Report on mechanical measurements in the main LHC dipole collared coils: March-April 2005

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This report gives the updated data concerning the mechanical measurements on inner and outer layers of the coils, assembled poles and collared coils.

1. The dashboard

The available data on coils size measurements by the end of year 2004 is given in table 1 together with the statistics on production rate during last 4 months.

Firm	Number of poles produces in 2 months		% of poles / pairs of layers measured in coil straight part	Number of measuring sections	Total number of measured poles / pairs of layers	Total number of measurements / number of magnets
	Jan-Feb 2005	Mar-Apr 2005				
Firm 1	104	84	25% / 0	5	755 / 0	~8100 / 319
Firm 2	120	96	0 / 25%	15	80 / 218	~13560 / 204
Firm 3	100	120	0 / 50%	5	0 / 960	~15300 / 380

Table 1. Statistics on coil production rate and coil size measurements for firms 1÷3.

- **Firm 1 (ALSTOM-JEUMONT)** – compared to the January-February period, the average speed of coil production decreased by ~20%. In last two months the average production rate was ~ 11 sets of poles per month compared to 14 sets of poles in the previous period. The poles are measured at a reduced number of measuring sections along the coil (5 instead 15). A new E-modulus machine (CTE) started to be used at Jeumont in parallel with the old one (only for the measurements on coil straight part). In order to cross-calibrate two machines, many coils were measured by both machines.
- **Firm 2 (ANSALDO)** – similarly to firm 1, during last two moths the average speed of coil production decreased by ~20%: actually the average production rate is ~ 12 sets of poles per month compared to 15 sets of poles achieved during January-February period. At this firm the coil size measurements are performed on one inner and one outer layer per magnet. The coils are measured in 15 sections along the coil. As shown in table 1 the total number of coil size measurements is approaching the value for firm-3, which however has produced twice more magnets.
- **Firm 3 (BNN)** – Compared to the January-February period, the average of coil production rate increased by ~20%: actually it is about 15 sets of poles per month. Over the last six months of production the coils at this firm are measured more

intensively: the measurements are taken in 5 longitudinal positions instead of 4 before (at 4 fixed positions and the 5th is moving along the coil).

2. Summary

Trends in coil sizes

Firm 1. The data on both inner and outer layers at firm 1 continues to show periodic negative (reduction of coil size) and positive trends in coil. However, by varying the curing shims thickness the amplitude of these trends was reduced for coil production over last 4 months. During March-April period the inner layer coil size was kept inside the recommended range of ± 0.1 mm. The situation with the outer layers coils is less good: the coils for magnets 241 and 242 have smaller sizes and the average on the outer layers coil size is systematically smaller than for the inner ones by ~60 μm. Unfortunately there is not much that can be done to improve this situation as there is no extra curing shims on the outer layer. Most of the magnets at firm 1 are being collared with nominal polar shims.

Firm 2. In the last four months of production the coil size is very stable on both the inner layer and the outer layers. The coil size variation is in the range of ± 0.05 mm and its systematic stays just in the middle of the recommended range, excellent results!

Firm 3. A small negative trend in coil sizes of both inner and outer layer, already mentioned in previous report, is being saturated for the inner layers coils but still present on outer layer coils. However, the coil size variation on both coil layers stays within the recommended range ± 0.1 mm.

Collared coils dimensional data

There are trends observed in data on collared coil dimensional (CCD) measurements taken over magnets straight part and coil end, particularly at firm 1. The magnet 1233 has very high value in CCD data over coil straight part and non-connection side coil end. At firm 2 a small decrease in systematic for CCD data over coil straight part is observed. At firm 3 the magnet 3361 has very low value in CCD data over non-connection side coil end.

We recall that for monitoring the coil size and collared coil dimensions measurements in the production the most important graphs from this report are daily updated and available on the **web site** at http://lhc-div-mms.web.cern.ch/lhc-div-mms/MMSPAGES/MA/obs_coil.html. You would need your 'Nice' password to retrieve the information from this web site.

3. Analysis and discussions

3.1 Coil size trends

Firm 1. The coil size at firm 1 is measured on assembled poles. In figure 1 the average of all measuring points is used to show the coil size trends. In this figure vertical dashed colored lines with number next to them shows the manipulations with curing shims aimed to reduce the trends in coil sizes. In figure 2 the coil sizes of the inner and the outer layers are plotted together with their E-modulus. According to the specification the poles assembled in a twin aperture dipole shall have a similar modulus of elasticity with maximum permissible difference ± 15% with respect to the average computed over the layers belonging to the same twin aperture dipole. For simplicity, in our plot the recommended range for E-modulus value is referred to the average on all the poles. Generally the situation with coil sizes and E-modulus is quite good at this firm.

Firm 2. The coil size is very stable in data of inner and outer layers coils and its variation is not exceeding ± 0.05mm range (see figure 3).
In figure 4 the coil sizes on the inner and outer layers are plotted together with their E-modulus. Despite some jumps in the values of E-modulus, the systematic stays in allowed range and in general the situation with coil sizes is quite good at this firm.

Firm 3. A small negative trend in coil size data for both inner and outer layers observed in the past is being saturated on the inner layer coils, however it is still present on the outer layers. Nevertheless the coil size on both layers is well within the recommended range of ±0.1 mm (see figure 5).
In figure 6 the inner and outer layers coil sizes are plotted together with their E-modulus. Already underlined in previous reports, despite significant trends in the coil E-modulus data on both coil layers, the coil size at firm 3 is rather stable. This is indicating that the curing process at this firm is very well optimized. In general the situation with coil sizes is quite good at this firm.

3.2 Collared coil dimensions trends (coil straight part and coil ends).

The available data on collared coil dimensions (CCD) measurements by the end of April is given in table 1 together with the statistics on production rate during last 4 months. For the details on the procedure of collared coil dimensions measurements at each dipole manufacturer see previous reports.
In figures 7÷9, the data on collared coil dimensional (CCD) measurements taken over magnets straight and coils connection (CS) and non-connection side (NCS) ends is shown as average on measuring points S2, S4, S6 and S8 which represents vertical collar's size.

Firm	Number of collared coils measured in 2 months		Number of measuring sections over coil SS /LJ/ coil ends	Total number of measured collared coils
	Jan-Feb 2005	Mar-Apr 2005		
Firm 1	24	24	6/2/3	248
Firm 2	20	27	3/2/3	197
Firm 3	32	27	8/2/3	377

Table 2. Statistics on collared coil dimensions measurements for firms 1÷3.

Firm 1. In this report the data belonging to the first 50 magnets, measured with different machine and already published in the previous reports, has been dropped. In figure 7 the CC dimensions for measurements taken over coil ends are shown together with the data on coil straight part. In this figure the magnets, collared with collars from FSG, are marked separately. There are trends observed in CCD data and the data on the magnet 1233 has exceptionally high value in coil straight part and non-connection side end, however the magnetic measurements shows no anomaly for this magnet and therefore, probably the CCD measurements were performed not correctly. As can be seen in figure 7 the history of the trends in CDD data is similar for coil straight part and coil ends, which indicates that the their source is most probably the variations in cable dimensions.

Firm 2. At firm 2, for the collared coils of the series, the variations in CCD data over coil straight part is even smaller than at firm 1 and generally not exceeding the ±0.05 mm range (see figure 8). However the variation in CCD data over coil ends is the largest among three firms. Moreover the CCD data along coil ends often shows strange profile, with very high value in transition between coil straight part and at the extremity of the coil and very low in the middle of coil end. As a result, in some of the magnets, like 2188, the average CCD data in coil ends is equal to the straight section (see appendix A).

Firm 3. At firm 3, for the last 100 magnets there is a significant reduction in CCD data variation for measurements taken over coil straight part. This is partially due to the actions taken by this firm, directed to the reduction of collars tolerances, particularly on the position of holes for collaring rods. A small positive trend in CCD data for connection side end started around CC 160 is being saturated, while a small negative trend is still present in CCD data for NCS side end. Due to these trends for the last 70 magnets there is significant difference in average value of CCD between connection and no-connection side coil ends.

3.3 Asymmetry in collar's deformation

The left-to-right side asymmetry with respect to the aperture axes in collars deformation produces the non-allowed multipole *b2*. In figures 10÷12 the asymmetry in collar's deformation between the lateral and central part of the collars are shown separately for each firm.

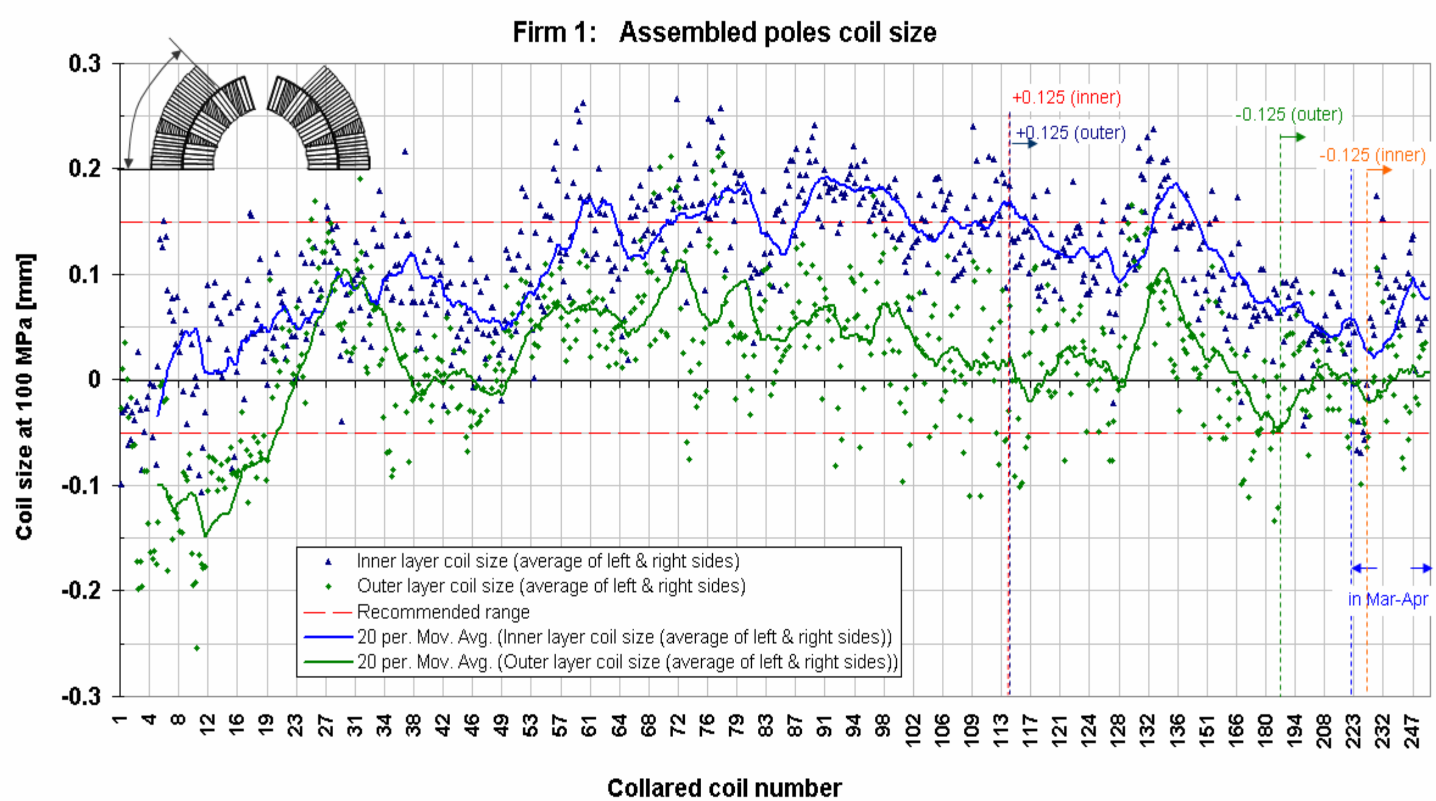
Firm 1. There is a small shift between moving averages on collar's asymmetry corresponding to the first and the second apertures. This shift is particularly visible in the data on last 60 magnets.

Firm 2. Compared to firm 1 the collar's asymmetry is a bit smaller at firm 2 and no visible differences between two apertures. The variation in collars asymmetry from one collared coil to another is also smaller than at firm 1.

Firm 3. The improvements in the collar's asymmetry at firm 3 were already underlined in previous report. There was a significant reduction in collar's asymmetry variation, however the systematic was at the limit of specification for b2 multipole and the corrective action was taken by collars producer. In the last 20 magnets the systematic on collar's asymmetry was moved back inside the recommended range.

Acknowledgments

We wish to acknowledge PE and J.P. Koutchouk for comments, discussions and valuable help.



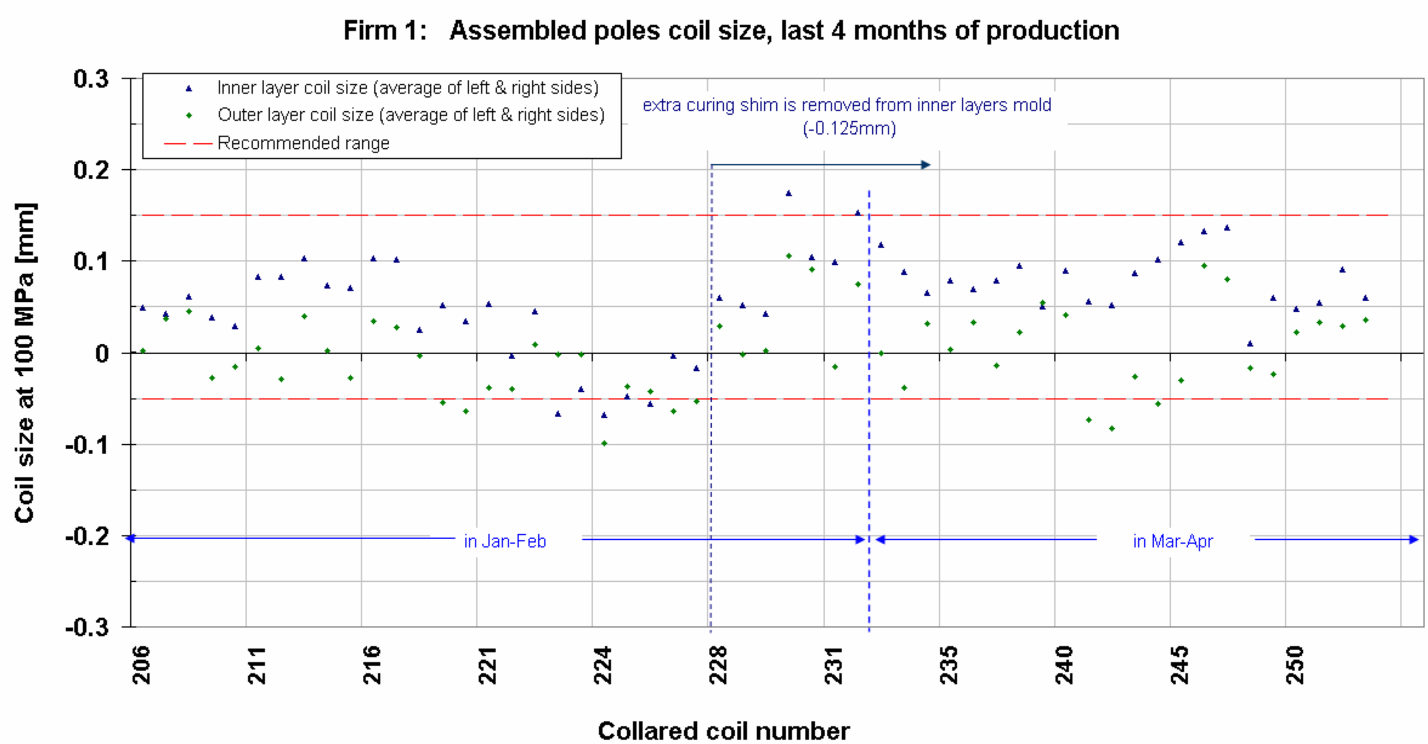


Fig. 1 Average coil size (as compared to the nominal azimuthal coil size) in the straight part of the assembled poles at Firm 1. Upper plot all data up to date, lower plot: last 4 month of production.

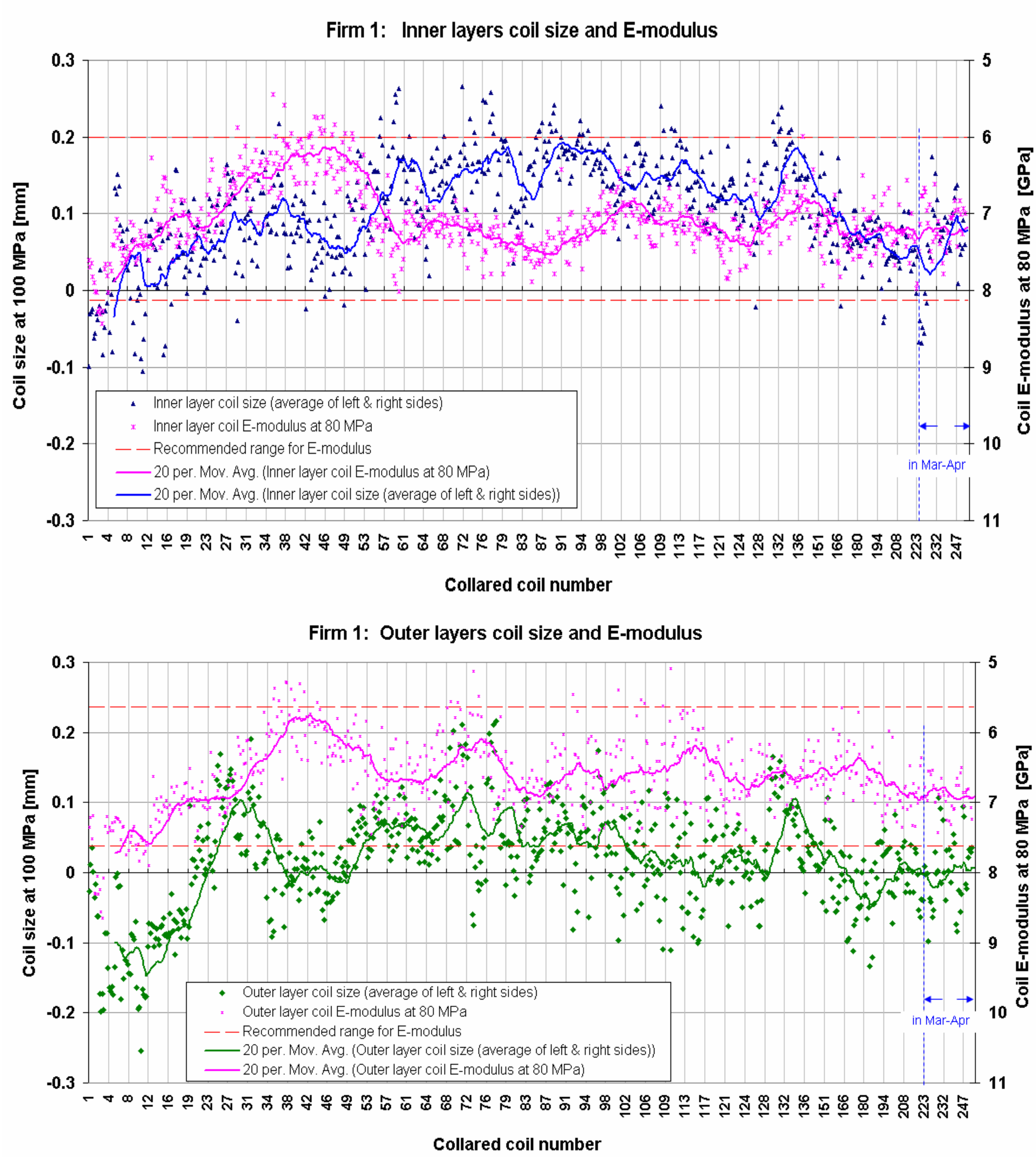
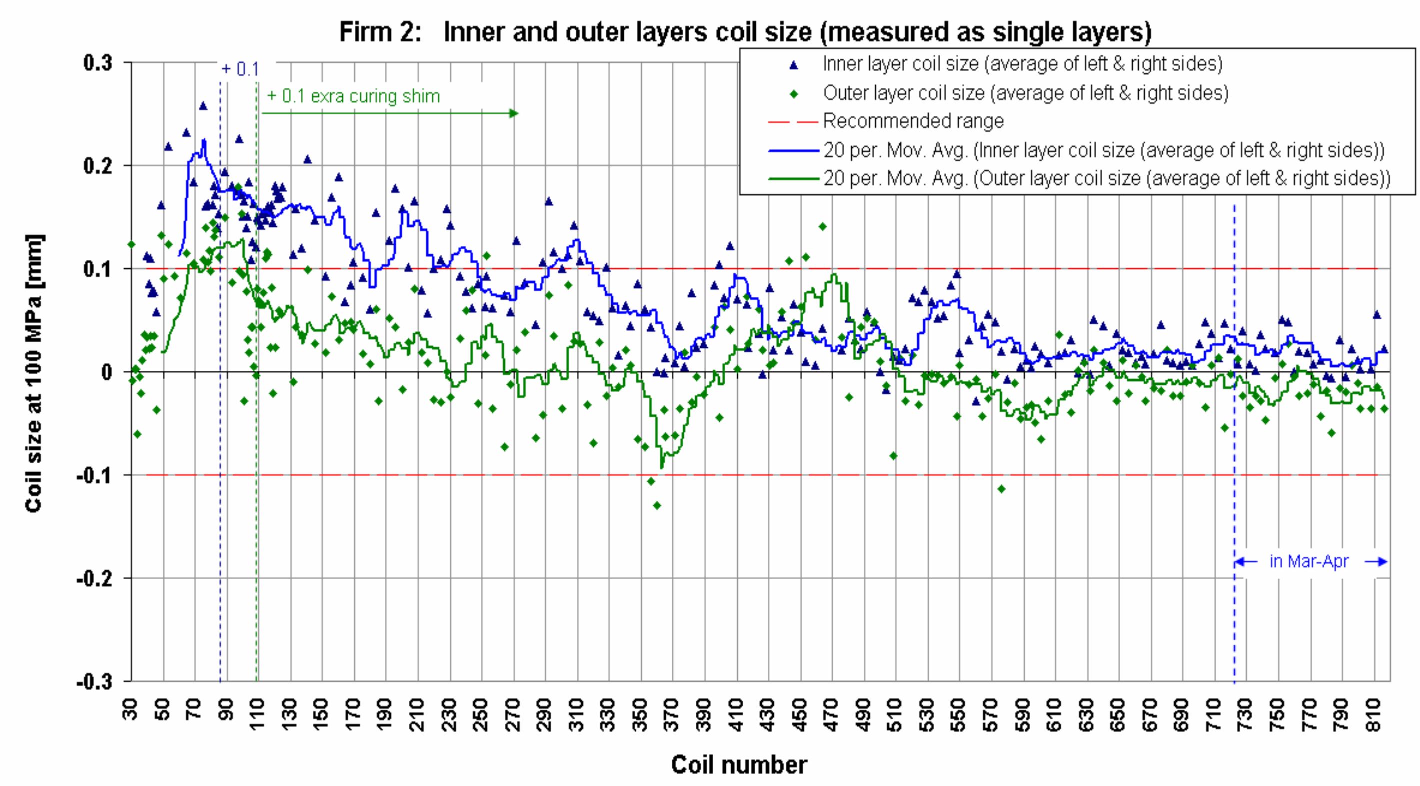


Fig. 2 Average coil size and coil E-modulus computed at 80 MPa compressive stresses (data from the measurements on assembled poles at Firm 1).



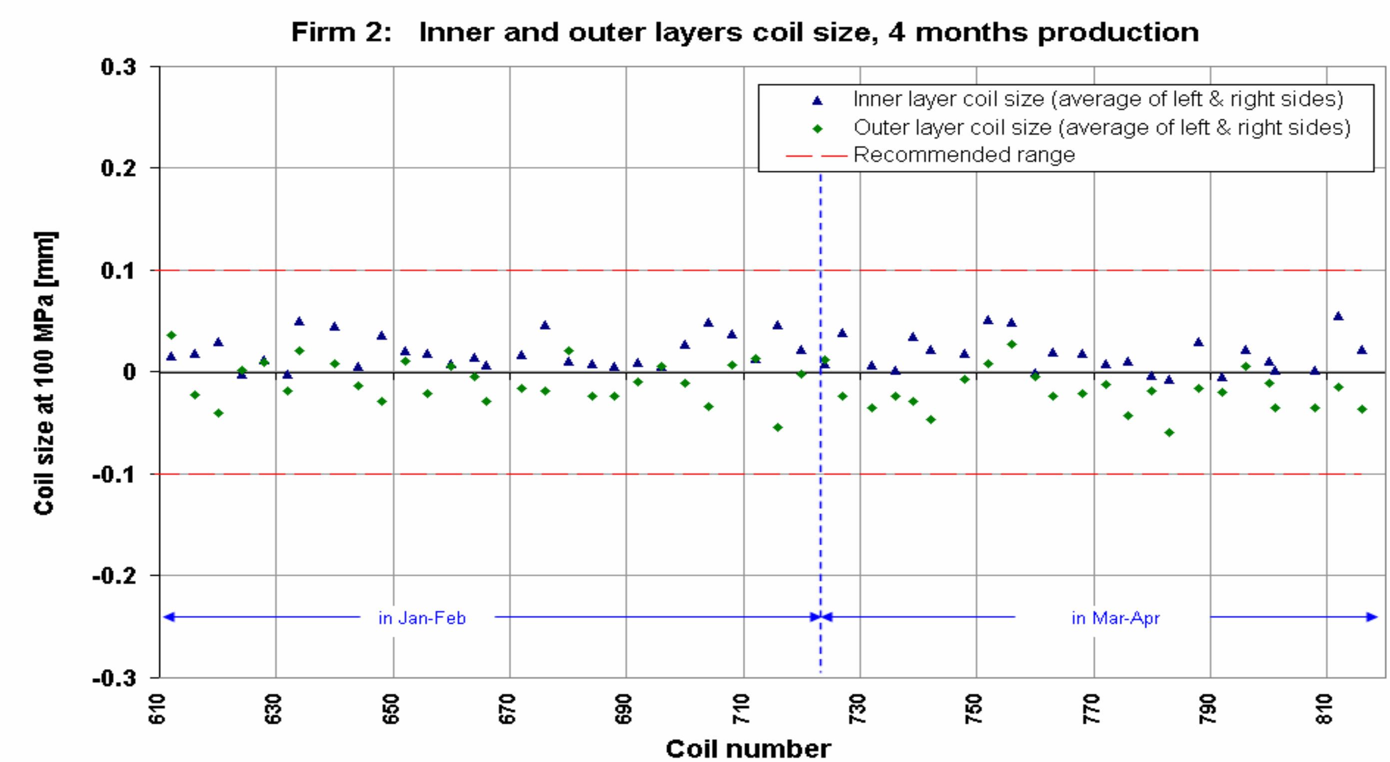


Fig. 3 Average coil size in the straight part of the single layers at Firm 2.
Upper plot all data up to date, lower plot: 4 month production.

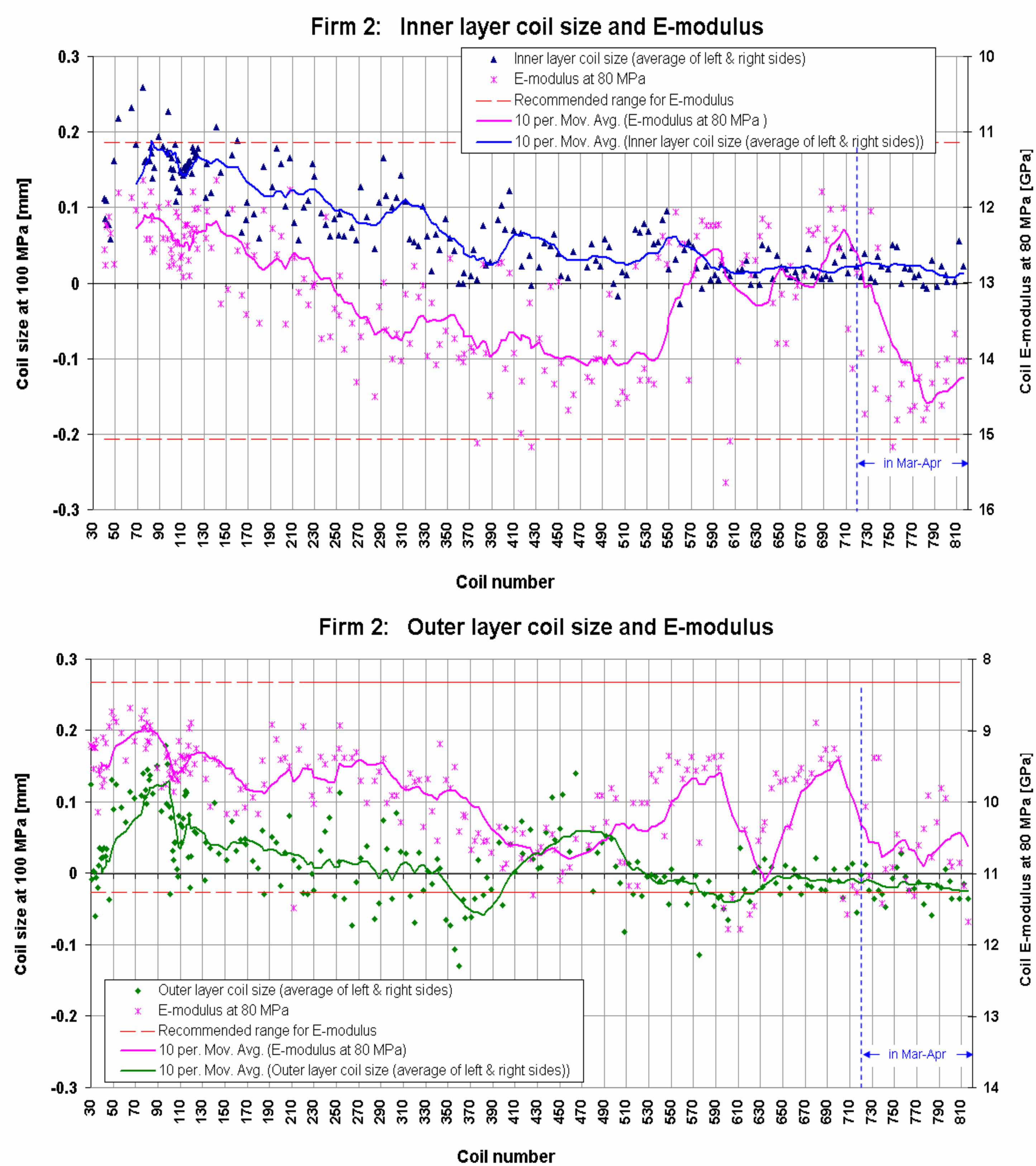


Fig. 4 Average coil size and coil E-modulus computed at 80 MPa compressive stresses (data from the measurements on single layers at Firm 2).

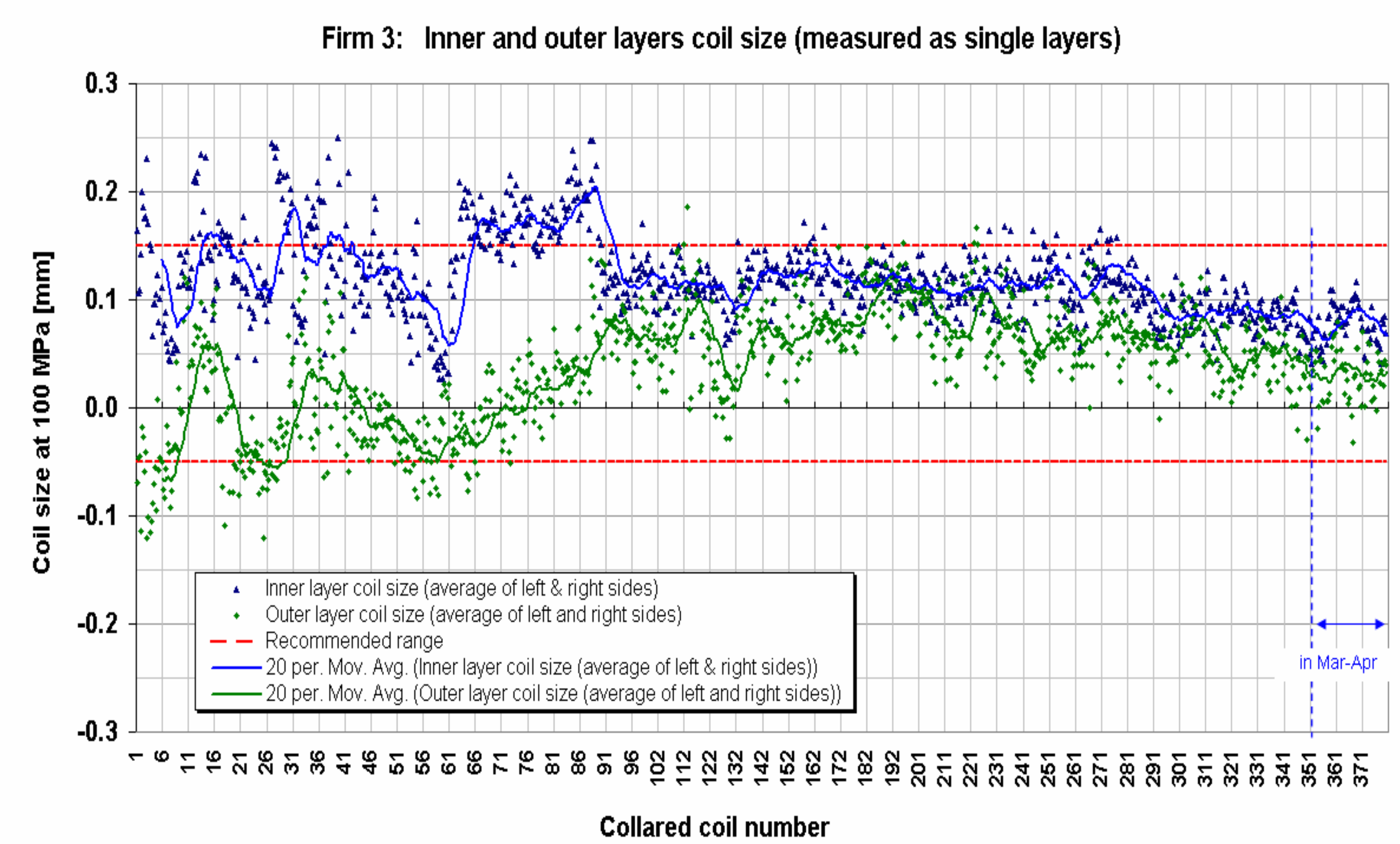
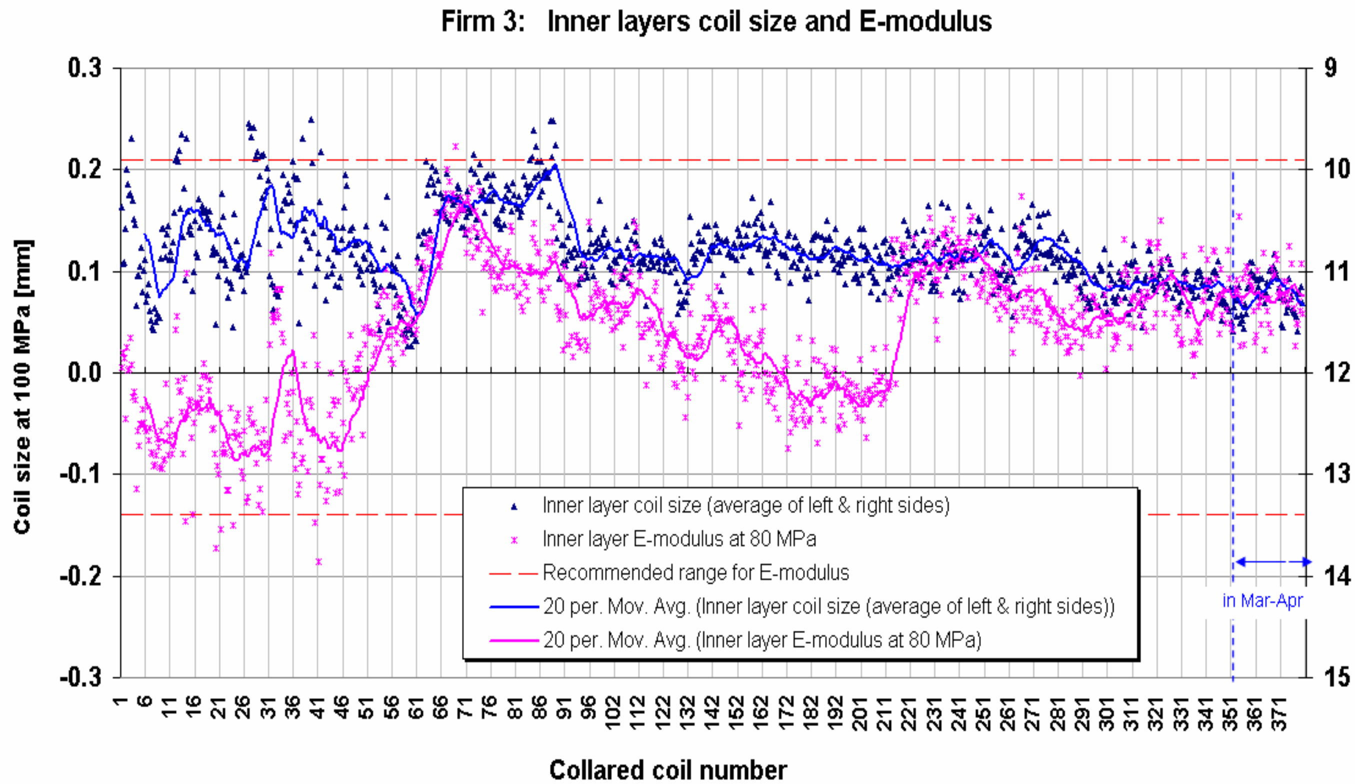


Fig. 5 Average coil size in the straight part of the single layers at Firm 3.
Upper plot all data up to date, lower plot: 4 month production.



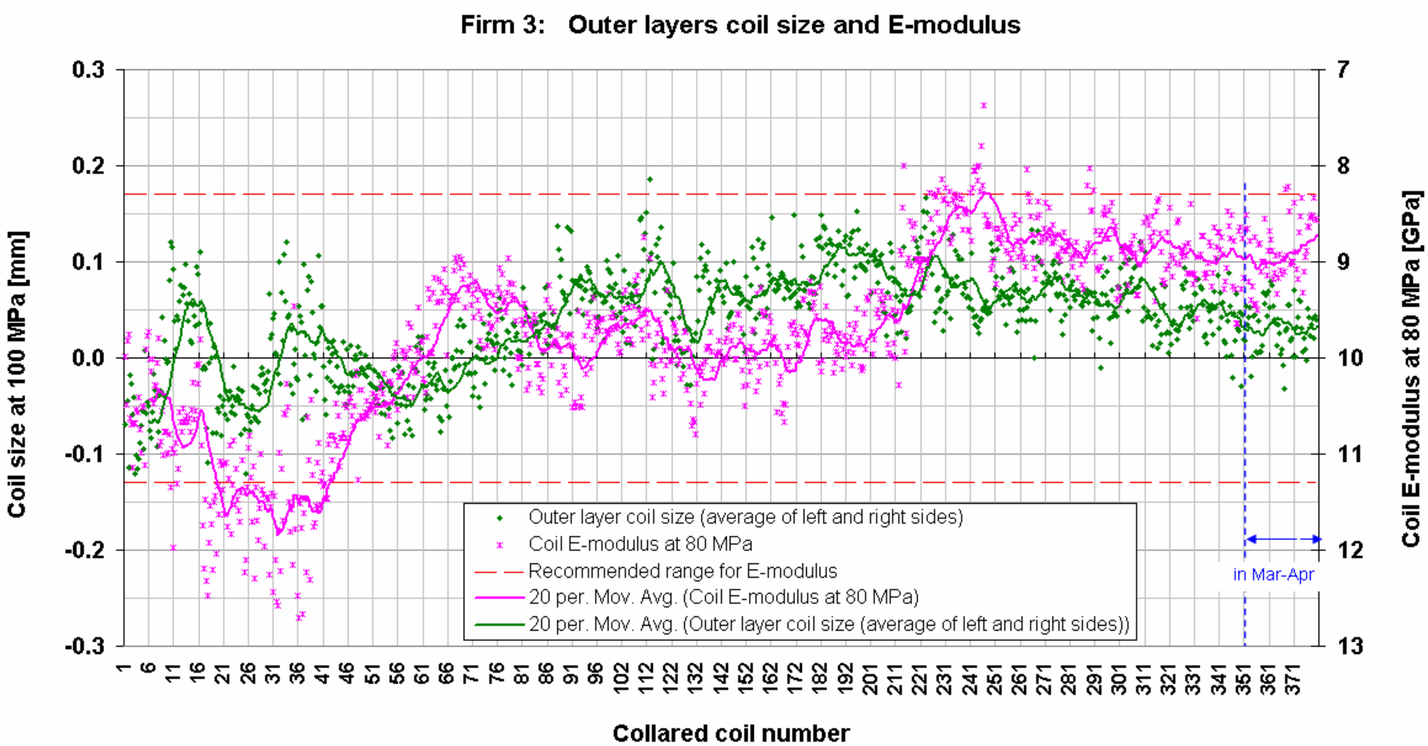


Fig. 6 Average coil size and coil E-modulus computed at 80 MPa compressive stresses (data from the measurements on single layers at Firm 3).

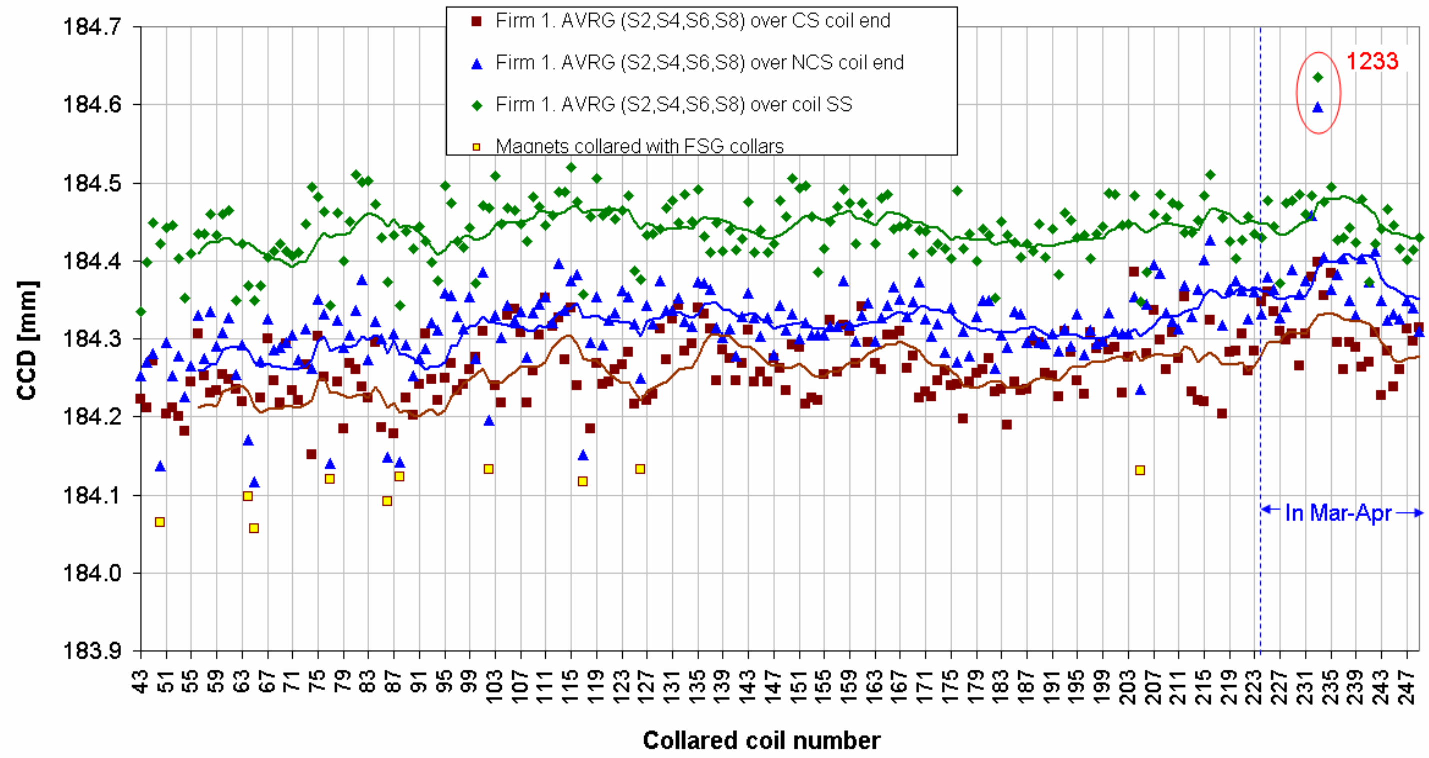


Fig. 7 CCD data for collared coils of firm 1 in averages for coil straight section (SS), connection side (CS) and non-connection side (NCS) ends.

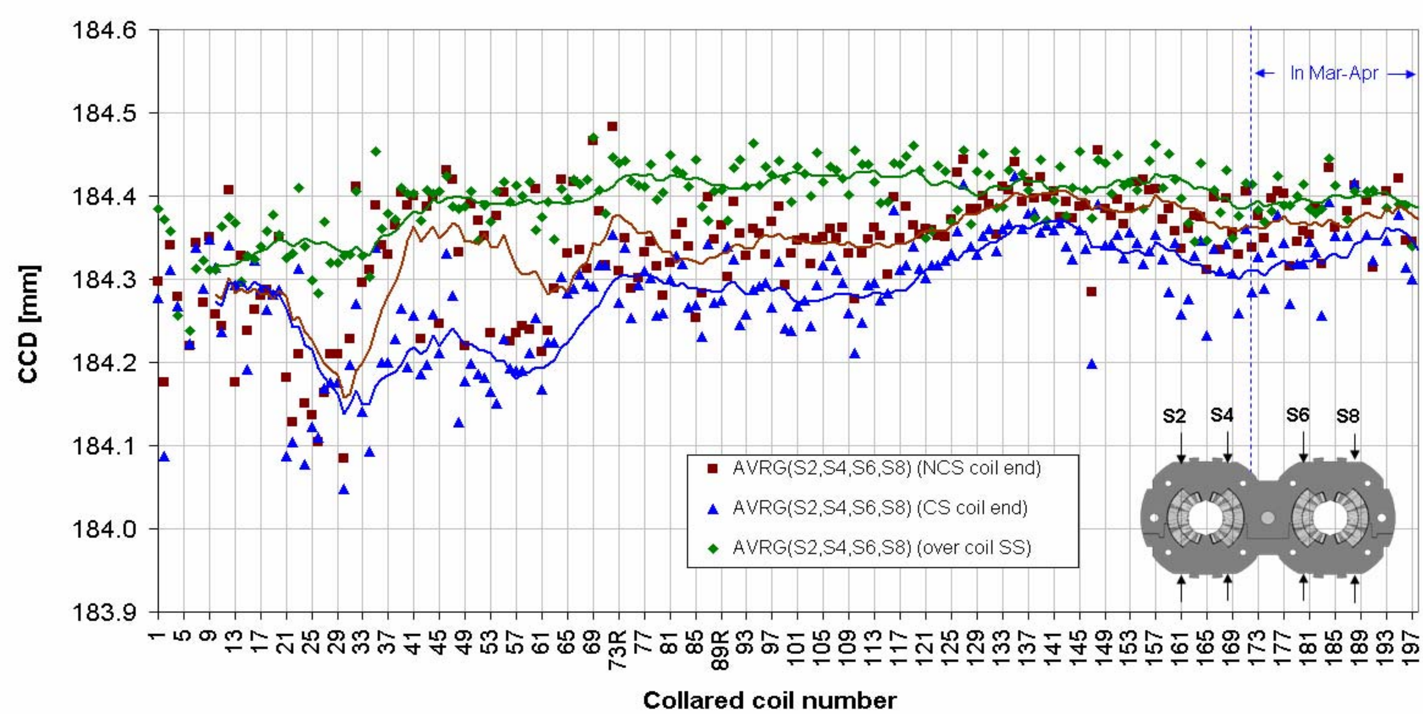


Fig. 8 CCD data for collared coils of firm 2 in averages for coil straight section (SS), connection side (CS) and non-connection side (NCS) ends.

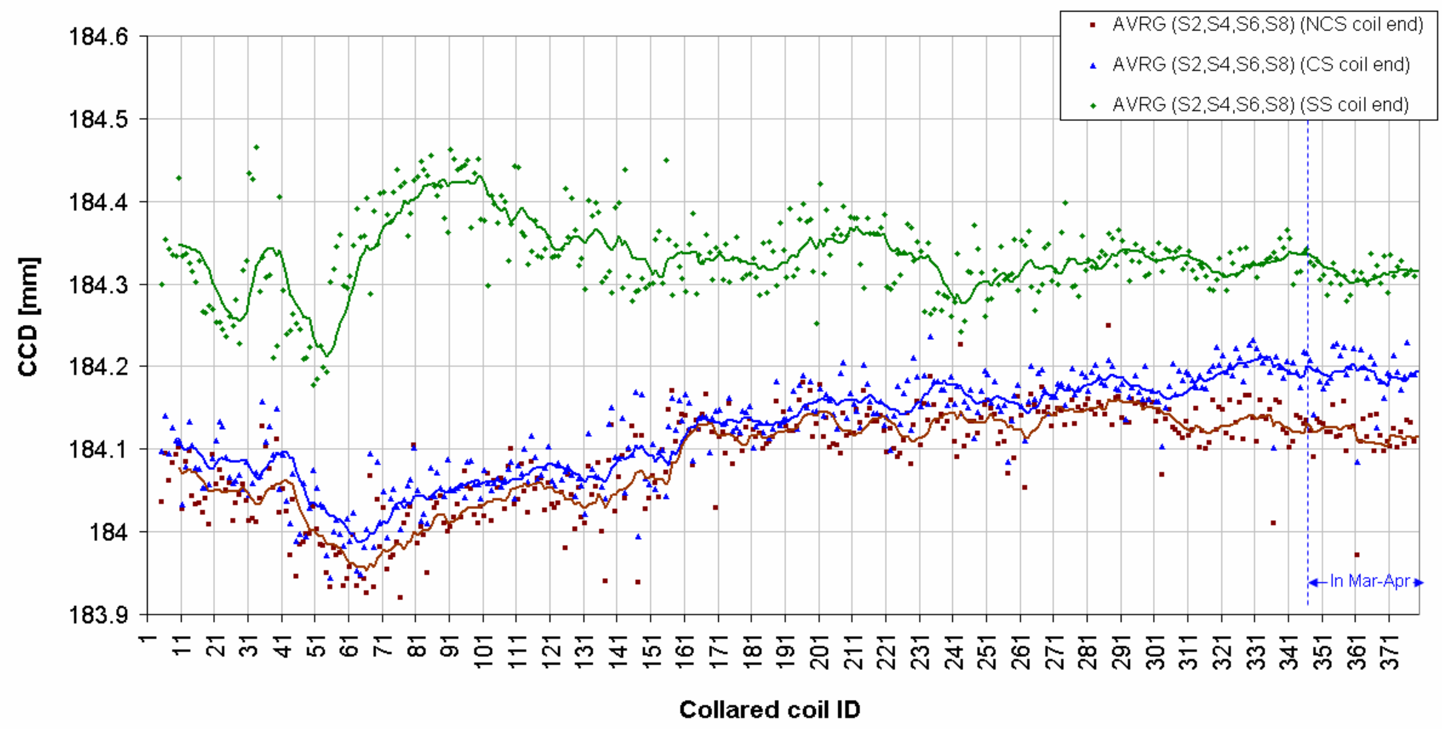


Fig. 9 CCD data for collared coils of firm 3 in averages for coil straight section (SS), connection side (CS) and non-connection side (NCS) ends.

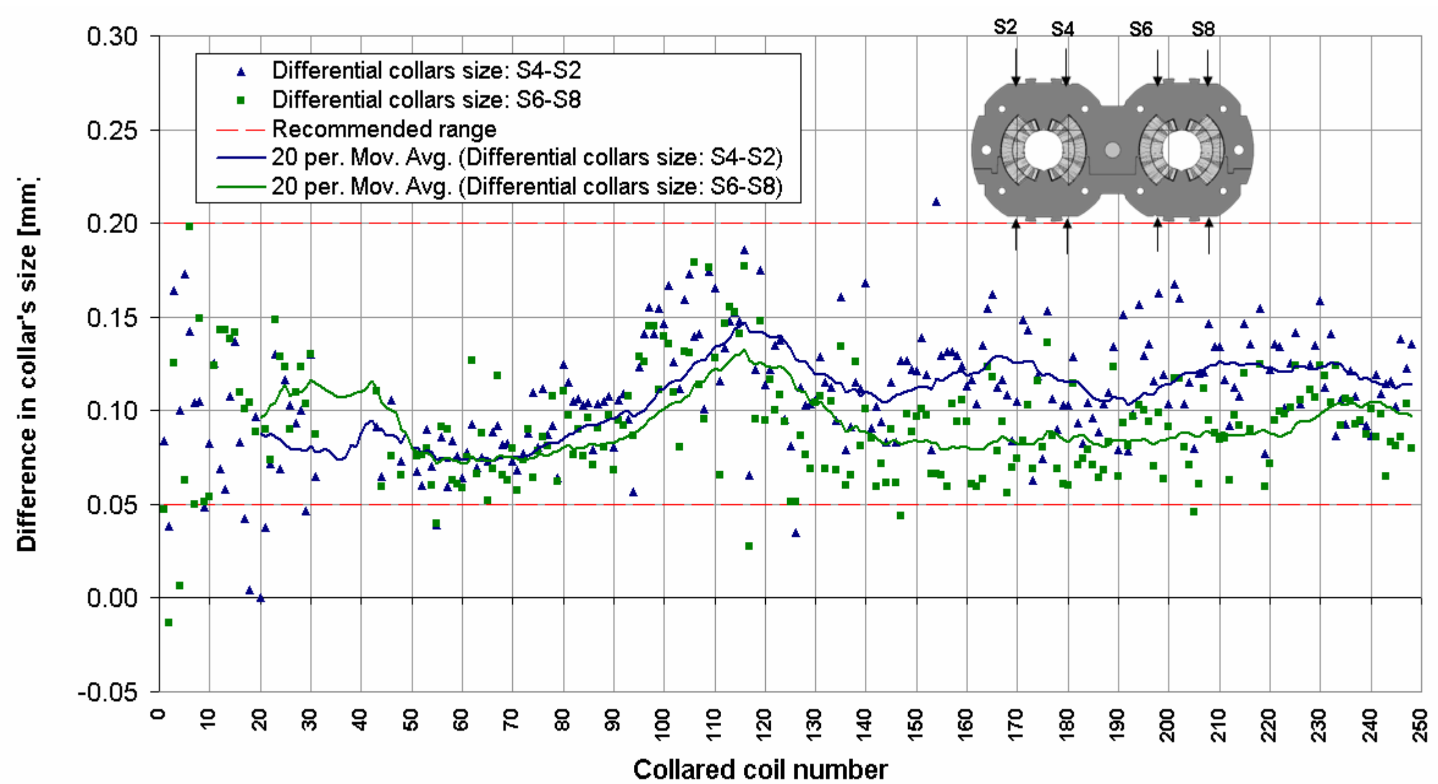


Fig. 10 Firm 1. Asymmetry in collar's vertical dimensions.

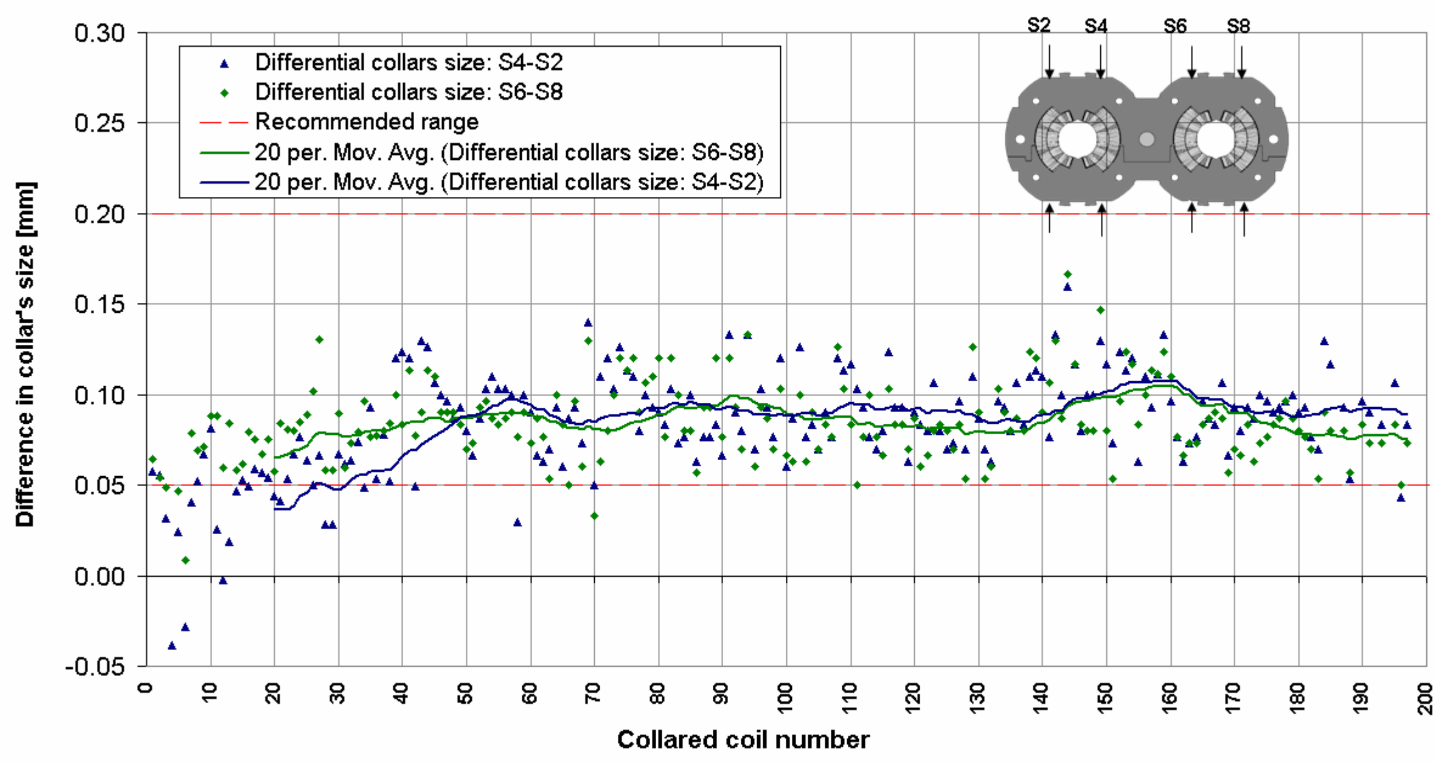


Fig. 11 Firm 2. Asymmetry in collar's vertical dimensions.

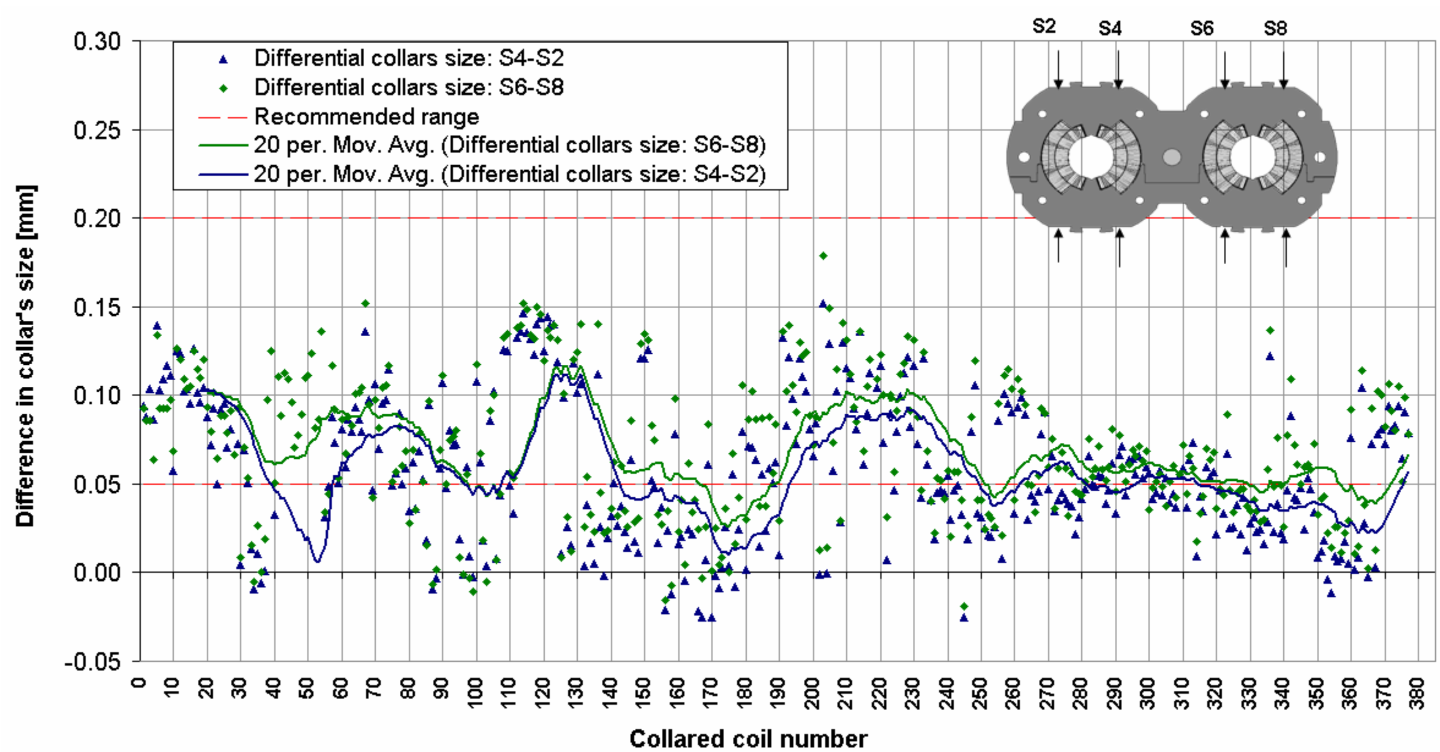


Fig. 12 Firm 3. Asymmetry in collar's vertical dimensions.

Appendix A.

The longitudinal profile of CCD data for magnet 2188 is shown in figure 13. There is an important non-symmetry in the shape of CCD profile between connection and non-connection side coil ends, which is rather common case for most of the magnets of firm 2. In the past the investigations carried out on the CCD and coil ends shims data trends have shown that the source of this non-symmetry is due to tolerances in coil ends components.

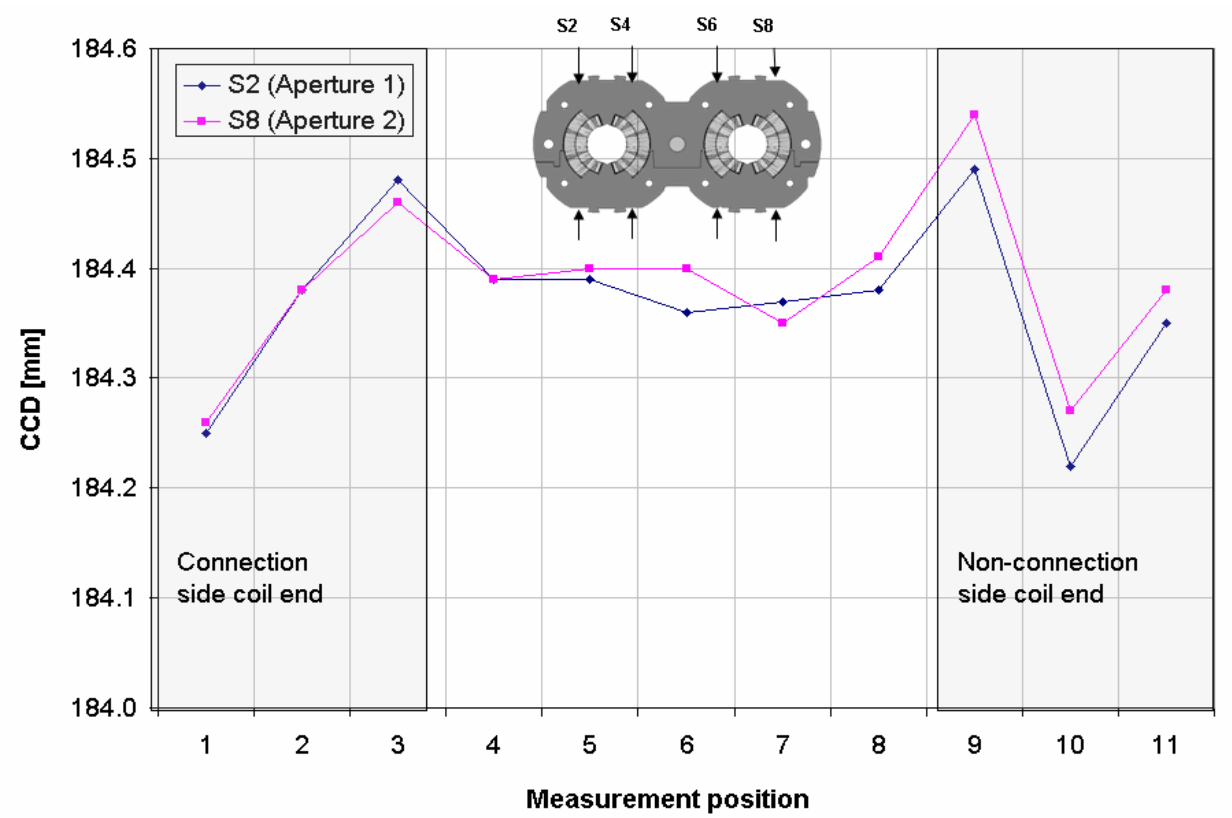


Figure 13