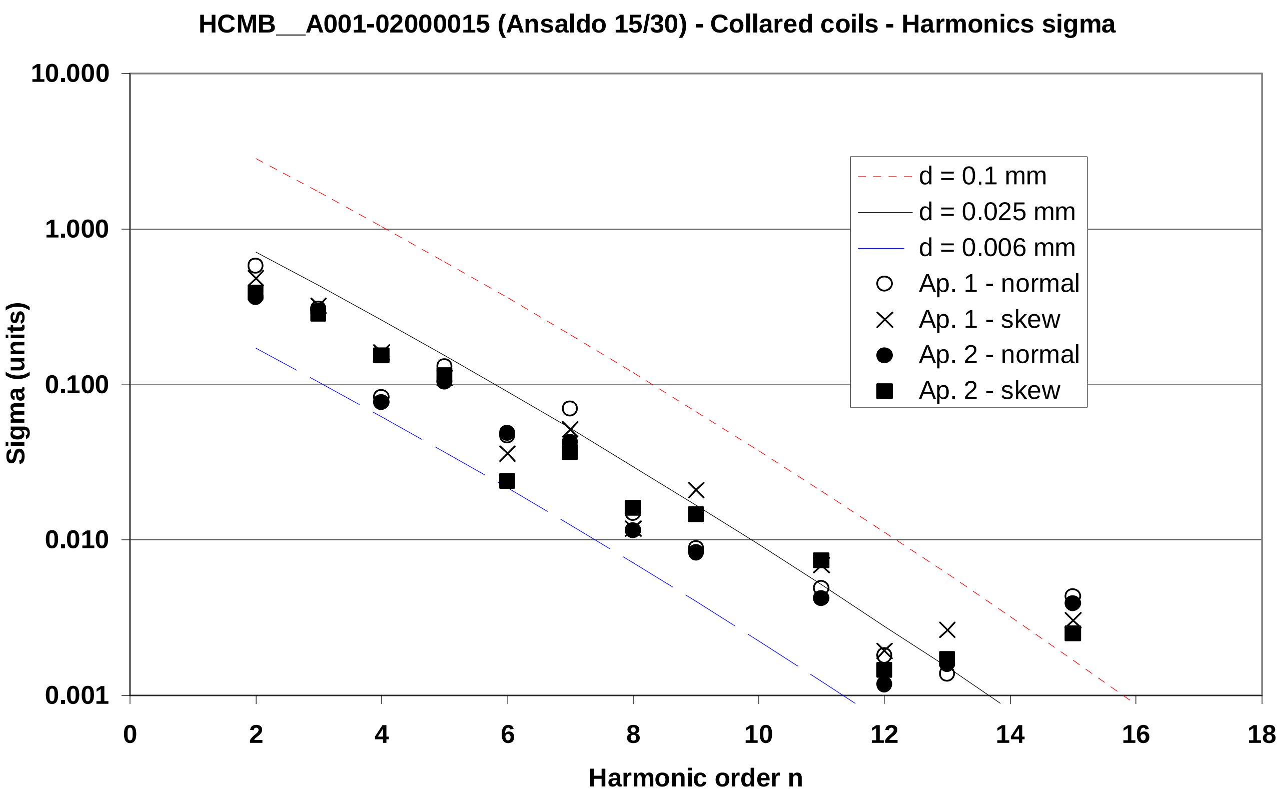
Twist of cold mass: result for rewelded magnet



Quality Control: Coil waviness from measurements

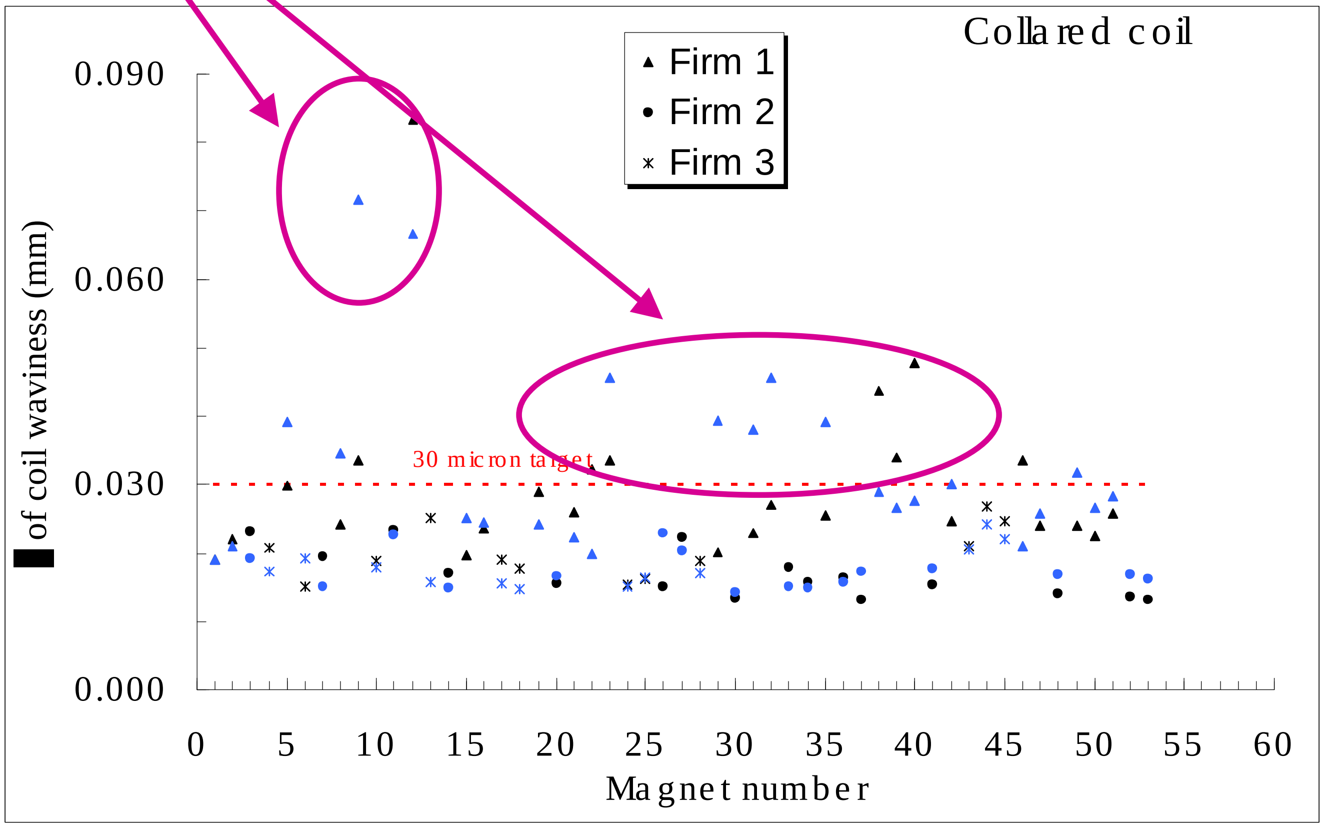
The standard deviation of multipoles along the axis are best fitted with parabola worked out through simulations (random movement of blocks)

We extract the amplitude of the random movement giving that pattern of the standard deviation (usually around 20-30 microns)



Quality Control: Warning to firms (coil waviness)

Firm 1 showed in several collared coils a coil waviness along the axis above what obtained from Firm 2 and 3 (up to 80 μm instead of 15-20 μm) - actions on curing mould - problem not yet solved - not critical for beam dynamics, but bad quality of assembly



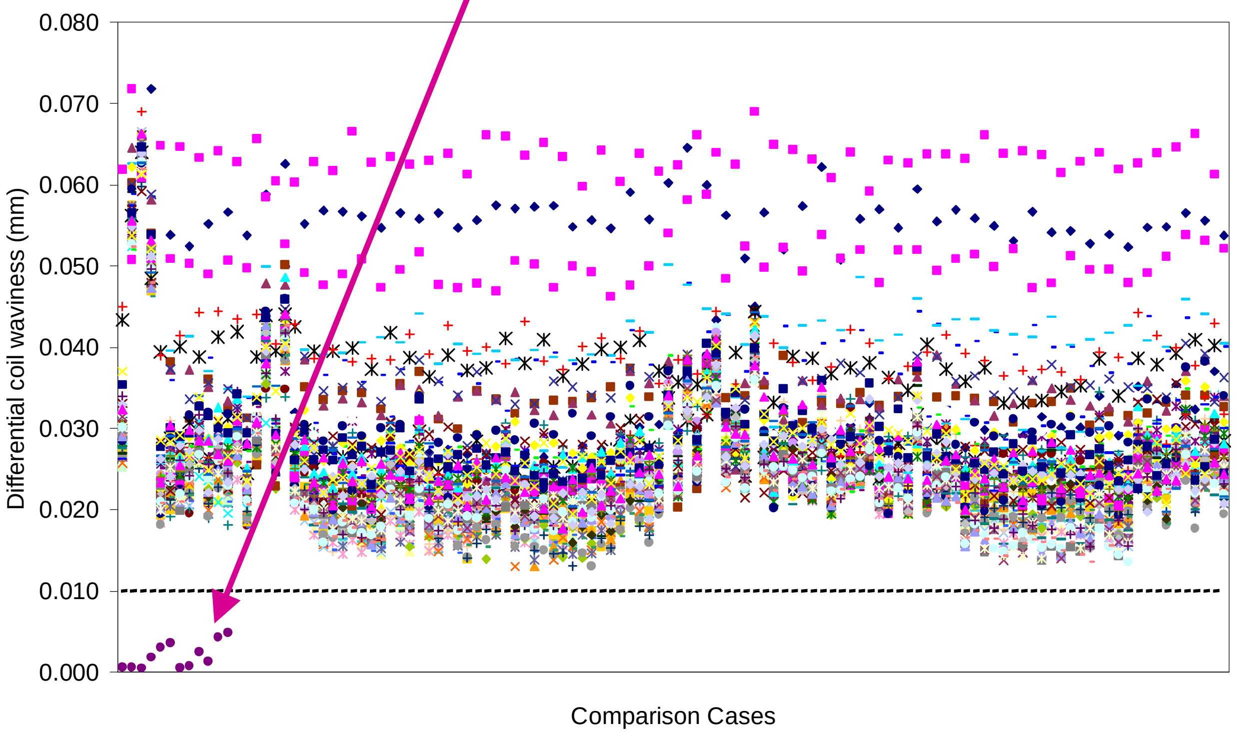
Coil waviness: Magnet Fingerprint

Problem: how to recognize if a new measurement refers to a magnet already in the database (This already happened) ?

An elegant solution based on coil waviness (S. Pauletta):

difference of two measures - extraction of 'differential' coil waviness -

if less than 10 microns, then it is the same magnet



Works also between collared coil and cold mass

A program (G.Bevillard) extracts all measurements from the database and calculates the differential coil waviness

Conclusion

- We have a method for dealing with statistical control and trend analysis of the dipole production:
  - Magnetic field of collared coil and cold mass
- Data in relational database to make rapid checks and log
- We have been able to detect measurement problems and problems with assembly:
  - Remeasurements and reassembly
- We believe our procedures will permit to check and steer production of the dipole (magnetic field)

Acknowledgements

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