Report on field quality in the main LHC dipole collared coils and cold masses: March-April 2004

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This report gives data relative to field quality measured in collared coils and cold masses during the period March 1– April 30 2004, comparison to beam dynamics targets and status of the holding points. Updated graphs can be found in the LHC-MMS field quality observatory http://lhc-div-mms.web.cern.ch/lhc-div-mms/MMSPAGES/MA/Obs.html.

EDMS n. **473453**

The dashboard

- Available measurements: 386 collared coils, 322 cold masses, 86 cryodipoles[1].
- In these two months, 67 collared coils: 24 from Firm1, 12 from Firm2 and 31 from Firm3.

What's new

- **Production rate** is at 33 collared coils per month. The problem of the previous months in Firm3 has been solved (see also Fig. 1 at pg. 3). Firm3 is now at 3.5 collared coils per week. A large increase of production rate is also observed in Firm1 (3 collared coils per week). Firm2 is at 1.5 collared coils per week.
- **Length of feedback loop:** The minimal delay between collared coil magnetic measurements and cold tests is 2.5 months (obtained for 3038).
- **Cold tests:** only three more magnets measured and analysed in these two months.
- **Coil size:** The situation at Firm1, where large coil sizes had to be compensated by non-nominal shims of larger thickness up to 0.2 mm, is improving. In these two months we only had a few cases of non-nominal shims.
- **Switch to cross-section 3:** the addition of 0.125 mm insulation (X-section 3) in the coil mid-plane is the baseline, and all manufacturers are producing X-section 3.
- **Trends in main field:** collared coil data of the more recent production show again an increase in spread of the transfer function (see Fig. 9, pg. 7). Integrated transfer function in cold masses is anyway well within targets (see Fig. 12, pg. 8).
- **Trends in odd multipoles:** we continue to have small positive trends in b_3 b_5 and b_7 (see Figs. 13-16, pg. 9 and 10).
- **Trends in even multipoles:** b_2 is approaching the limit imposed by beam dynamics (see Figs. 17-18, pg. 11).
- **Trends in skews:** the situation for the systematic a_4 in Firm2 is worsening (see Figs. 25, pg. 15). We have a systematic component of about 0.5 units in the more recent production.
- **Assembly faults:** we are facing a worrying increase of the assembly faults detected with magnetic measurements. In these two months, 4 decollarings have been asked and 2 additional measurements with the short mole are still to be done. At the same time, decollarings of 2035, 2065, 3175 have proved that the analysis was correct. The rate of assembly defects in the first four months of the year is 8%, which is clearly not acceptable for a mature phase of the production. Actions are being taken to understand this quality degradation.

[1] These numbers refer to complete measurements available in Oracle databases

CONTENTS

The new format of the report

We changed the format of the report and of most of his plots to better adapt it to this phase of the production. This report and the following ones are organized as follows

- The first section deals with the number of measured magnets in the last two months and the assembly data (X-section type and shim size). Its structure is unchanged with respect to the previous reports.
- The summary of the measured field quality of all collared coils versus beam dynamics targets has been shifted to the second Section. This gives a quick overview of the status of field quality versus beam dynamics computed over all the collared coils.
- The largest section has been devoted to trends in field quality.
  - The previous plots, that were showing measured field quality versus magnet progressive number[2], have been replaced by graphs with moving averages (one per firm). Each marker is the average of 5 measurements:
    - the collared coil characterized by the progressive number in the horizontal axis
    - the two collared coils previously produced by the same firm
    - the two collared coils produced afterwards by the same firm

    With this smoothing of the data, we lose the detail of the individual magnet, but we gain a better visualization of trends in the production.
  - We dropped the separation between apertures (except for the case of b2 and b4) since data of the previous reports show that the difference is negligible
  - We added plots for the bending strength in cold masses, since these measurements are giving important additional information on this critical parameter. When comparing these plots to collared coils, one has to take into account that usually the last 70 collared coils have not yet become cold masses, and therefore a different pattern has to be expected in the end of the plot.
  - We dropped the plot with the reduction to nominal shims for main field, b5 and b7 since in this phase of the production (shims nominal within 0.1 mm) the impact on non-nominal shims is relevant only for b3.
  - Cold mass data are shown only for the bending strength, since for the multipoles they are adding little information to what measured in collared coils.
- The final Section is devoted to field quality used to detect a faulty assembly procedure. We added a summary plot of the faulty assemblies found with magnetic measurements, and the cases occurred during the two months are briefly discussed. The plot of coil waviness, previously in Section 1, is also given.
- A list of magnets and special topics (when present) are given in the Appendix.

[2] We recall the definition of magnet progressive number, used as horizontal axis in most of our trend plots: it is a number running from 1 to 1232 which is associated to each magnet, according to the date of collaring.

PART I: MEASURED MAGNETS AND ASSEMBLY DATA

- 67 new collared coils have been measured (collared coils 320th to 386th).
  - 24 of Firm1 (1101-2,1105-26).
  - 12 of Firm2 (2065,2067, 2068, 2074-80,2082,2083)
  - 31 of Firm3 (3135, 3150-52, 3154-58, 3160-68, 3170-81,3183)

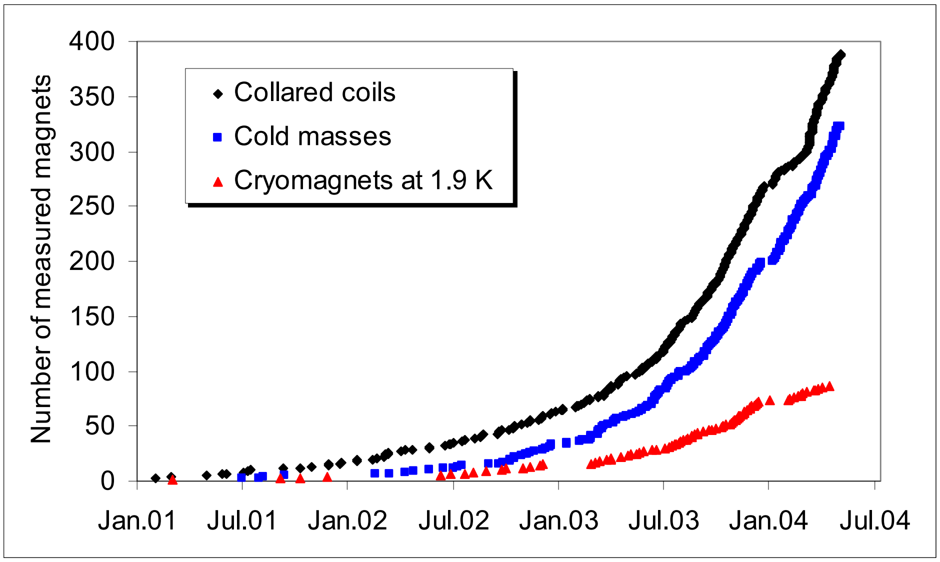


Fig. 1: Number of magnets measured at CERN at 1.9 K and at the manufacturers at room temperature at different stages of assembly procedure

- Cross-section: all the 67 collared coils have X-section 3.
- Shims are nominal in Firm2 and in Firm3. The situation of coil size is improving in Firm1: nominal shims are mostly used for outer layer and thinner shims of 0.05 mm are used for the inner layer (only one case of 0.1 mm thinner shim).

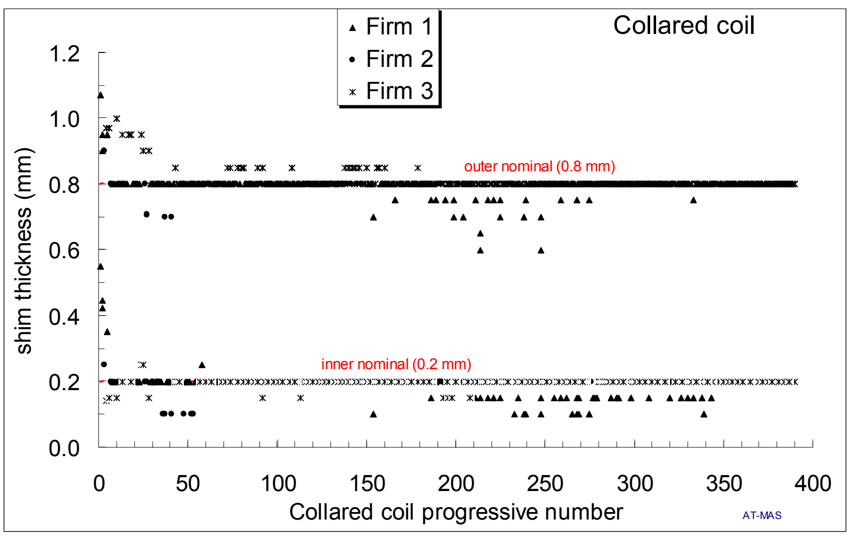


Fig. 2: Thickness of the polar shims used in the collared coils

PART II: MEASUREMENTS VERSUS BEAM DYNAMICS TARGETS

2.1 Summary of systematics components

- Best estimates of skew and even normal systematics are given in Fig. 3, with an error at 95% confidence limit (two sigma). All the multipoles are within specifications. Details on trends are given in Part III.

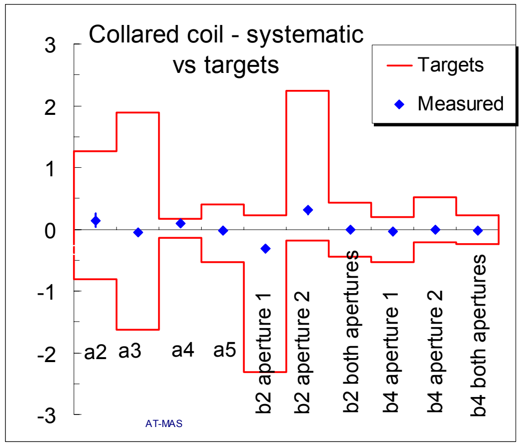
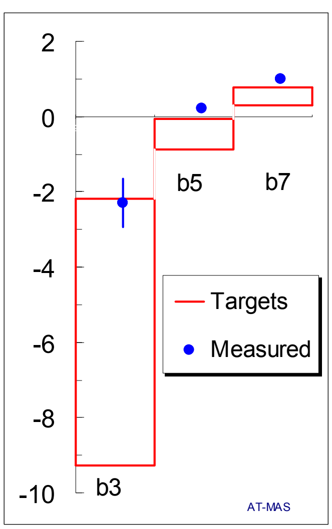


Fig. 3: Best estimate for systematic skew multipoles and even normal multipoles (markers) versus beam dynamics limits (red line). An error of two sigma (95% confidence limit) is associated to the best estimates of systematics.

- Best estimates for systematic odd normal multipoles are shown in Fig. 4. In the left part, raw data are plotted. This gives the actual situation for global values relative to all manufactured collared coils, which are slowly moving towards optimal ranges: b_3 is now within target and b_5 is larger than the upper target of 0.25 units.
- In the right part of Fig. 10, data are reduced to nominal shims and separated according to the three cross-sections (34 collared coils have cross-section 1, 138 have cross-section 2, 217 have cross-section 3, plus one hybrid 1-2). With cross-section 3, b_3 is within targets, 1.15 units below the upper limit (i.e., 1.85 units at high field), and also b_5 is within targets, at the edge of the upper limit (i.e., 1.1 units at injection). Finally, b_7 is 0.25 units larger than the limits (i.e. 0.31 units at injection). A small positive drift is being observed for these three normal odd multipoles, see also Section 3.2



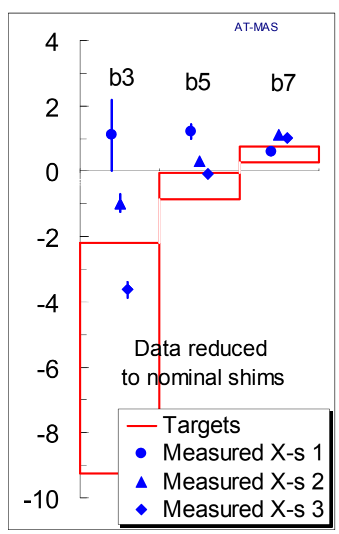


Fig. 4: Best estimate for systematic odd normal multipoles (markers) versus beam dynamics limits (red line). An error of two sigma (95% confidence limit) is associated to the best estimates of systematics. Raw data (left) and data reduced to nominal shims and separated according to different cross-sections (right).

2.2 Summary of random components

- We evaluate the standard deviation of the bending strength and multipoles for all Firms and separated according to different Firms. We analyse only magnets with cross-section 3 (217 collared coils). Standard deviation of multipoles in collared coil are divided by 1.18 to give the best estimate of the random due to geometric in the cold mass, and compared to the target for the beam dynamics (**whose budget includes also the random components induced at 1.9 K**). All values are well within targets, with the exception of main field in straight part B and b3 at Firm1, whose large spread is induced by non-nominal shims.

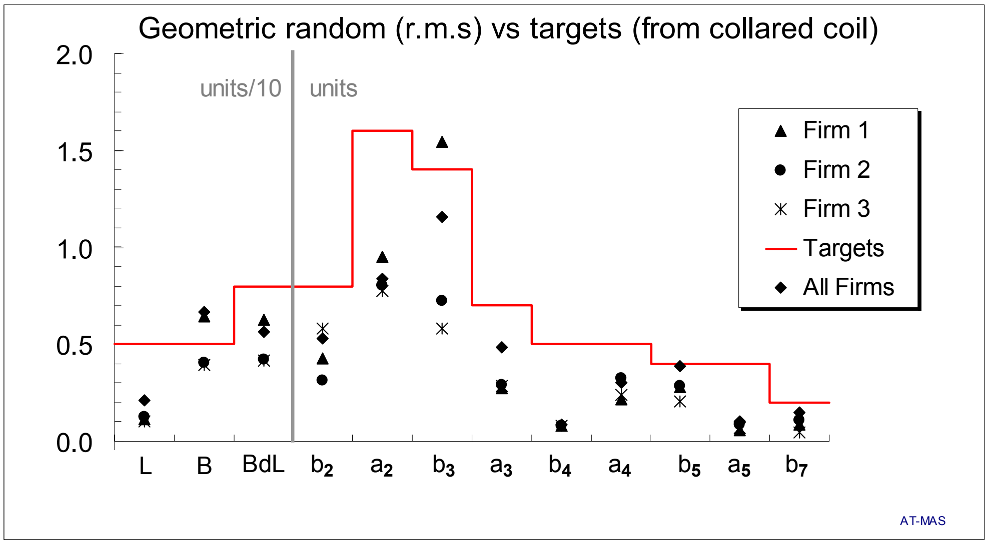


Fig. 5: Random component in the measured collared coils and rescaled to cold mass values, cross-section 3 only compared to targets for random at 1.9 K.

- We give an estimate of the actual spread due to the geometric component in the first two arcs. The first arc is made up of magnet with R polarity (141 collared coils available, 31 cross-section 1 and 110 cross-section 2) and the second of L polarity (25 cross-section 2 and the others of X-section 3)
- The spread of the first arc is out of target only for b3 and b5. This is mainly due to the use on non-nominal shims and to the change from X-section 1 to X-section 2.
- In the second arc all values are within targets. The situation for b3, which is on the edge (i.e. the geometric is eating all the budget for the random at 1.9 K), will improve for the next octants where magnets of cross-section 2 will not be present any more.

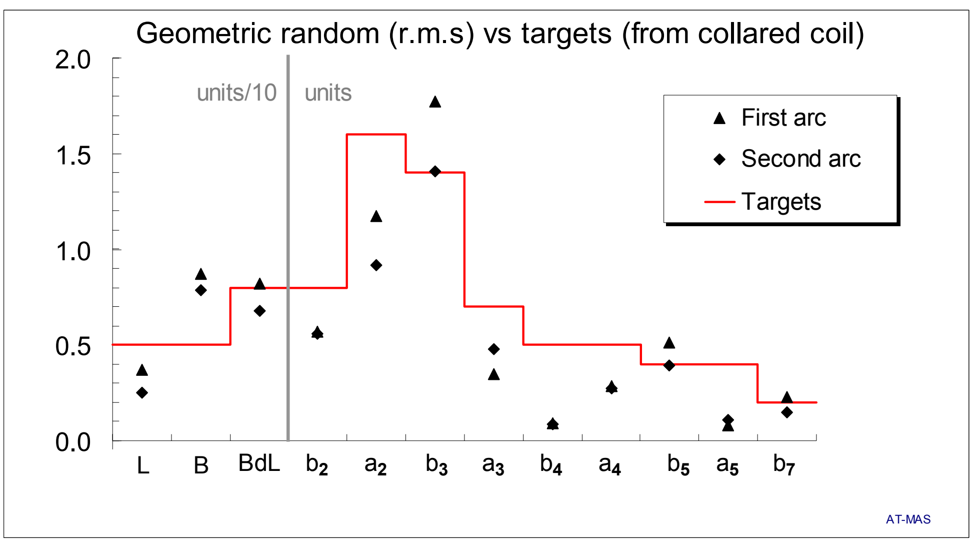


Fig. 5: Random component in the measured collared coils (rescaled to cold mass), for the first and second arc, compared to targets for random at 1.9 K.

PART III: TRENDS IN FIELD QUALITY

3.1 Trends in bending strength

3.1.1 Trends in magnetic length

- Magnetic length of the recent production of collared coils is extremely stable in all Firms (see Fig. 7). Magnetic length in Firm 1 is 3-4 units higher than in Firm2 and Firm3.

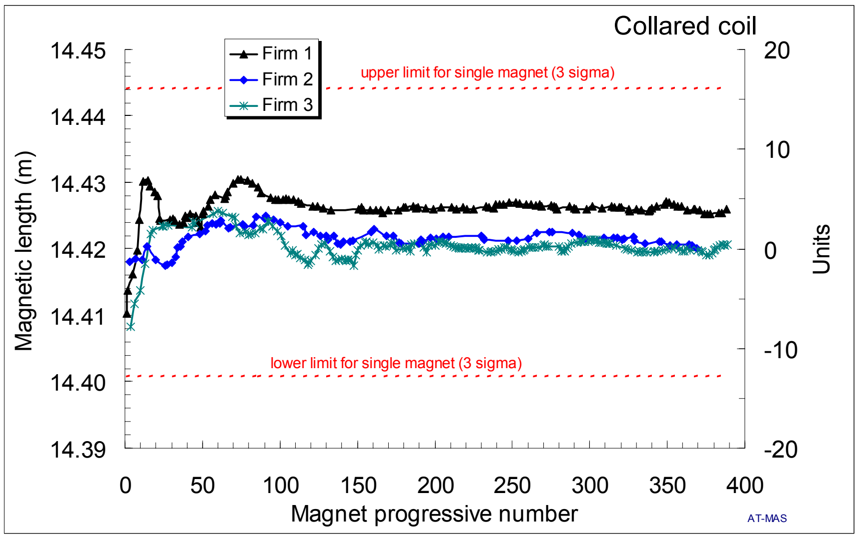


Fig. 7: Magnetic length of the measured collared coils, separated per Firm (each dot is average of 5 consecutive magnets of the same firm).

- Magnetic length of the recent production of **cold masses** is also extremely stable in all Firms (see Fig. 8). When iron laminations are added, magnetic length in Firm3 is getting smaller than in Firm1 and 2. The net result is that there are around 8 units of difference between Firm1 and Firm3, and Firm2 is in between.

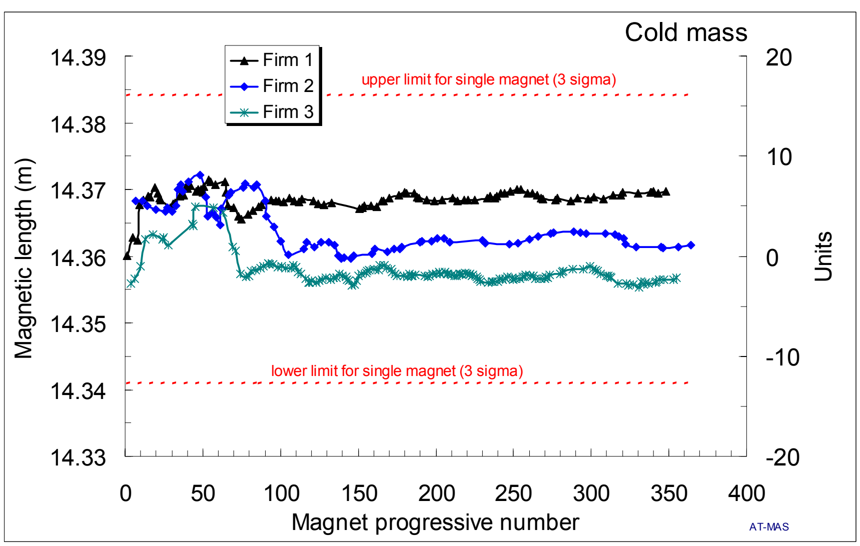


Fig. 8: Magnetic length of the measured **cold masses**, separated per Firm (each dot is average of 5 consecutive magnets of the same firm).

3.1.2 Trends in transfer function

- Transfer function in collared coils 320th to 386th is decreasing at Firm1, and is rather stable in Firm2 and Firm3 (see Fig. 9). Firm1 transfer function in collared coils is around 10 units less than in Firm2 and Firm3.

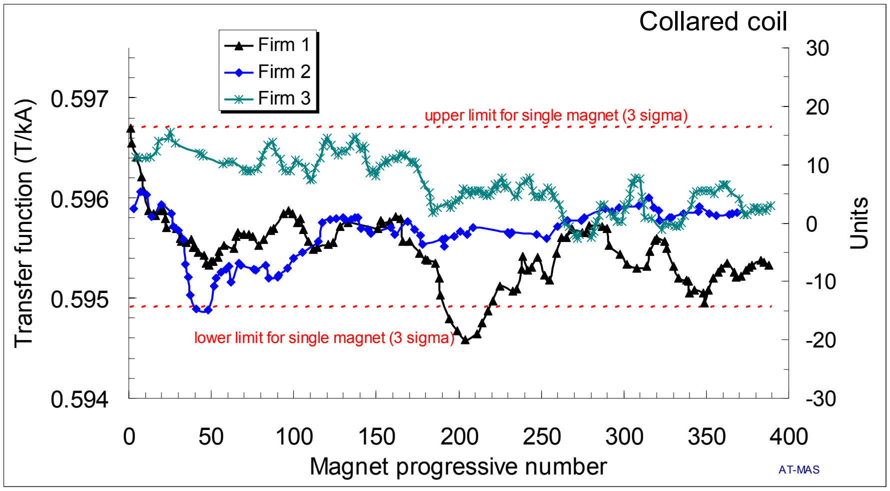


Fig. 9: Transfer function of the measured collared coils, separated per Firm (each dot is average of 5 consecutive magnets of the same firm).

- The systematic difference in transfer function between firms observed in collared coils is confirmed, but slightly reduced, in **cold mass** data (see Fig. 10).

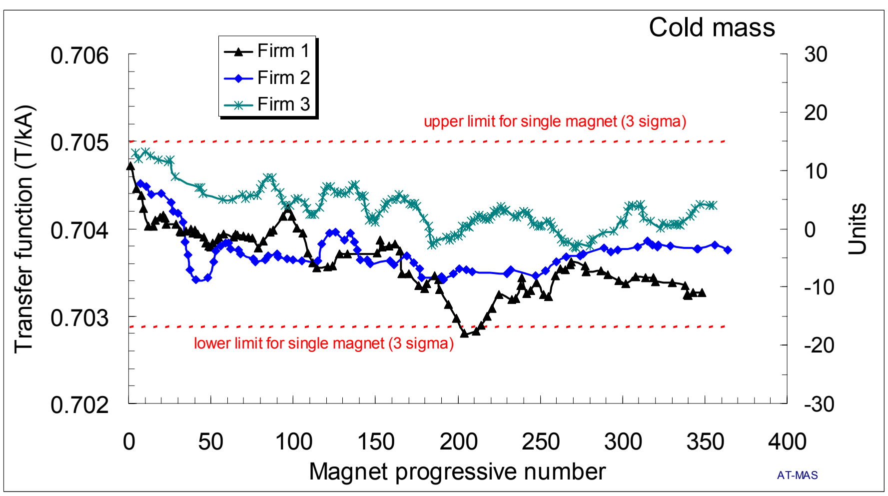


Fig. 10: Transfer function of the measured **cold masses**, separated per Firm (each dot is average of 5 consecutive magnets of the same firm).

3.1.3 Trends in integrated transfer function

- Due to the compensation between the lower transfer function in Firm1, and the longer magnetic length, the integrated transfer function shows a rather low spread between firms (10 units) in recent production (see Fig. 11).

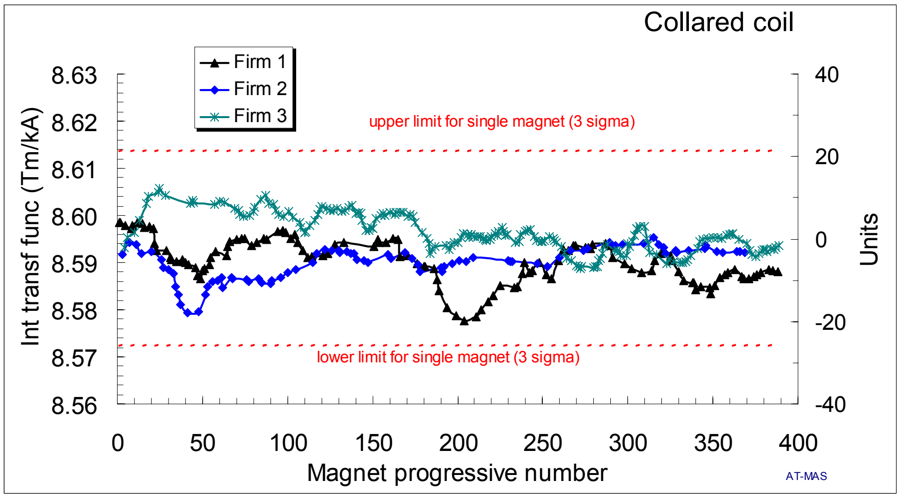


Fig. 11: Integrated transfer function of the measured collared coils, separated per Firm (each dot is average of 5 consecutive magnets of the same firm).

- In the **cold masses** data the spread of integrated transfer function between firms is further reduced (see Fig. 12). Trends in the more recent production are negligible.

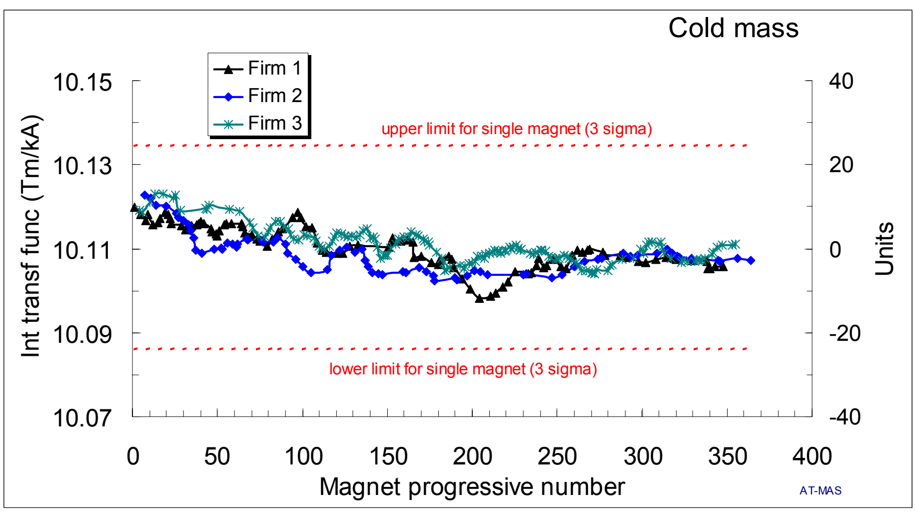


Fig. 12: Integrated transfer function of the measured **cold masses**, separated per Firm (each dot is average of 5 consecutive magnets of the same firm).

3.2 Trends in odd multipoles

- Normal sextupole is within targets in all Firms (see Fig. 13). Production is very stable in Firm2 and Firm3. Low values of b3 in Firm1 are mainly due to non-nominal shims (see Fig.14, where this effect is subtracted). Cross-section 3 has been introduced at magnet progressive number 170 approximately.
- Collared coils produced in March and April 2004 (320^{th} to 386^{th} in Figs. 13 and 14) have a b3 which is placed 1 to 2 units below the upper target, which is the optimal for beam dynamics.
- The last collared coils of Firm1 and Firm3 are approaching the upper target: this trend should be carefully monitored.

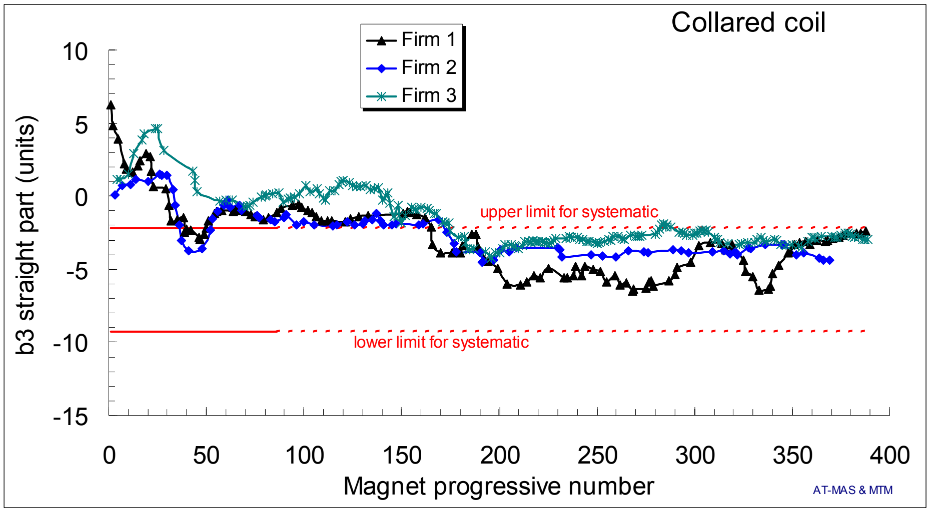


Fig. 13: Average b3 in straight part of the collared coils, separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles.

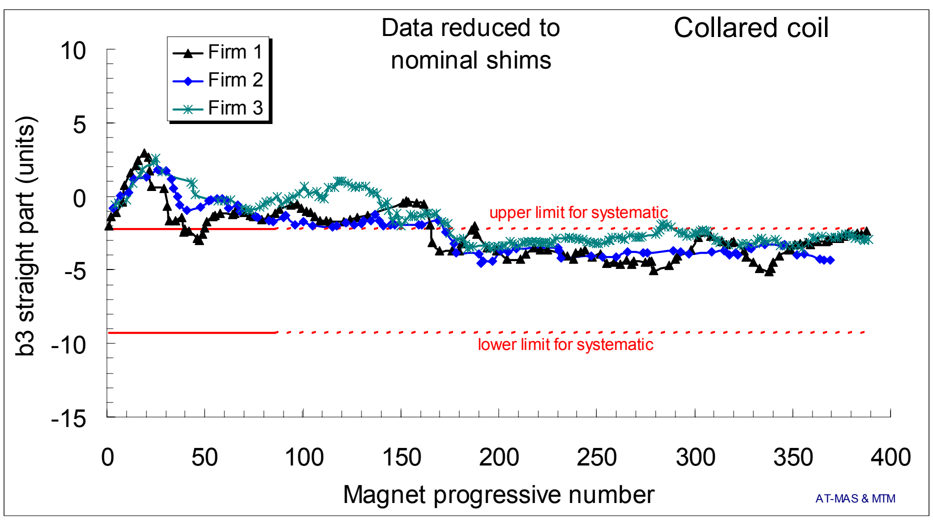


Fig. 14: Average b3 in straight part of the collared coils, separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles. Data reduced to nominal shims

- Firm2 and Firm3 have a normal decapole b5 within targets, whereas Firm1 is around 0.8 units larger than upper target (see Fig. 15).
- We observe an upward trend of b5 in Firm3 in the more recent production. As for b3, these trends should be carefully monitored.

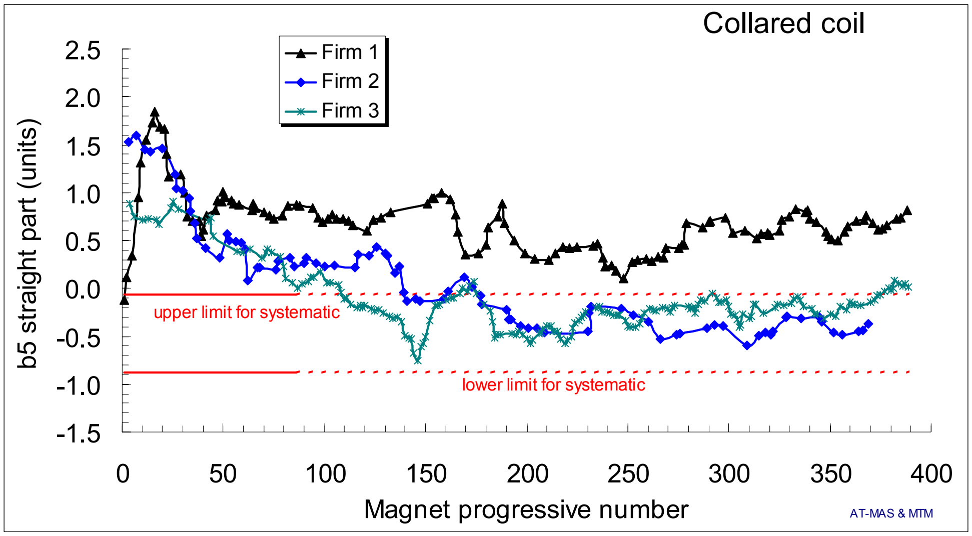


Fig. 15: Average b5 in straight part of the collared coils, separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles.

- Normal 14th pole b7 is larger than targets in Firm1 and Firm3, and on the upper target in Firm2 (see Fig. 16). It is stable in Firm3, and has upward trends in Firm2 and Firm3.

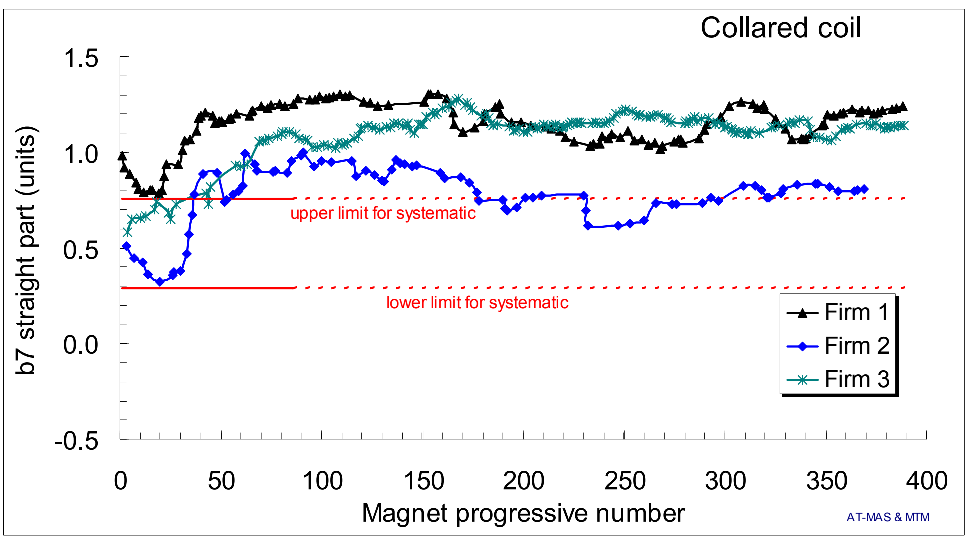


Fig. 16: Average b7 in straight part of the collared coils, separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles.

3.3 Trends in even multipoles

For each multipole being subject to beam dynamics specifications, we present two separated plots for the systematic per aperture, plus a plot of the systematic per beam, i.e. the average of both apertures (that should be zero due to two-in-one symmetry).

3.3.1 Trends in normal quadrupole

- The systematic per aperture is drifting towards the limit (see Figs. 17 and 18). A corrective action could become necessary. A change of the insert shimming would be probably the easiest in this phase of the production. Some experience has been already acquired on 1002 and 1005, which had no "Chinese hat" between insert and yoke.
- We observe a strong correlation between the two apertures in Firm3 (firstly pointed out by I. Vanenkov).

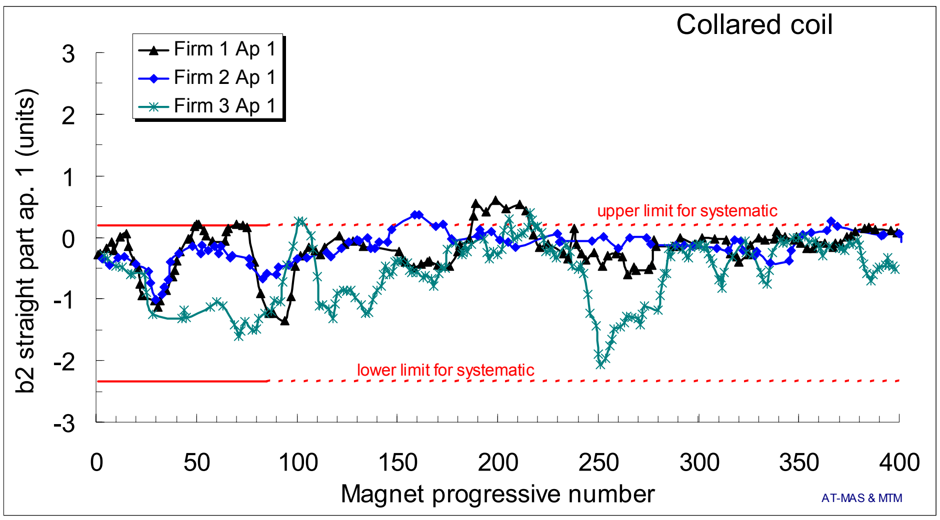


Fig. 17: Average b2 in straight part of the collared coils (Aperture 1), separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles.

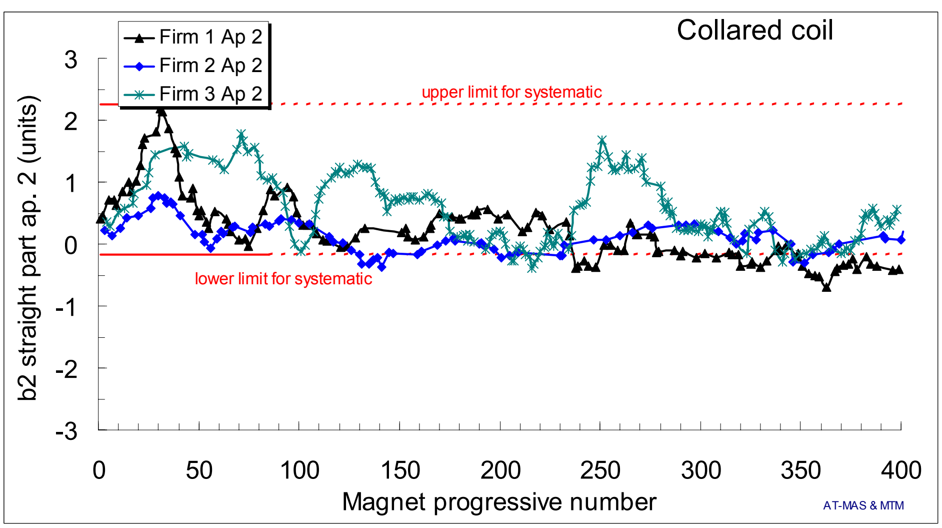


Fig. 18: Average b2 in straight part of the collared coils (Aperture 2), separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles.

- The systematic normal quadrupole per beam is within specifications (see Fig. 19).

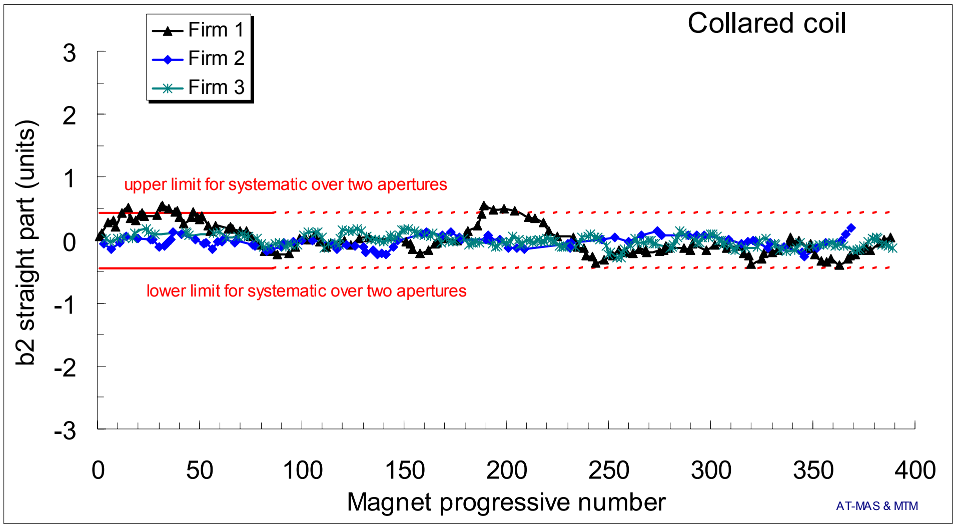


Fig. 19: Average b2 in straight part of the collared coils (both Apertures), separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles.

3.3.2 Trends in normal octupole

- The systematic per aperture is within specifications in both apertures (see Figs. 20 and 21).
- The systematic per beam is also within specifications (see Fig. 22).

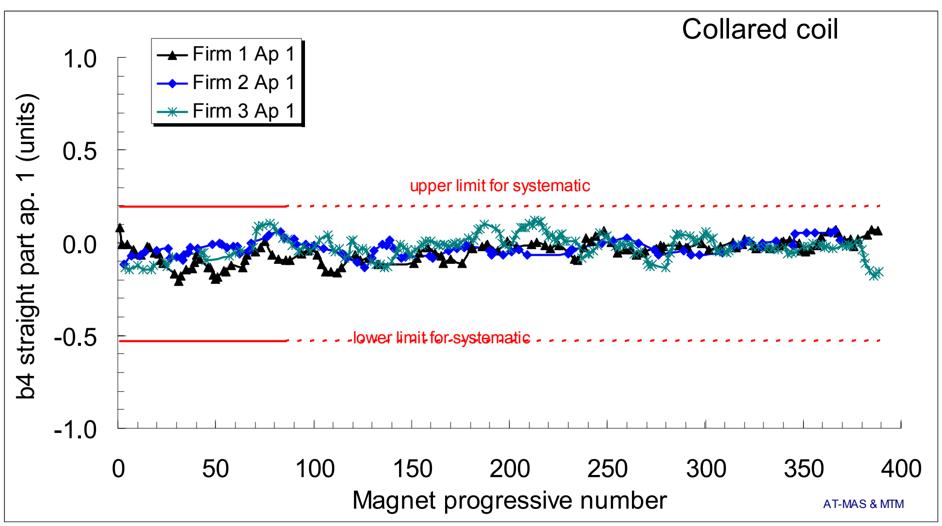


Fig. 20: Average b4 in straight part of the collared coils (Aperture 1), separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles.

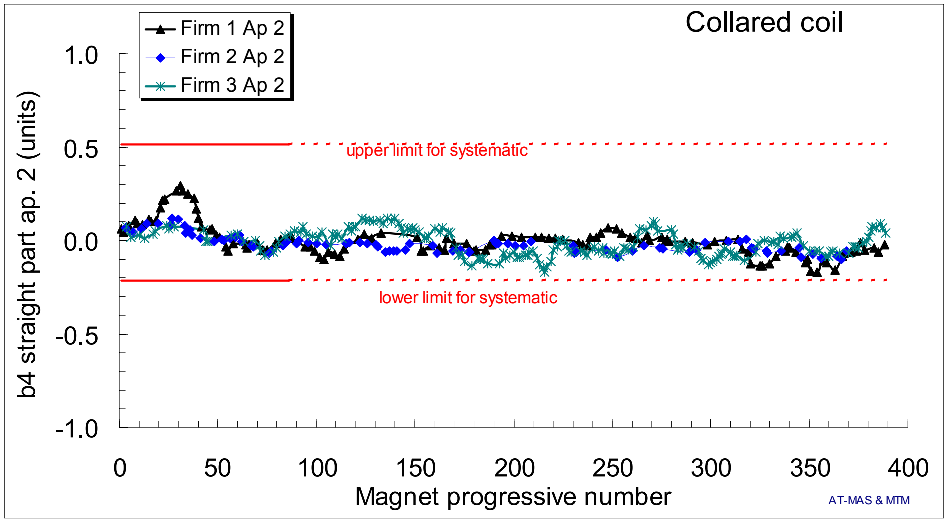


Fig. 21: Average b4 in straight part of the collared coils (Aperture 2), separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles.

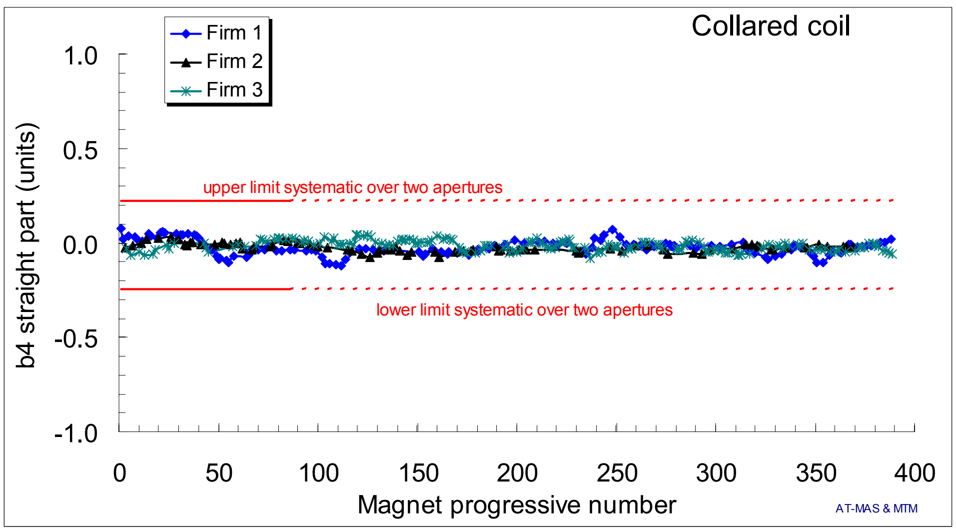


Fig. 22: Average b4 in straight part of the collared coils (both Apertures), separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles.

3.4 Trends in skew multipoles

- Skew quadrupole a2 is well within targets, and no trends are observed (see Fig. 23).

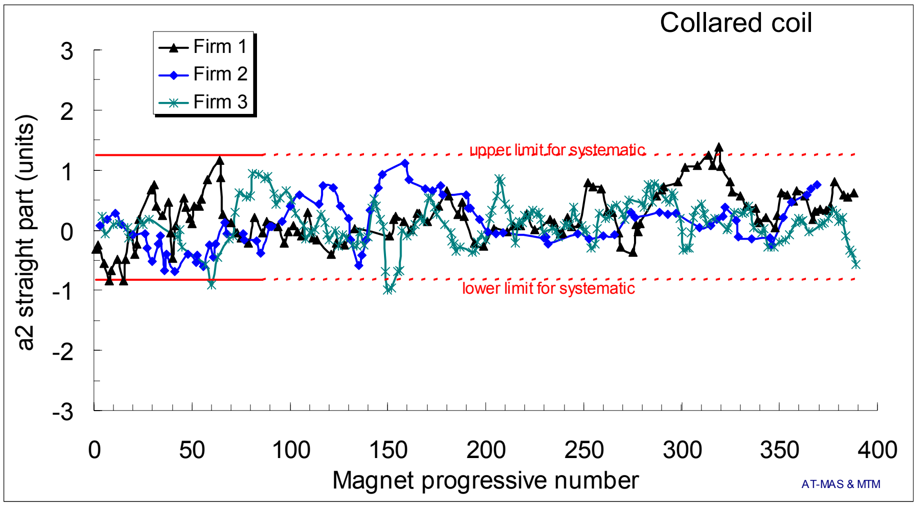


Fig. 23: Average a2 in straight part of the collared coils, separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles.

- Skew sextupole a3 is well within targets (see Fig. 24). There is a positive systematic component in Firm3 (around 0.8 units), and a slightly negative component (around 0.25 units) in Firm1 and Firm2. Indeed, beam dynamics targets are very loose, and therefore there is no concern on this multipole.

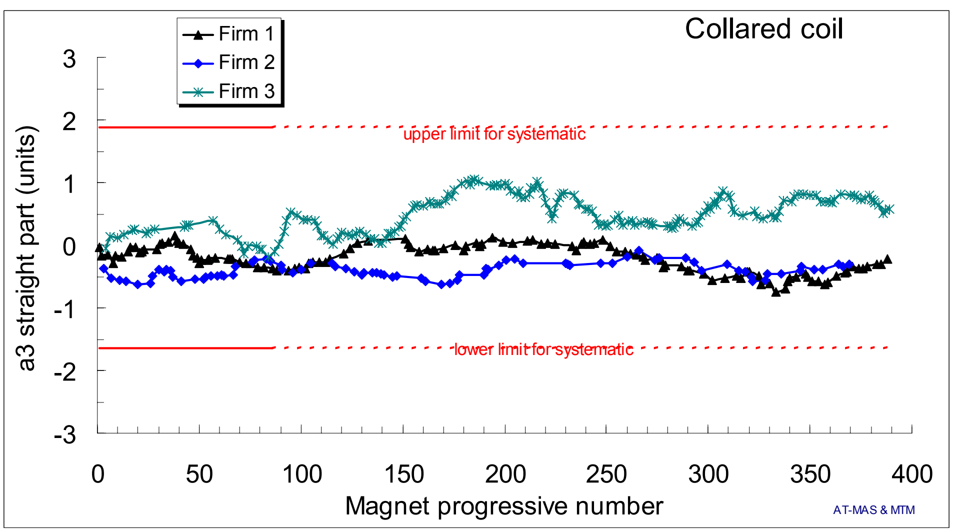


Fig. 24: Average a3 in straight part of the collared coils, separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles.

- Skew octupole a4 is within the tight beam dynamics targets for Firm1 and Firm3 (see Fig. 25). There is a positive systematic component in Firm2 (around 0.5 units) that could drive the systematic at the edge of the allowed range. Investigations about origins and possible cures are under analysis.

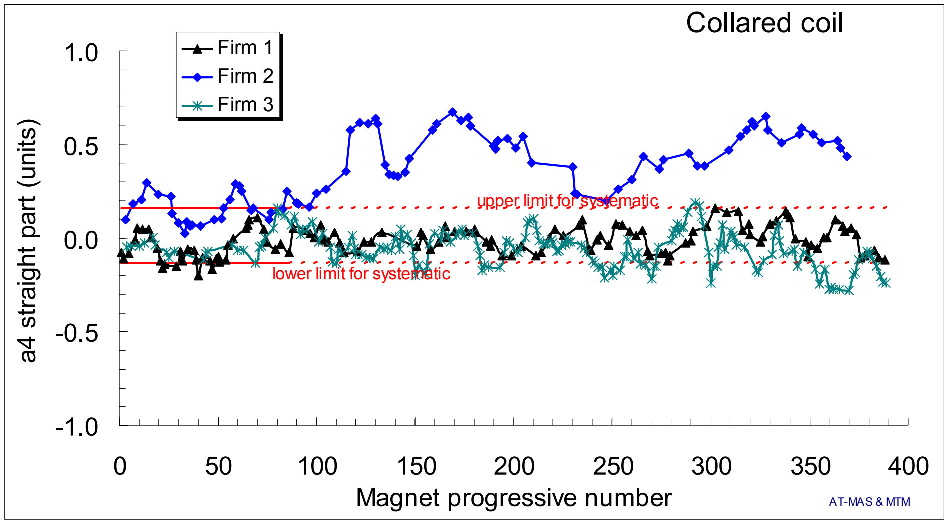


Fig. 25: Average a4 in straight part of the collared coils, separated per Firm (each dot is average of 5 consecutive magnets of the same firm), and beam dynamics targets for the systematic (red lines) based on correlations with 86 cryodipoles.

3.5 Trends in systematic differences between firms

The more relevant signature of Firms is in b_7.

- Normal 14th pole: b_7 at Firm2 is 0.5 units lower than Firm2 and Firm1 (see Fig. 16). This difference is four times the natural sigma within the same manufacturer measured in cross-section 3. Firm2 is within targets, whereas both Firm1 and Firm3 are outside.

We observe a small systematic difference between firms (from one to two times the natural sigma within the same manufacturer) in the following cases.

- Normal decapole b_5: Firm1 has a systematic b_5 of 0.8 units larger than Firm2-3. This difference is two times the natural sigma within the same manufacturer (see Fig. 15). Firm2 and Firm3 are within targets, whereas Firm1 is outside.
- Skew sextupole a_3: Firm3 has a systematic a_3 of 0.49 units, against –0.41 units in Firm2, Firm1 being at -0.16 units (see Fig. 24). This difference is two-three times the natural sigma within the same manufacturer. All Firms are within targets
- For the transfer function, Firm1 is showing values 10 to 15 units smaller than Firm2 and Firm3 (see Fig. 9). This difference is one to two times the natural sigma within the same manufacturer.
- Skew octupole a_4: Firm2 has a systematic a_4 of 0.37 units, against 0.0 to –0.07 units in Firm3 and Firm1 (see Fig. 25). This difference is equal to the natural sigma within the same manufacturer. Firm1 and Firm3 are within targets, whereas Firm2 is outside.

Systematic differences between firms are small or negligible in a_2, b_2 b_3 and b_4.

PART IV: QUALITY CONTROL

4.1 Summary of assembly defects

The following 8 decollarings have been asked for anomalies in magnetic measurements that, according to simulations, could be traced back to defects in the assembly procedure or in the components. In all cases the defect has been found.

- 2002, collared in July 2001, opened in July 2001. Bad assembly: a double coil protection sheet;
- 1027, collared in October 2002, opened in November 2002. Bad assembly: a missing outer shim;
- 2032, collared in May 2003, opened in November 2003. Bad coil curing: block 6 not glued to the copper wedge;
- 2035, collared in July 2003, opened in April 2004. Bad coil curing: block 6 not glued to the copper wedge;
- 3135, collared in January 2004, opened in February 2004. Bad assembly: block 6 pushed inward by a folded outer shim;
- 1099, collared in February 2004, opened in March 2004. Bad coil curing: block 6 not glued to the copper wedge;
- 2065, collared in February 2004, opened in April 2004. Bad coil curing: block 6 glued in a wrong position (0.5 mm inward) to the copper wedge;
- 3175, collared in May 2004, opened in May 2004. Bad coil curing: block 6 not glued to the copper wedge.

Two more magnets from Firm2 and one from Firm1 have to be decollared. The plot in Fig. 26 summarizes these defects found along the production. From Fig. 27 one can observe that after a quiet period of the production (from collared coil 120th to 300th), where no defect were found, the recent manufactured collared coils have a very high rate of defects (around 8%). This worrying situation is under analysis.

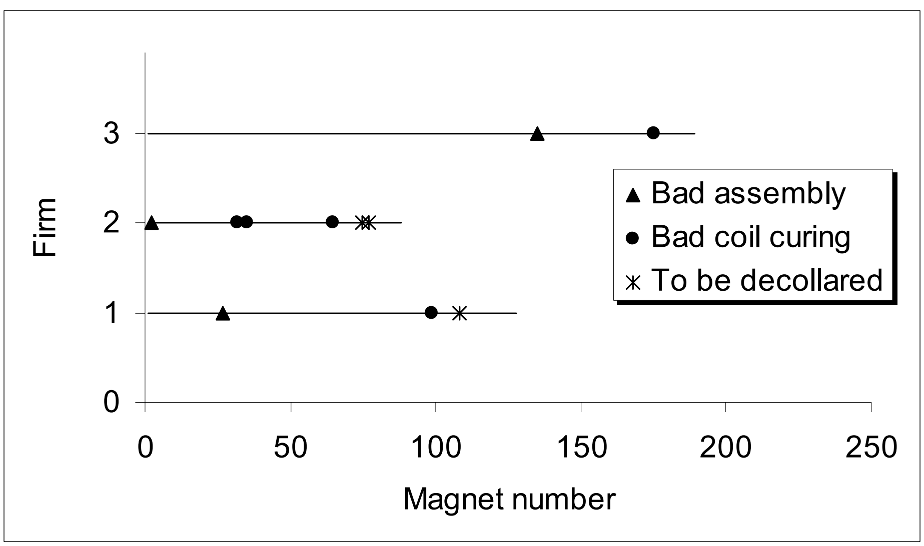


Fig. 26: Collared coils decollared for assembly defect or faulty component, divided according to Firm (y axis) and error type (markers), and total number of collared coils manufactured up to now (solid line).

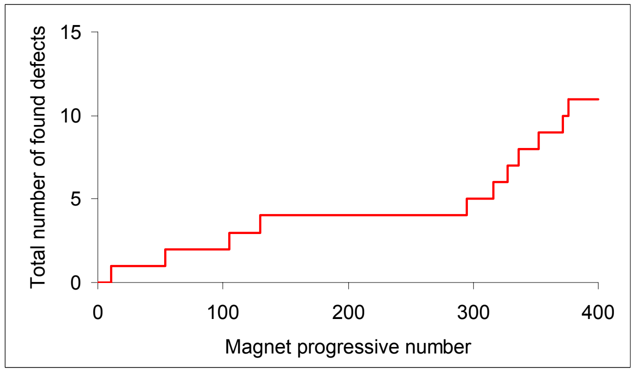


Fig. 27: Total number of defects found with magnetic measurements versus magnet progressive number.

4.2 Holding point results

In these two months, four collared coils have been not approved and de-collaring has been asked for assembly faults

- 2075, 2065, 2077 for estimated inward movements of block 6 of 0.5 to 1 mm in one or more section along the magnet axis
- 3175 for estimated inward movement of block 6 of 0.5 mm in two section along the magnet axis

Two collared coils are waiting for a measurement with the short mole to have more information on the defect.

- 1108 for a suspect missing thickness on outer layer pole
- 1122 for a suspect block 6 inward shift.

4.3 Estimated coil waviness

- Coil waviness estimated from the variation of the multipoles along the axis is below 30 microns. The general situation of this parameter is very good in all firms (see Fig. 28).

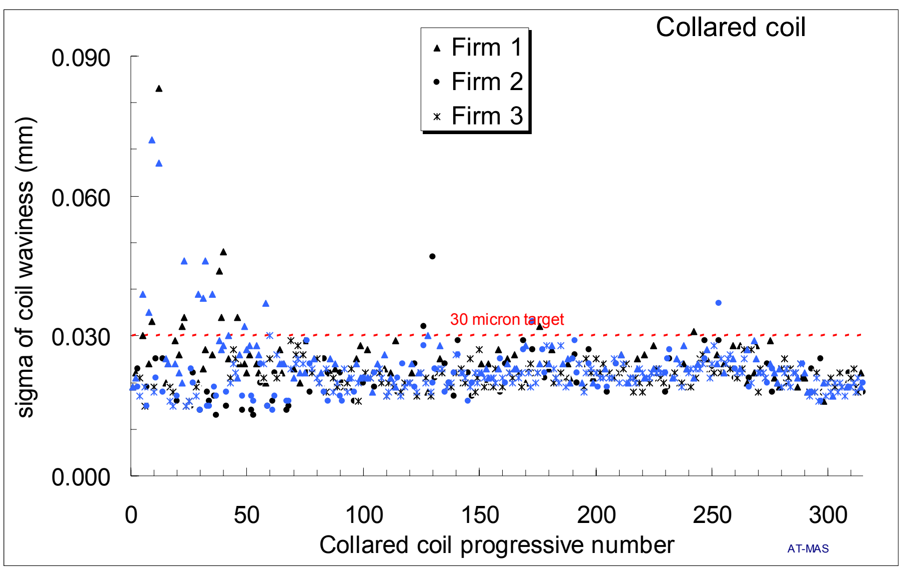


Fig. 28: Estimated coil waviness in the straight part of the measured collared coils (black dots: aperture 1, blue dots: aperture 2).

Acknowledgements

We wish to acknowledge all colleagues involved in the measurements at room temperature and at 1.9 K, and all the firm personnel. We thank W. Scandale and L. Rossi for useful comments on the novel format of the manuscript, and P. Hagen and C. Vollinger for data analysis and fruitful discussions.

Appendix A: collared coil assembly data

Table I: Magnet number, collared coil progressive number used in figures, and cross-section (data available on May 1 2004) for Firm1 and Firm2.

Magnet name	Progr. number	X-section	Magnet name	Progr. number	X-section	Magnet name	Progr. number	X-section	Magnet name	Progr. number	X-section
1001	1	1	1071	214	3	2001	3	1	2071	315	3
1002	2	1	1072	238	3	2002	11	1	2072	276	3
1003	5	1	1073	239	3	2003	7	1	2073	297	3
1004	8	1	1074	218	3	2004	20	1	2074	321	3
1005	9	1	1075	221	3	2005	14	1	2075	352	3
1006	12	1	1076	248	3	2006	30	1	2076	346	3
1007	15	1	1077	225	3	2007	27	1	2077	328	3
1008	16	1	1078	235	3	2008	26	1	2078	329	3
1009	19	1	1079	233	3	2009	34	1	2079	364	3
1010	21	1	1081	244	3	2010	33	1	2080	366	3
1011	22	1	1082	252	3	2011	56	1	2081	309	3
1012	23	1	1083	259	3	2012	37	2	2082	345	3
1013	29	2	1084	255	3	2013	36	2	2083	369	3
1014	31	2	1085	262	3	2014	41	2	2084	392	3
1015	32	1	1086	265	3	2015	61	2	2088	391	3
1016	35	2	1087	268	3	2016	48	2			
1017	38	2	1088	269	3	2017	52	2			
1018	39	2	1089	275	3	2018	53	2			
1019	40	2	1090	277	3	2019	59	2			
1020	64	2	1091	279	3	2020	62	2			
1021	42	2	1092	278	3	2021	67	2			
1022	47	2	1093	287	3	2022	68	2			
1023	49	2	1094	290	3	2023	76	2			
1024	50	2	1095	291	3	2024	126	2			
1025	51	2	1096	298	3	2025	77	2			
1026	46	2	1097	308	3	2026	83	2			
1027	54	2	1098	302	3	2027	85	2			
1028	55	2	1099	316	3	2028	90	2			
1029	58	2	1100	314	3	2029	91	2			
1030	65	2	1101	325	3	2030	96	2			
1031	66	2	1102	357	3	2031	100	2			
1032	70	2	1104	319	3	2032	105	3			
1033	73	2	1105	326	3	2033	131	2			
1034	75	2	1106	343	3	2034	117	2			
1035	79	2	1107	359	3	2035	130	3			
1036	82	2	1108	376	3	2036	115	2			
1037	86	2	1109	338	3	2037	122	2			
1038	88	2	1110	320	3	2038	137	2			
1039	97	2	1111	333	3	2039	141	2			
1040	102	2	1112	339	3	2040	145	3			
1041	99	2	1113	330	3	2041	139	2			
1042	106	2	1114	340	3	2042	135	2			
1043	186	2	1115	349	3	2043	147	3			
1044	121	2	1116	348	3	2044	159	2			
1045	94	2	1117	351	3	2045	201	3			
1046	104	2	1118	363	3	2046	253	3			
1047	109	2	1119	354	3	2047	232	3			
1048	158	2	1120	367	3	2048	161	2			
1049	112	2	1121	371	3	2049	190	3			
1050	114	2	1122	378	3	2050	177	2			
1051	154	2	1123	374	3	2051	247	3			
1052	124	2	1124	368	3	2052	169	2			
1053	153	2	1125	385	3	2053	178	3			
1054	162	2	1126	383	3	2054	173	3			
1055	133	2	1128	388	3	2055	191	3			
1056	181	2	1130	396	3	2056	209	2			
1057	128	2				2057	192	3			
1058	165	2				2058	197	3			
1059	151	2				2059	231	3			
1060	166	2				2060	260	3			
1061	170	3				2061	205	3			
1062	188	2				2062	230	3			
1063	176	3				2063	289	3			
1064	180	3				2064	266	3			
1065	242	3				2065	336	3			
1066	189	2				2066	274	3			
1067	211	3				2067	322	3			
1068	194	2				2068	356	3			
1069	204	3				2069	293	3			
1070	199	3				2070	318	3			

Table II: Magnet number, collared coil progressive number used in figures, and cross-section (data available on May 1 2004) for Firm3.

Magnet name	Progr. number	X-section	Magnet name	Progr. number	X-section	Magnet name	Progr. number	X-section
3001	4	1	3071	179	2	3141	299	3
3002	6	1	3072	168	2	3142	300	3
3003	10	1	3073	171	2	3143	301	3
3005	17	1	3074	172	2	3144	303	3
3006	18	1	3075	174	3	3145	306	3
3007	24	1	3076	175	2	3147	311	3
3008	25	1	3077	200	3	3148	310	3
3009	28	1	3078	184	3	3149	317	3
3010	57	1	3079	183	3	3150	331	3
3011	43	1	3080	182	3	3151	332	3
3012	44	2	3081	195	3	3152	360	3
3013	45	2	3082	213	3	3153	313	3
3014	60	2	3083	185	3	3154	350	3
3015	63	2	3084	193	3	3155	324	3
3016	69	2	3085	196	3	3156	323	3
3017	72	2	3086	198	3	3157	337	3
3018	71	2	3087	207	3	3158	342	3
3019	74	2	3088	208	3	3160	327	3
3020	80	2	3089	210	3	3161	334	3
3021	78	2	3090	212	3	3162	344	3
3022	81	2	3091	215	3	3163	335	3
3023	84	2	3092	216	3	3164	341	3
3024	87	2	3093	217	3	3165	353	3
3025	89	2	3094	219	3	3166	355	3
3026	108	2	3095	220	3	3167	358	3
3027	92	2	3096	222	3	3168	362	3
3028	93	2	3097	224	3	3170	365	3
3029	95	2	3098	223	3	3171	361	3
3030	98	2	3099	226	3	3172	370	3
3031	202	3	3100	227	3	3173	373	3
3032	203	3	3101	228	3	3174	379	3
3033	206	3	3102	403	3	3175	372	3
3034	101	2	3103	229	3	3176	380	3
3035	347	3	3104	234	3	3177	375	3
3036	103	2	3105	236	3	3178	377	3
3037	107	2	3106	237	3	3179	382	3
3038	111	2	3107	240	3	3180	381	3
3039	113	2	3108	241	3	3181	384	3
3040	187	3	3109	243	3	3182	389	3
3041	110	2	3110	245	3	3183	386	3
3042	116	2	3111	246	3	3184	390	3
3043	119	2	3112	249	3	3185	387	3
3044	118	2	3113	250	3	3186	394	3
3045	120	2	3114	251	3	3187	393	3
3046	123	2	3115	254	3	3189	395	3
3047	125	2	3116	256	3	3190	397	3
3048	127	2	3117	257	3	3504	13	1
3049	129	2	3118	258	3			
3050	132	2	3119	261	3			
3051	134	2	3120	263	3			
3052	136	2	3121	264	3			
3053	138	2	3122	267	3			
3054	140	2	3123	273	3			
3055	142	2	3124	272	3			
3056	143	3	3125	270	3			
3057	144	2	3126	271	3			
3058	146	2	3127	280	3			
3059	148	3	3128	281	3			
3060	149	3	3129	282	3			
3061	150	2	3130	283	3			
3062	152	2	3131	284	3			
3063	155	2	3132	285	3			
3064	156	2	3133	286	3			
3065	157	2	3134	288	3			
3066	160	2	3135	295	3			
3067	312	3	3136	292	3			
3068	163	2	3137	296	3			
3069	164	2	3138	305	3			
3070	167	2	3139	304	3			
			3140	294	3			