Report on mechanical measurements in the main LHC dipole collared coils: January-February 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
	Nov-Dec 2004	Jan-Feb 2005				
Firm 1	80	104	25% / 0	5	650 / 0	~8000 / 235
Firm 2	76	120	0 / 25%	15	80 / 194	~13200 / 180
Firm 3	100	100	0 / 50%	5	0 / 900	~15000 / 350

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

- **Firm 1 (ALSTOM-JEUMONT)** – as can be seen in table 1, compared to the November-December period, the average speed of coil production was increased by ~40%. In last two months the average production rate was ~ 14 sets of poles per month compared to 10 sets of poles in the previous period. The poles are measured at a reduced number of measuring sections along the coil (5 instead 15).
- **Firm 2 (ANSALDO)** – In the last 4 months at firm 2 the coil production speed is continuously growing up: compared to November-December period, the average coil production speed was increased by ~50 % and reached the highest production rate achieved at firm 2 since the beginning of the mass production: 15 sets of poles per month. At this firm the coil size measurements usually 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 November-December period, the average of coil production rate remained unchanged: 10 sets of poles per month. At this firm, the highest rate was registered during June-July period of 2004 year: ~20 sets of poles per month. Over the last four months of production the coils at this firm are

measured more intensively: the measurements are taken in 5 longitudinal positions instead of 4 before and some layers are measured in all 14 positions.

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. Moreover, data on the coils for magnets 224 and 225 shows rather small coil dimensions on both layers. In fact, in order to stay in allowed limits of coil pre-stress, the magnet 225 was collared with non-nominal polar shims (thicker by 0.05mm) on the inner layer. As an action, the additional curing shim introduced before was removed from the inner layer for coils starting from magnet 225. As a result, we could see an increase in coil sizes in the last 6 pole sets. It wasn't possible to do the same for the outer layer coils as the additional curing shim already has been removed before. However, the coil size on the outer layer coils shows some recovery in last produced coils. Most of the magnets at firm 1 are being collared with nominal polar shims.

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

Firm 3. For the last 50 magnets at firm 3 a small negative trend in coil sizes of both inner and outer layer is observed. This trend is being increased for the last produced outer layer coils and now the coil size of outer layer coils is approaching the lower limit of coil size variation recommended range ± 0.1 mm.

Collared coils dimensional data

There is no important trend observed in data on collared coil dimensional (CCD) measurements taken over magnets straight part at any firm. Underlined in previous reports, a strong positive trend observed in CCD data of firm2 for the measurements taken over coil is being vanished in the last magnets. No important remarks on the CCD data from firms 1 and 3, except two magnets where rather low value in CCD data over coil ends is observed: 1205 (was traced back to the use of FSG collars, which explained the smaller CCD values) and 3336.

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 the past, due to coil oversize, many magnets of firm 1 were collared with non-nominal shims. In order to bring the coil size down, starting from the pole set 115 (blue and red dashed lines in figure 1) the coils are cured with additional curing shim, made of polyimide tape, 0.125 mm thick. Later, due to too small coils size in the magnets 183 and 184, particularly on the outer layer, CERN suggested to remove the additional curing shim in order to recover the optimum coil dimensions. The extra curing shim for outer layer coils was removed starting from the magnet 187 (green dashed line in figure 1). However, we should admit that at list at this firm the efficiency of curing shims is very low (this was already noticed in previous reports). However, as we can see with the moving average, after removal of the additional curing shim on outer layer coils, the average coil size has been slightly increased. We observe similar effect for the inner layer coils dimensions: after removal the additional curing shims starting from the coils for magnet 226, the negative trend on inner layer coils has been stopped. 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.

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. In the last two months of production, the situation with the E-modulus of inner layer coils has been improved: there are almost no sudden jumps as observed before. Opposite, the outer layers coils still shows important trends in E-modulus and for some of the coils the E-modulus value moves outside of the recommended range (see figure 4). Nevertheless, in general the situation with coil sizes and E-modulus is quite good at this firm.

Firm 3. A small negative trend in coil size data for both inner and outer layers is present for last 50 magnets. This trend is more affecting the outer layer coils as their dimensions were always smaller compared to the inner layers. However the coil size on both layers is still 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. The situation with the coil sizes at this firm is so far the best among all three firms.

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 February 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.

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
	Nov-Dec 2004	Jan-Feb 2005		
Firm 1	18	24	6/2/3	224
Firm 2	17	20	3/2/3	170
Firm 3	29	32	8/2/3	350

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

As can be seen in figures 7÷9, the data on collared coil dimensional (CCD) measurements taken over magnets straight part is rather stable at all firms and generally consistent with the coil size variation.

Firm 1. In this report the data belonged 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 is some difference in nominal dimensions of these collars compared to collars from another producer and this explains systematically smaller CC dimensions over coil ends. Compare to the data on straight part, the CCD over coil ends are varies in wider range. In the recent production we observe some non-symmetry in CCD data for measurements taken over coil ends. In one case this was traced back to malfunctioning of one measuring sensor, while it stays unclear for several other cases. It has been noticed also that this asymmetries in CDD data starts to appear for the collared coils in which the coil ends were measured with the new press and the shims for coil ends were computed following the new procedure. The PE was informed and the action was taken to verify the new measurements procedure.

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). Already underlined in previous reports, a significant positive trend observed in CCD data over coil ends since the CC 1112, is being vanished in the last magnets.

Firm 3. At firm 3, despite smallest coil size variation compared to firms 1 and 2, the CCD taken over coil straight part varies in a larger range compared to other firms, which is probably due to particularity of FSG collars, mainly used by this firm. However for the last 60 magnets at this firm we notice a significant reduction in CCD data variation. 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. There is a small positive trend in CCD data for connection side end started around CC 160, which is not seen at NCS side.

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. Usually for firm 3 CC we observe the largest variation for the asymmetry in collar's deformation between lateral and central part of the collars, but in the last 80 magnets this asymmetry is considerably reduced: from ±0.15 mm to ±0.05 mm or even smaller. The same observation can be seen in magnetic measurements data on *b2* multipole. The largest difference in collars asymmetry of firm 3 compared to other firms is due to particularity of FSG collars. The investigations conducted at CERN to trace back the source of rather high r.m.s in b2 multipole for firm 3 magnets resulted in better control and improvement in FSG collars quality[1].

Acknowledgments

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[1] F. Bertinelli, E. Boter-Rebollo, S. Berthollon-Vitte, I.Vanenkov, " Impact of collar's geometrical tolerances on field quality in LHC dipoles", LHC/MAS Internal Note 2005-01, EDMS 566238.

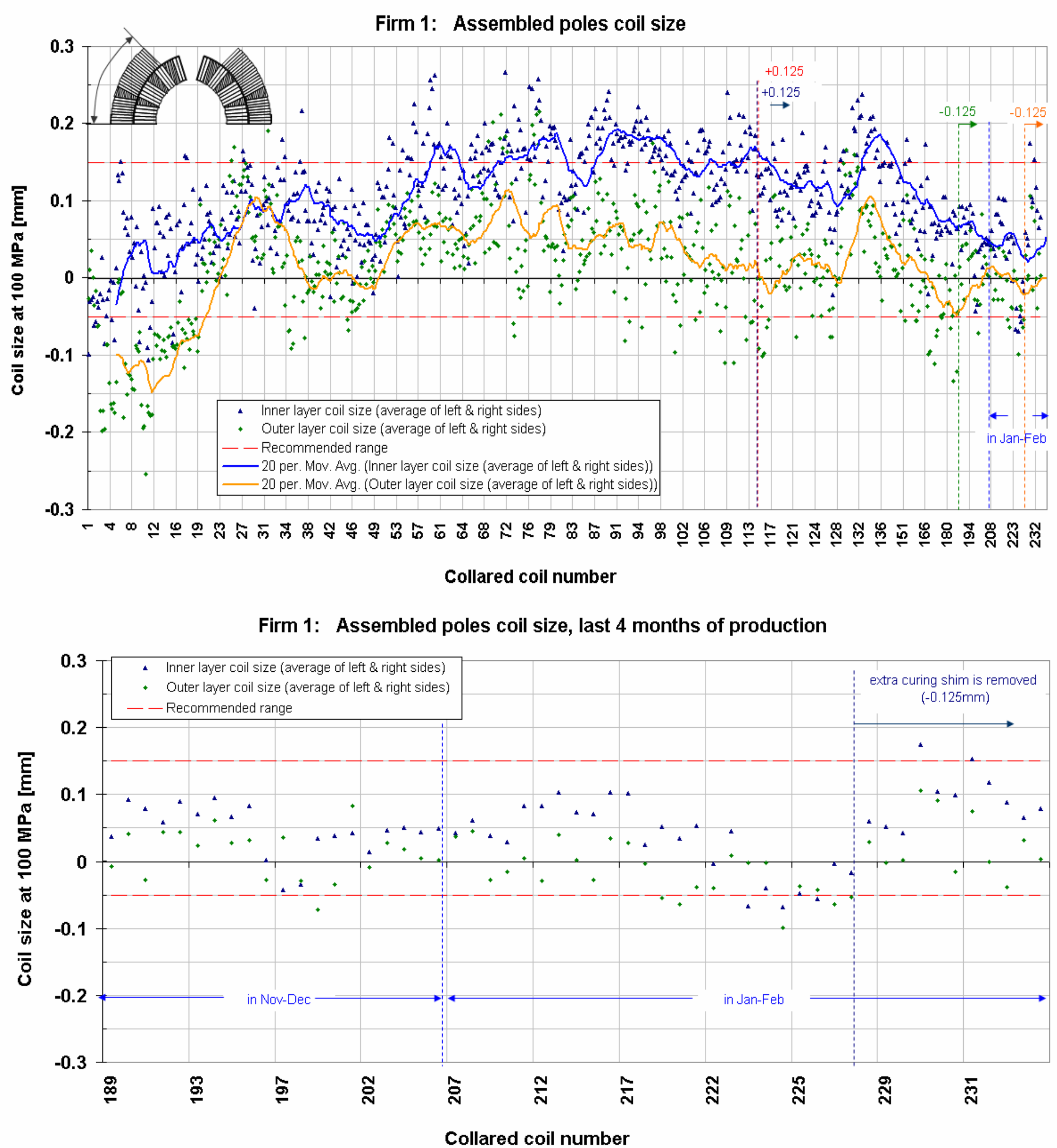
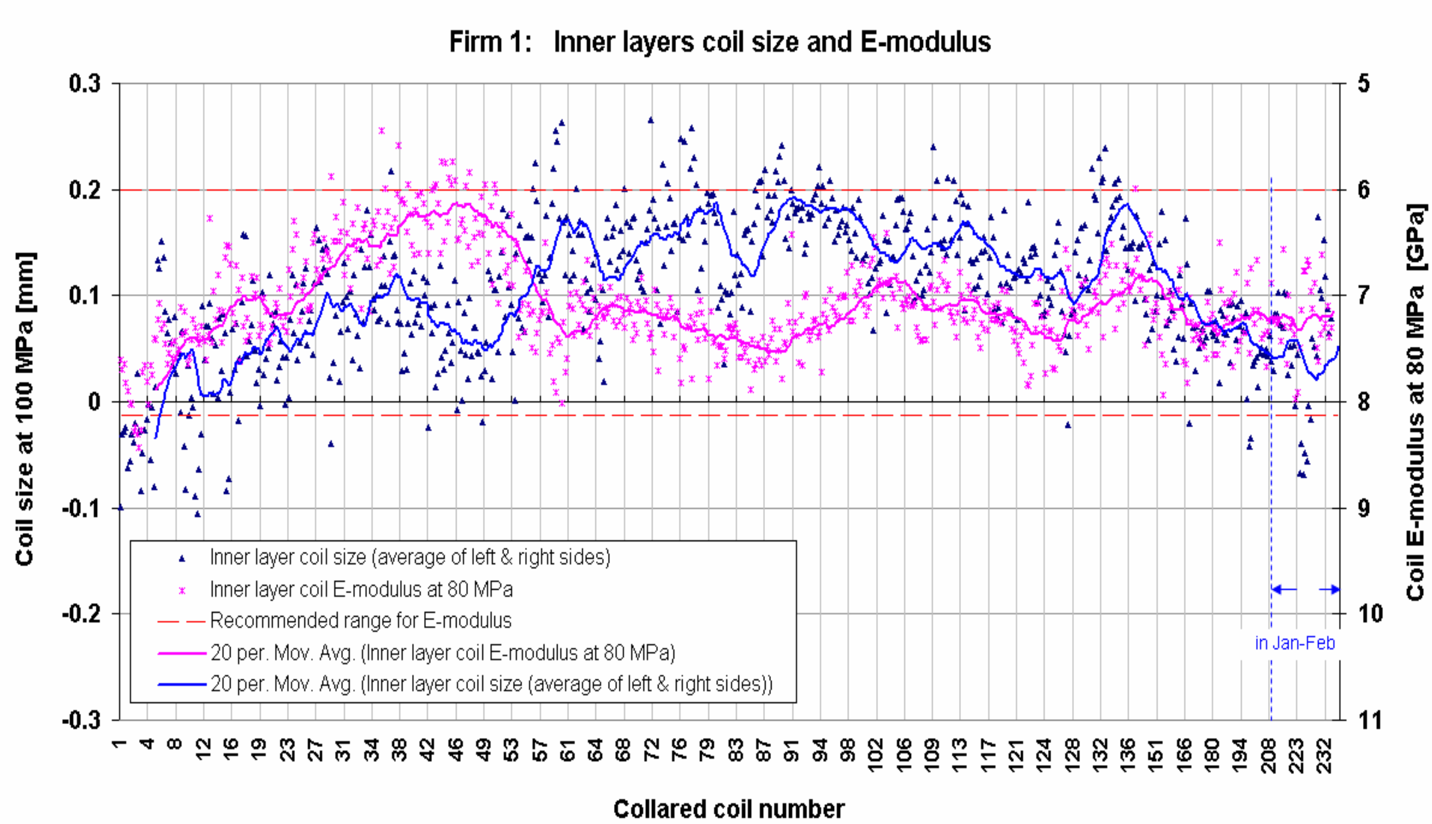


Fig. 1 Average coil size (as compared to the nominal azimuthal coil size) in the straight part of the assembled poles at Firm 1. Upper plot all data up to date, lower plot: last 4 month of production.



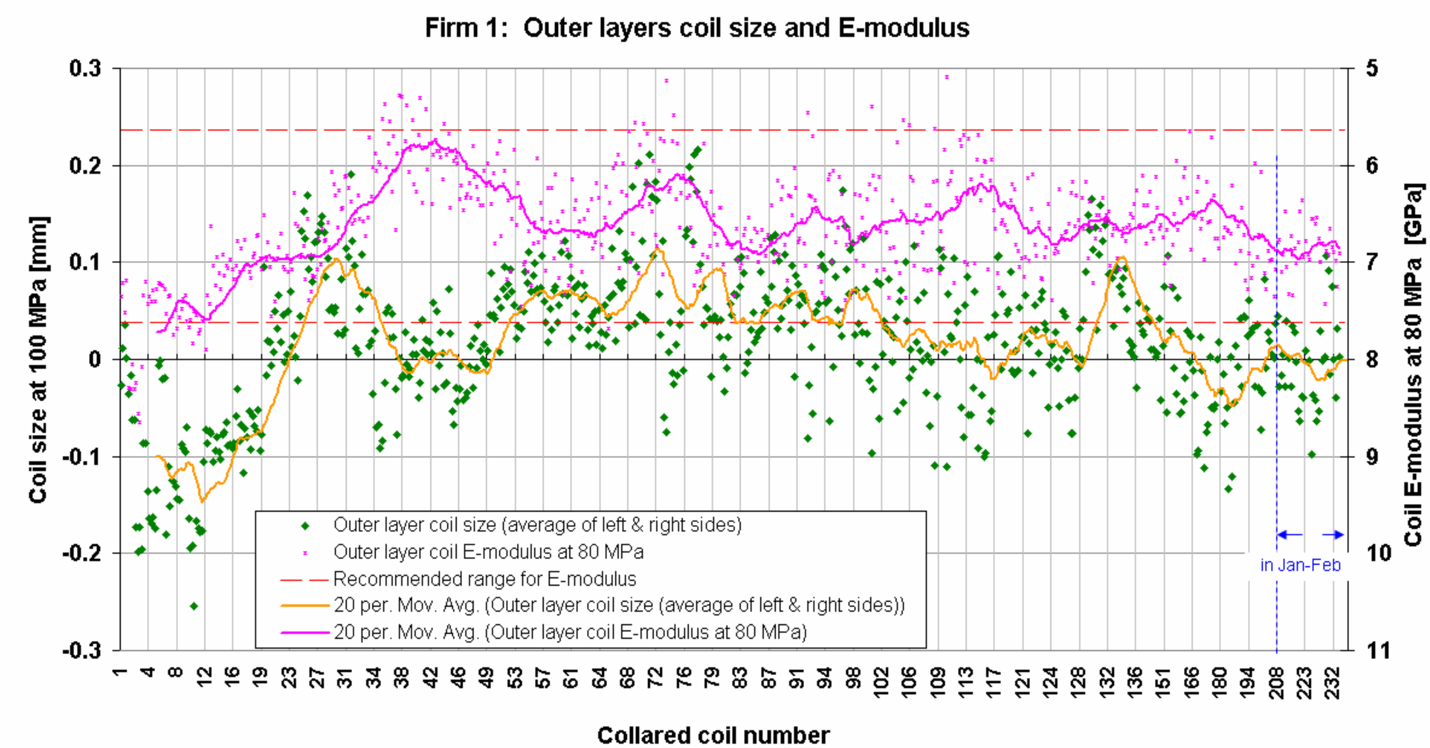
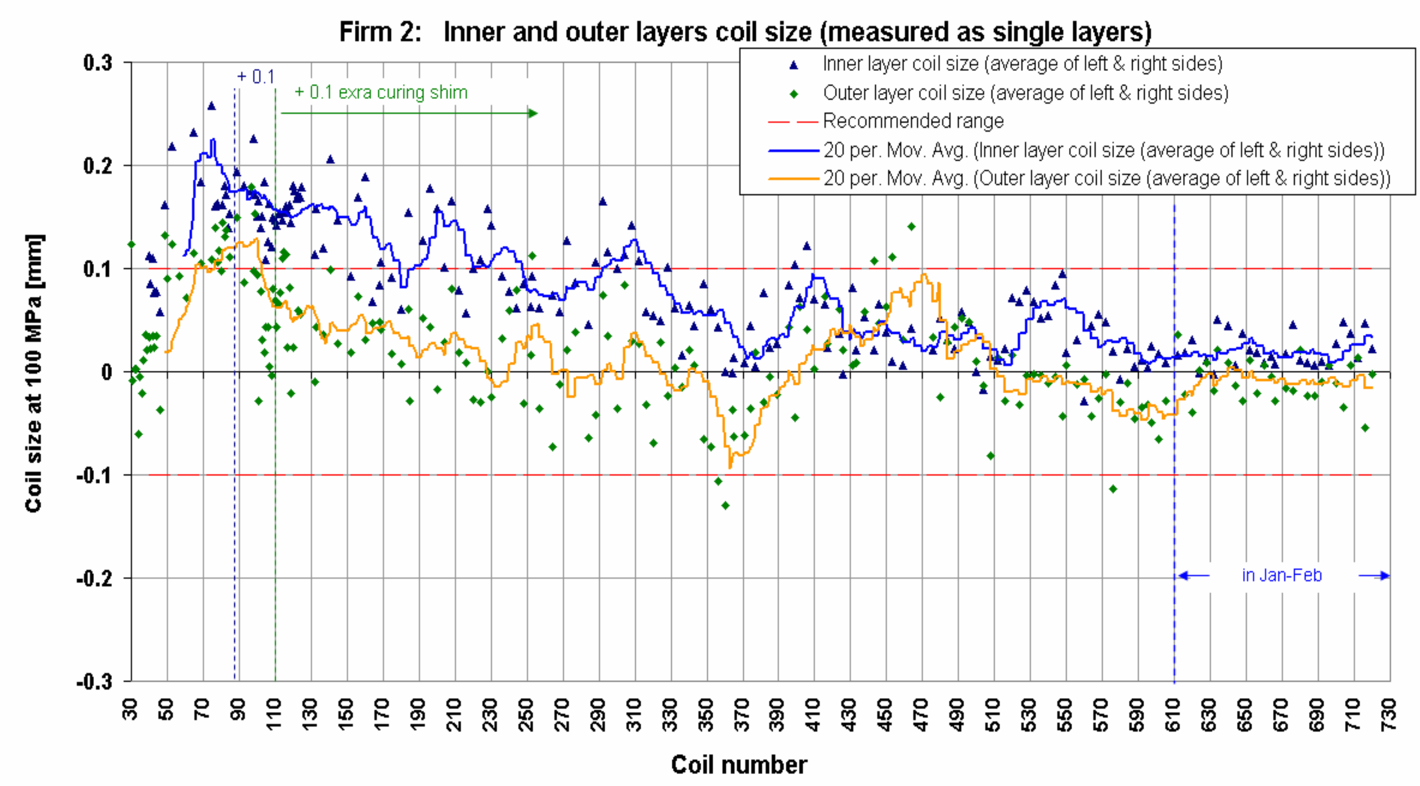


Fig. 2 Average coil size and coil E-modulus computed at 80 MPa compressive stresses (data from the measurements on assembled poles at Firm 1).



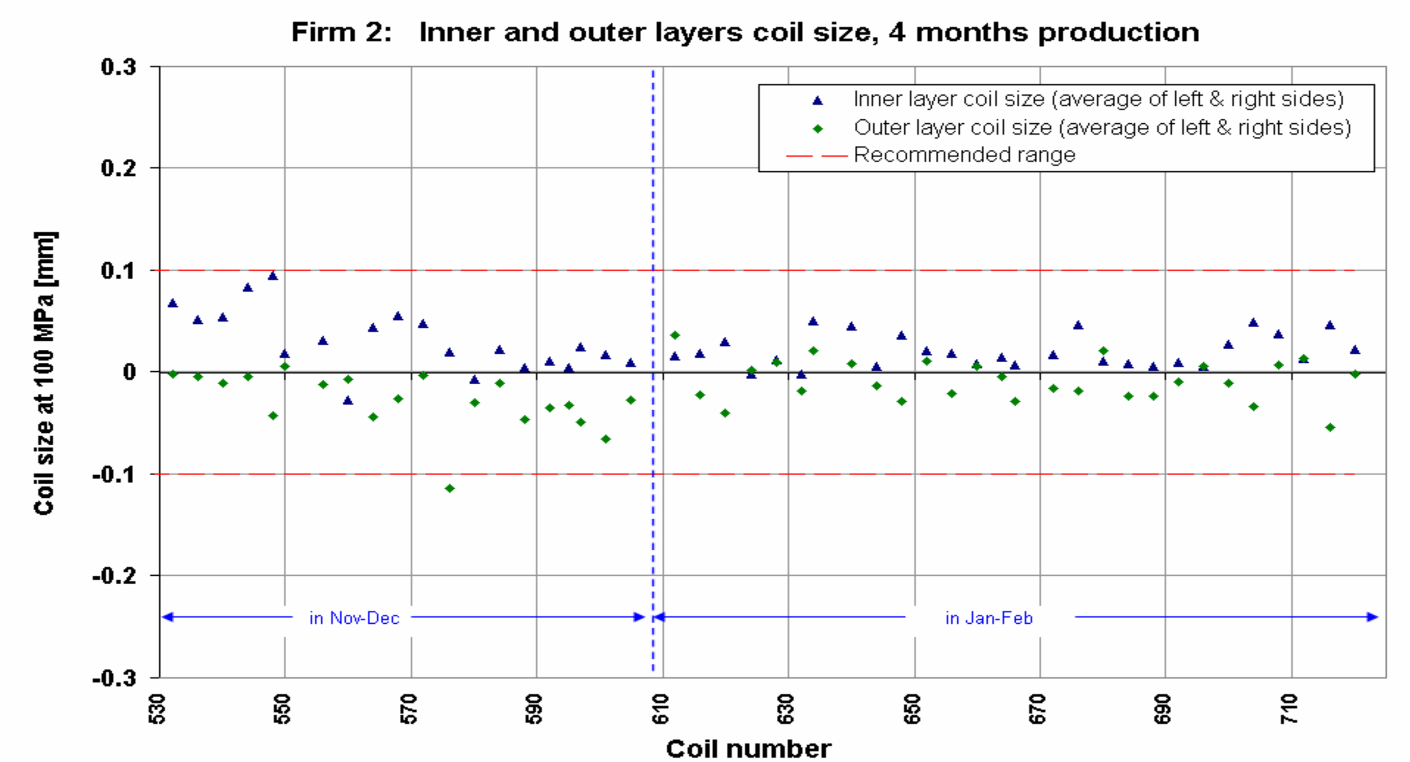
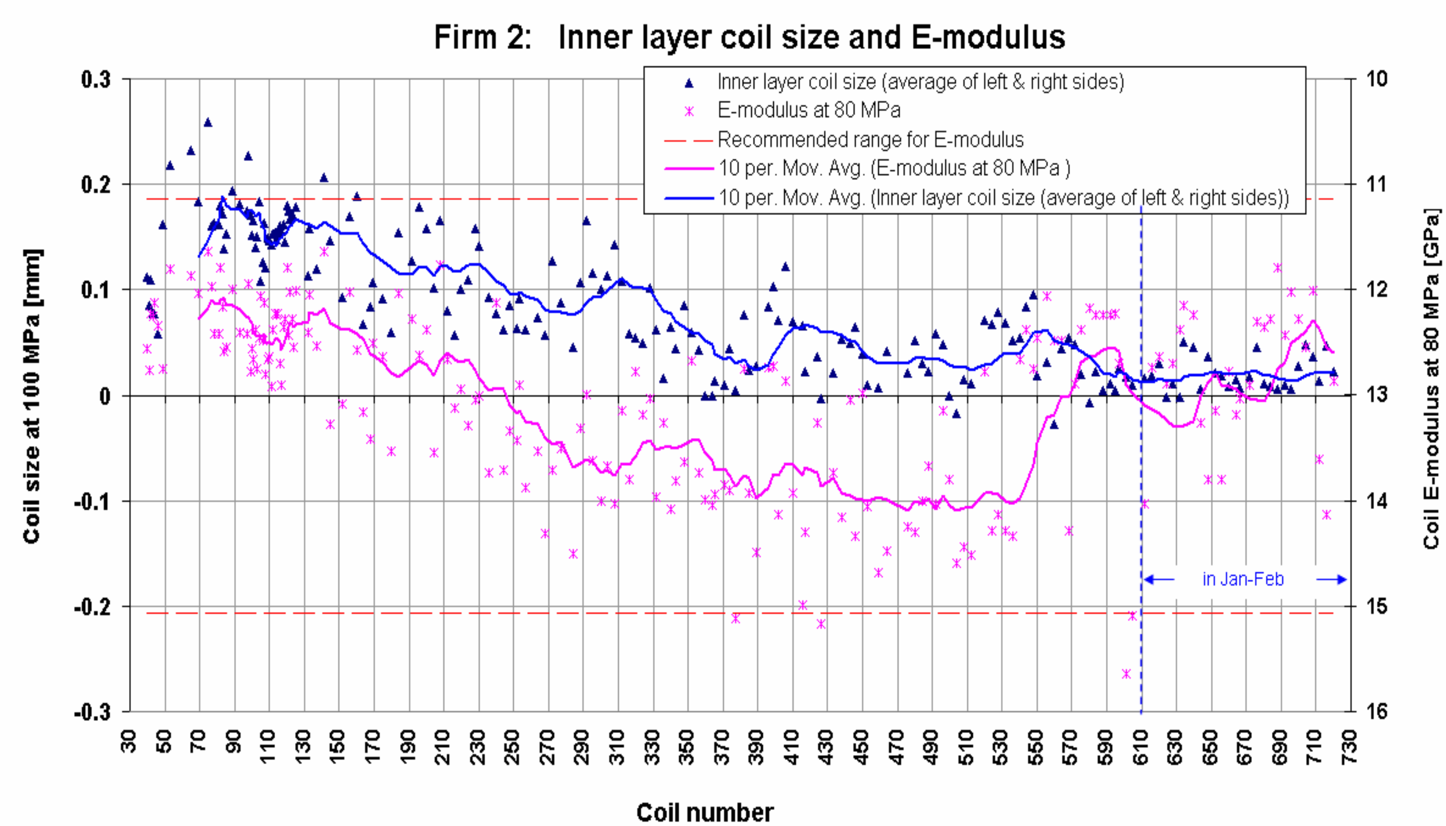


Fig. 3 Average coil size in the straight part of the single layers at Firm 2.
Upper plot all data up to date, lower plot: 4 month production.



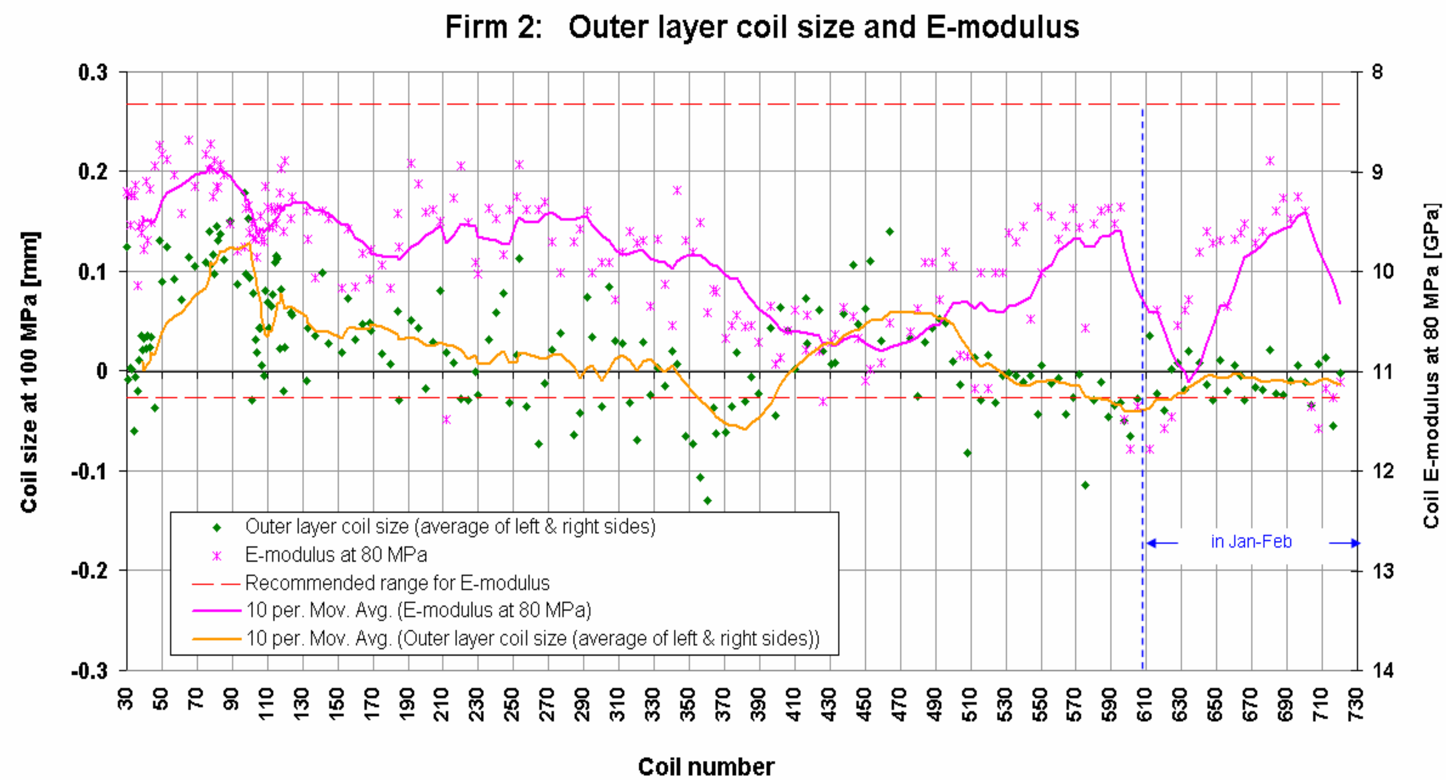
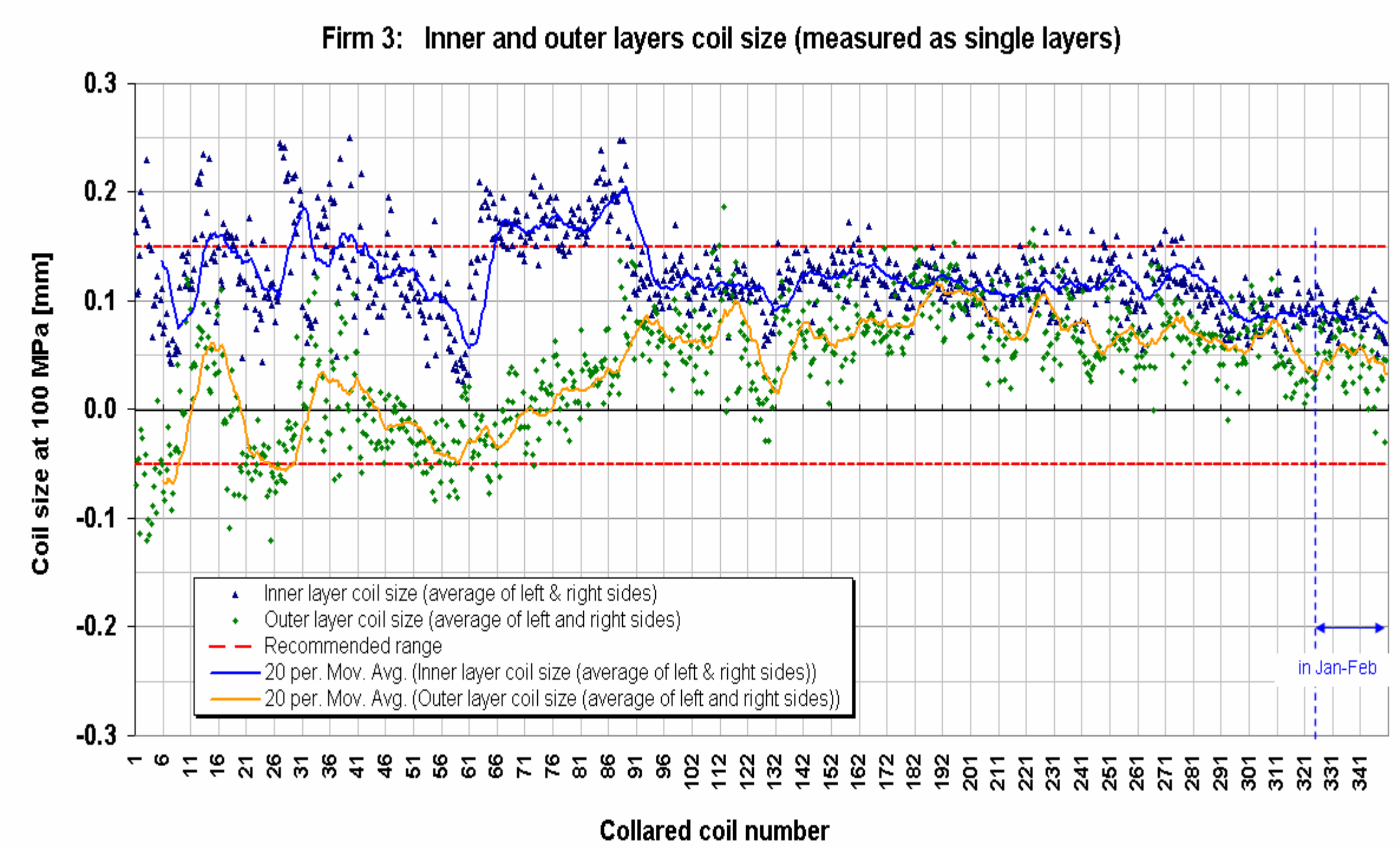


Fig. 4 Average coil size and coil E-modulus computed at 80 MPa compressive stresses (data from the measurements on single layers at Firm 2).



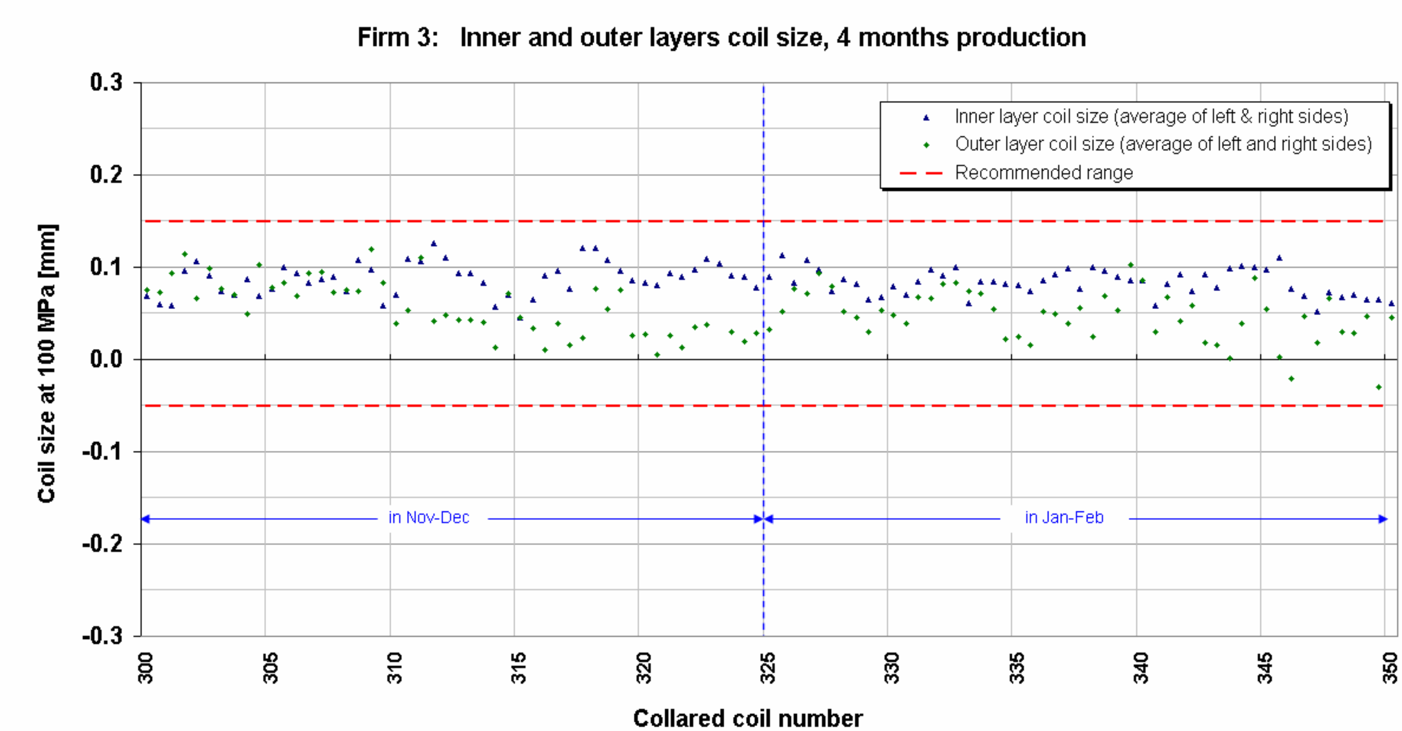


Fig. 5 Average coil size in the straight part of the single layers at Firm 3. Upper plot all data up to date, lower plot: 4 month production.

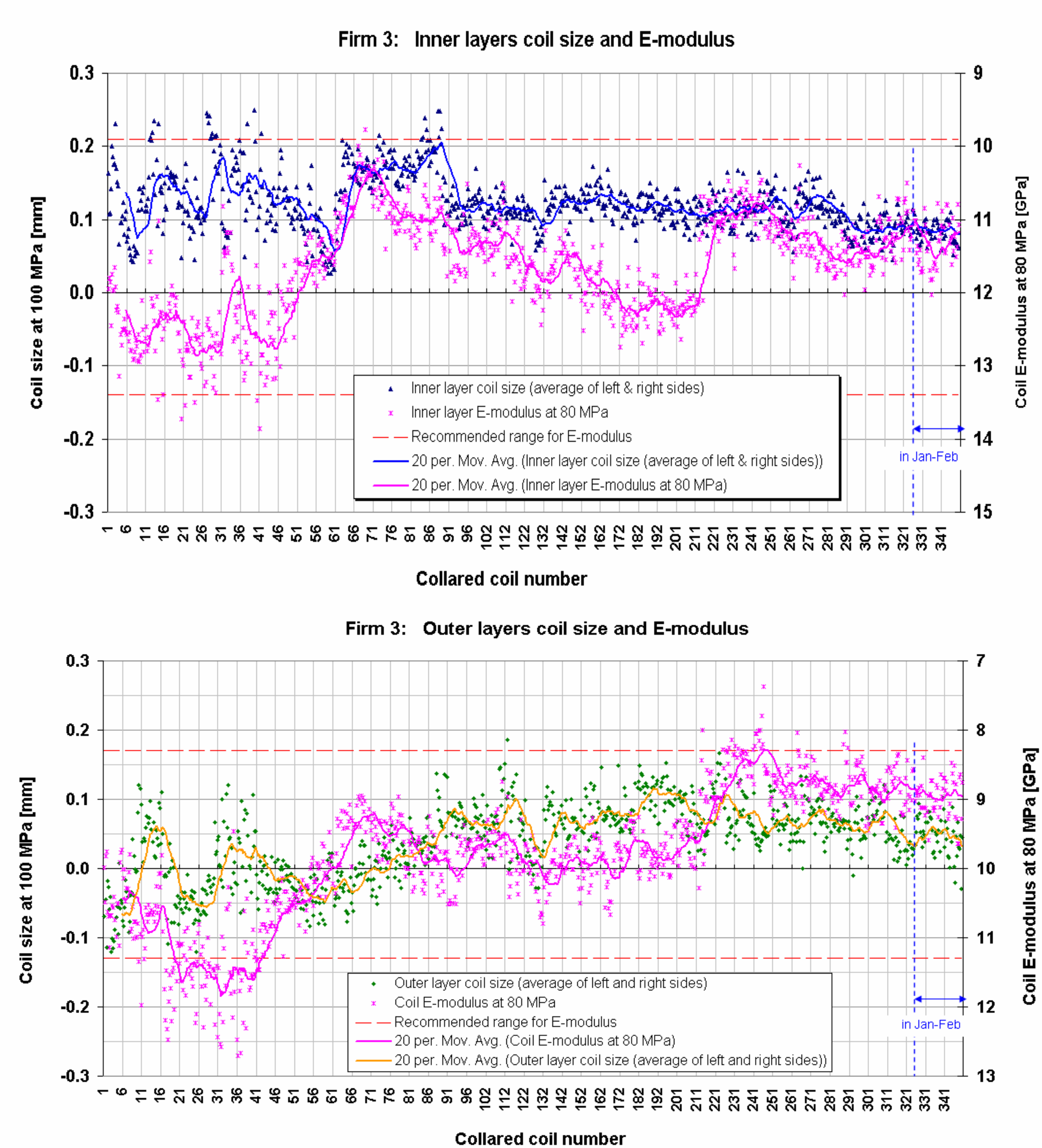


Fig. 6 Average coil size and coil E-modulus computed at 80 MPa compressive stresses (data from the measurements on single layers at Firm 3).

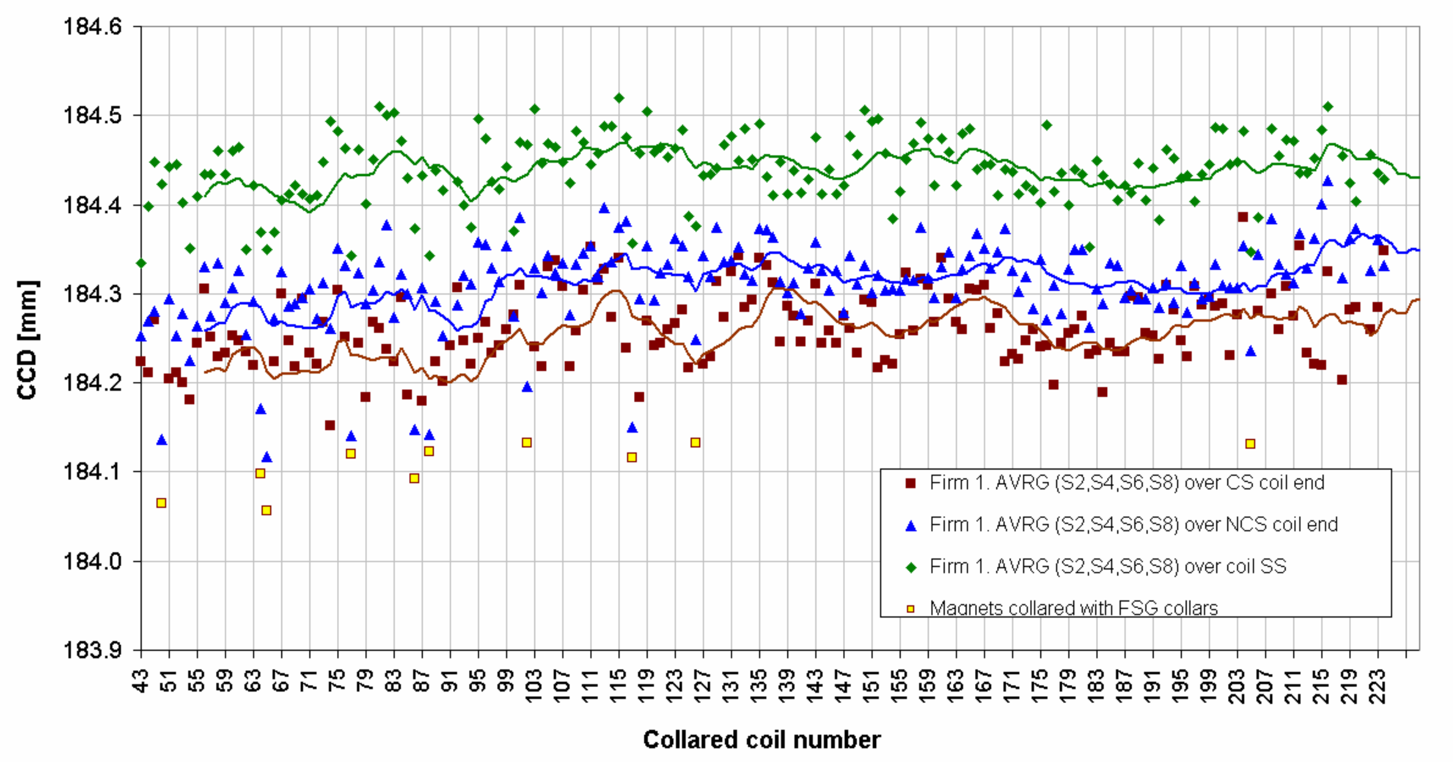


Fig. 7 CCD data for collared coils of firm 1 in averages for coil straight section (SS), connection side (CS) and non-connection side (NCS) ends.

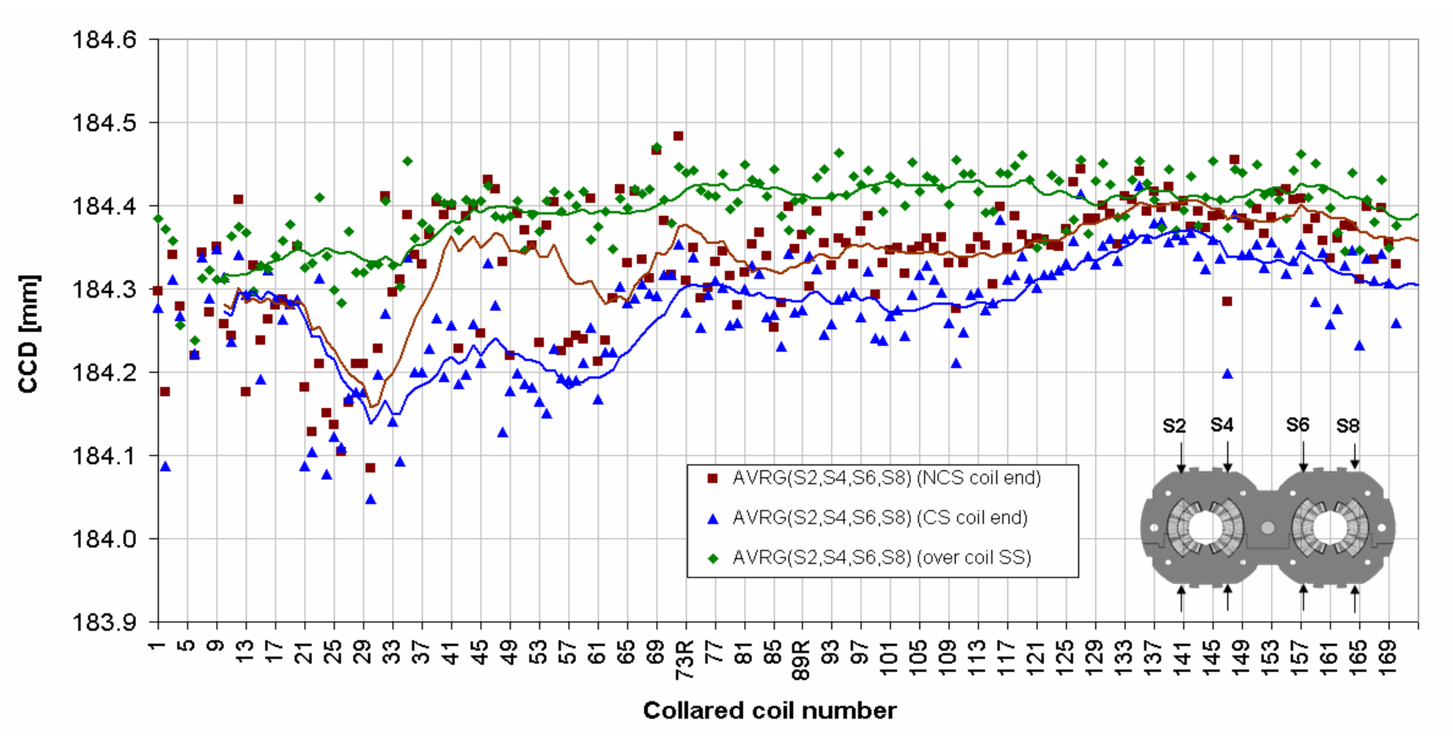


Fig. 8 CCD data for collared coils of firm 2 in averages for coil straight section (SS), connection side (CS) and non-connection side (NCS) ends.

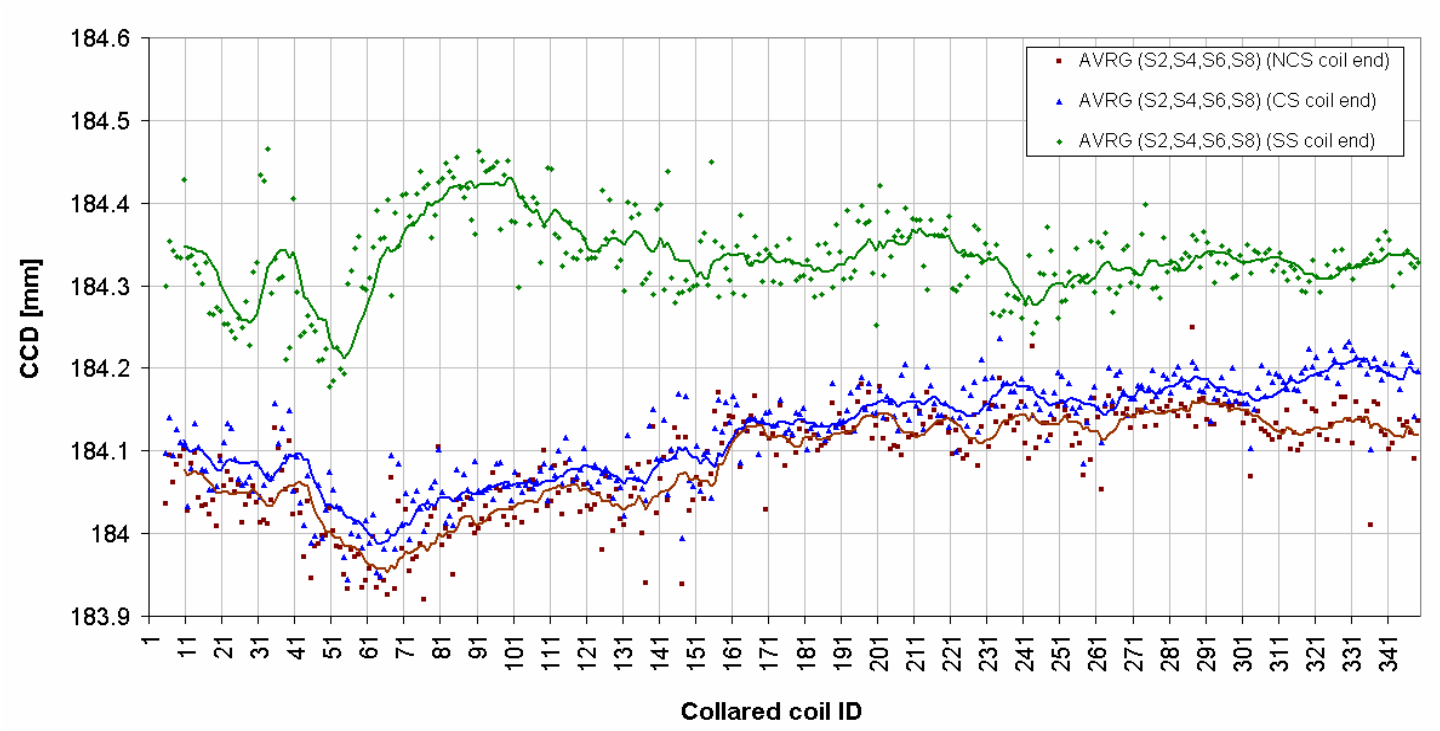


Fig. 9 CCD data for collared coils of firm 3 in averages for coil straight section (SS), connection side (CS) and non-connection side (NCS) ends.

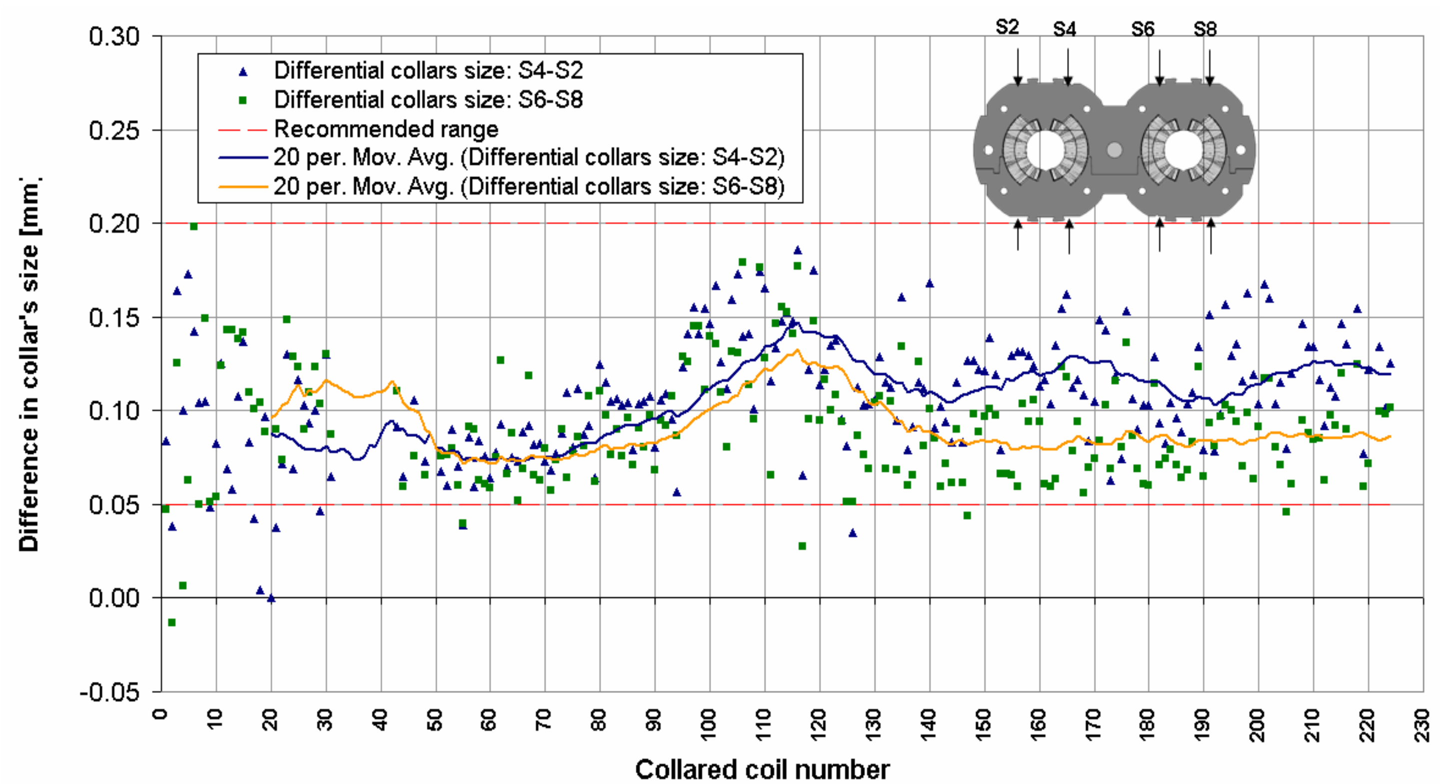


Fig. 10 Firm 1. Asymmetry in collar's vertical dimensions.

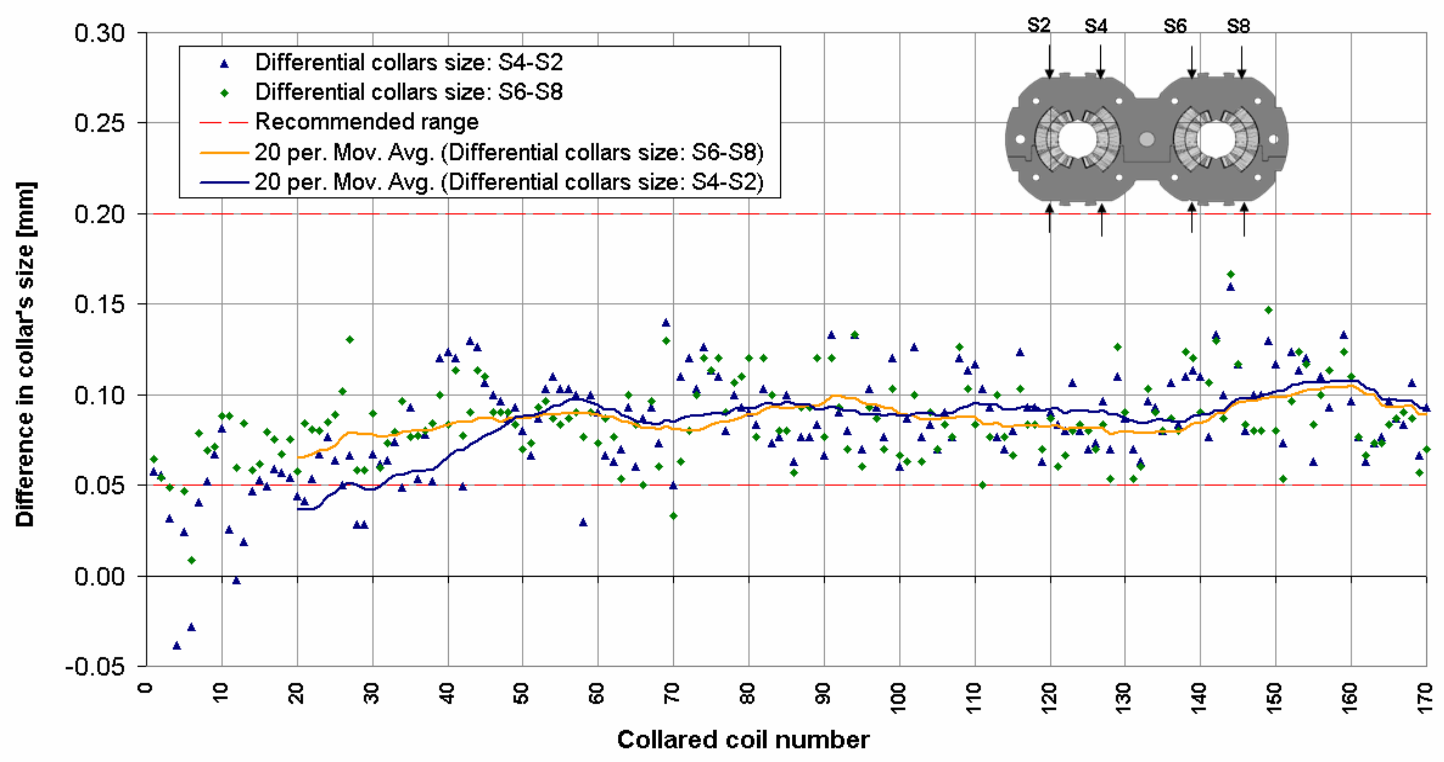


Fig. 11 Firm 2. Asymmetry in collar's vertical dimensions.

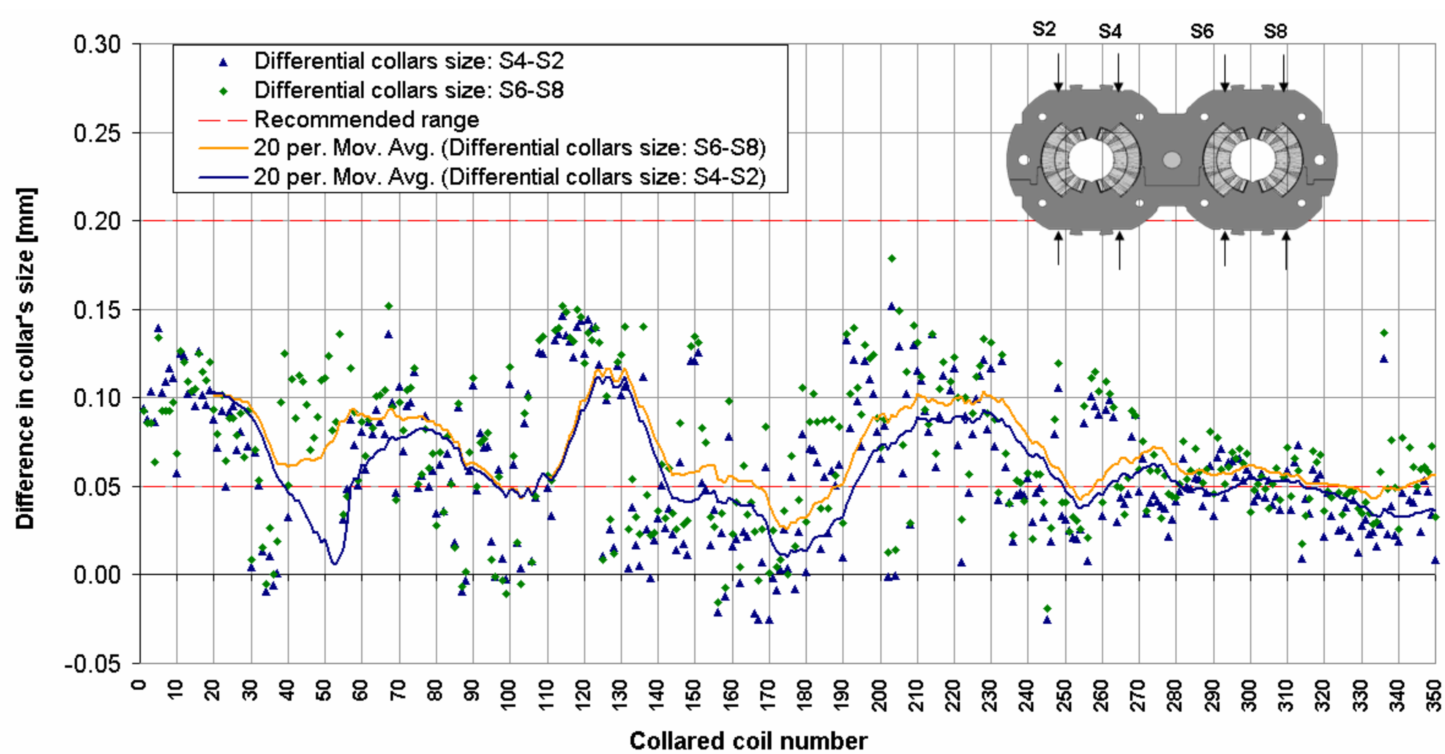


Fig. 12 Firm 3. Asymmetry in collar's vertical dimensions.