Report on mechanical measurements in the main LHC dipole collared coils: April-June 2003

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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.

The dashboard

- **Firm 1 (ALSTOM-JEUMONT)** – up to date, 248 (48 during last tree months) assembled poles have been produced and all measured.
- **Firm 2 (ANSALDO)** – in total, 54 assembled poles have been measured with the IMMG press; but only 4 during last three months and these at a reduced number of positions (three in the coil straight part). Up to date, 185 inner and outer layers have been produced, but only 65 inner and 75 outer have been measured (typically, one inner and one outer layer per magnet are measured).
- **Firm 3 (NOELL)** – NOELL keeps measuring all produced coils layers. Up to date, more then 200 inner and outer layers have been measured.

What is new

Change of measuring procedure at JEUMONT. The updated Collared Coil Database software package, developed at CERN, was installed at ALSTOM and at JEUMONT. This software allowed to introduce a simplified measuring procedure at JEUMONT, as proposed by CERN, and this way significantly reduces the time of measurements and data treatment. The procedures for pairing the poles and computing the collaring shims (previously done manually by JEUMONT and by ALSTOM) are embedded into the post-processor and viewer applications.

Trends in coil sizes. A positive trend in the coils size is observed for the last 15 pole sets at firm 1. If the nominal shims will be kept for the CC 58 -60, a too high coil pre-stress in these magnets is to be expected (from 5 to 10 MPa higher than the upper limit).

Coil waviness. We present a standard deviation of coil size measured in many positions along the coil for tree firms.

Web site. We recall that the web site is available for monitoring the coil size measurements in the production at http://lhc-div-mms.web.cern.ch/lhc-div-mms/MMSPAGES/MA/Obs_coil.html. You need your Nice password to retrieve the information from this web site.

1. Data of coil size measurements

Coil size trends and their impact on the coil pre-stress in the magnets.

Firm 1. The coil size at firm 1 is measured on assembled poles. The data on the coil size continues to show a significant non-systematic variation (fig. 1), but for the coil of series production the coil size variation is smaller compared to the coils of pre-series (0.2-0.3 mm instead of 0.5 mm). It should be stated that starting from CC 27 a new measuring procedure ahs been implemented at firm 1 (the map of measuring positions along the coil was changed). For the last 15 pole sets (1 pole set includes 4 poles which are supposed to be used in the same collared coil), a positive trend in the coil size is noticed.

Each coil is measured in 15 longitudinal positions. The standard deviation (one sigma) of coil size variation along the coil is shown in figure 2. The area below the red dashed line in this figure shows the allowed range for coil waviness. The number of coils appeared in excess of this range.

The difference in coil size between the left and right sides of coils is shown in figure 3. In figures 4 and 5, the inner and outer layers coil sizes are plotted together with their E-modulus (notice that the scale for E-modulus axis is reversed).

Firm 2. Only 24 new layers: 11 inner layers and 13 outer layers have been measured in last 3 months. As can be seen in figure 6, the coils of pre-series magnet seem to exhibit a trend and were deemed to be too large. As a corrective action, starting from the inner layer № 75 (red dashed line in fig. 6) the inner layers coils were cured with an extra shim of 0.1 mm in the curing mould. Later, similar action was taken also for the outer layers coils, starting from the outer layer № 98 (blue dashed line in fig. 6). The variation in the coil size in the inner and outer layers coils of series production is in the order of 0.1 mm.

Each coil is measured in 15 longitudinal positions. The standard deviation (one sigma) of coil size variation along the coil is shown in figure 7. The area below the red dashed line in this figure shows the allowed range for coil waviness.

The difference in coil size between left and right sides of coils is shown in figure 8.

In figures 9 and 10, the inner and outer layers coil sizes are plotted together with their E-modulus (notice that the scale for E-modulus axis is reversed). Remark: a significant difference in the values of E-modulus between Firm 1 (figures 4 and 5) and Firm 2 (figures 9 and 10), is mostly due to two facts: first, that the coils at Firm 1 are measured in pole configuration, while the shown data for Firm 2 is related to the coil size measurements done on individual coil layers and second, that measuring machines at two firms are of different design.

Firm 3. More then 60 inner and outer layers have been measured in last 3 months. The coils from №135 till №165 exhibit coil size variation bigger than usual (fig. 11), probably due to manipulations with the curing of coil extremities (due to the problem with end-spacers, it was decided to slightly open the curing mould at the coil ends, in order to reduce the applied pressure during the polymerization). The variation of the coil size along the coil for the subset of the inner layer coils №135-155 shown in fig. 12. In this figure we can see, that the coil size at the coil extremities in most of the inner layer coils is larger than average value shown in fig. 11.
The curing shims in the outer layer mould were increased by 0.1 mm starting from the coil № 117 in order to get the outer layer coil size bigger (blue dashed line in fig. 11). The standard deviation (one sigma) of coil size variation along the coil is shown in figure 13. Here we see that most of the coils (apart the inner layers №135-154 with the problem mentioned above) are well inside the allowed tolerances range (red dashed line in figure 13). In fact, among tree firms, the firm 3 is producing the coil with the smallest coil waviness.
The difference in coil size between left and right sides of coils is shown in figure 14. Here, the difference appears to be around zero in average.
In figures 15 and 16, the inner and outer layers coil sizes are plotted together with their E-modulus (notice that the scale for E-modulus axis is reversed).

2. Measurement data of the collared coil dimensions

Trend graphs (straight part of the coil)

For the details on the procedure of collared coil dimensions measurements at each dipole manufacturer see previous reports.

Firm 1. In figures 17 and 21 the CC dimensions for measuring points S1-10 are shown (each plot gives the data on two symmetrical points). Starting from collared coil 27, the measurements are taken manually at few points (3, 5, 7 and 10) and only at three longitudinal positions in the coil straight part (see figures 18 and 20). The more interesting points for our analysis are the points S2, S4, S6 and S8 and they are not measured in the magnets 27-50. The new measuring system is still not operational at firm 1.

Firm 2. In figures 22 and 26 the CC dimensions for measuring points S1-10 are shown (each plot gives the data on two symmetrical points). The CC dimensions are measured in 78 pre-defined positions along the coil, where 54 positions are taken in the straight part of the coil (each 0.25 m). For the first 7 collared coils the measurements were done manually, whereas starting from the CC-8, the automated measuring machine is in use.

Firm 3. In figures 27 and 31 the CC dimensions for measuring points S1-10 are shown (each plot gives the data on two symmetrical points). At firm 3, for the collared coils of the series, the CC dimensions are measured in 16 pre-defined positions along the coil, where 8 positions are taken in the straight part of the coil (an agreement was achieved between CERN and firm 3 to add 5 measuring positions in order to have more accurate statistics on this data).

We notice an important difference in CC dimensions between two apertures in CC 28 and CC 38-42. The reading of the sensor at the points S2 shows a systematic shift downwards, compared to the symmetrical sensor S8 (fig. 28). The difference between S4 and S2 in the CC36-42 is up to 0.4 mm! (fig. 36). If this is measured values are correct, we should have measured more then 20 units of multipole *b2* in these magnets, which is not the case. Therefore we consider that the calibration of these sensors has to be verified.

Asymmetry in collar's deformation

The left-to-right side asymmetry with respect to the aperture axes in collars deformation produces non-allowed multipole b2. In figures 32-34 the asymmetry in collar's deformation between the lateral and central part of the collars are shown separately for each firm.

Firm 1. We repeat, that starting from magnet 32 at firm 1 there no measurements done at the measuring points S2, S4, S6 and S8, that is why only the data for the pre-series magnets is shown.

Firm 3. The data on measuring points S2 and S4 from the CC 28 and CC 38-42 is dropped due to the problem with sensor S2.

At CERN request, at firm 3 an empty collar-pack was measured to verify the nominal dimensions of the collars. The data on this measurement is shown in figure 35. From this figure we could see, that the systematic offset for the S4-S2 and S4-S6 values of the order of 0.07-0.08 mm, observed in figures 32-34 seems due to the difference in the nominal dimensions of the empty collars.

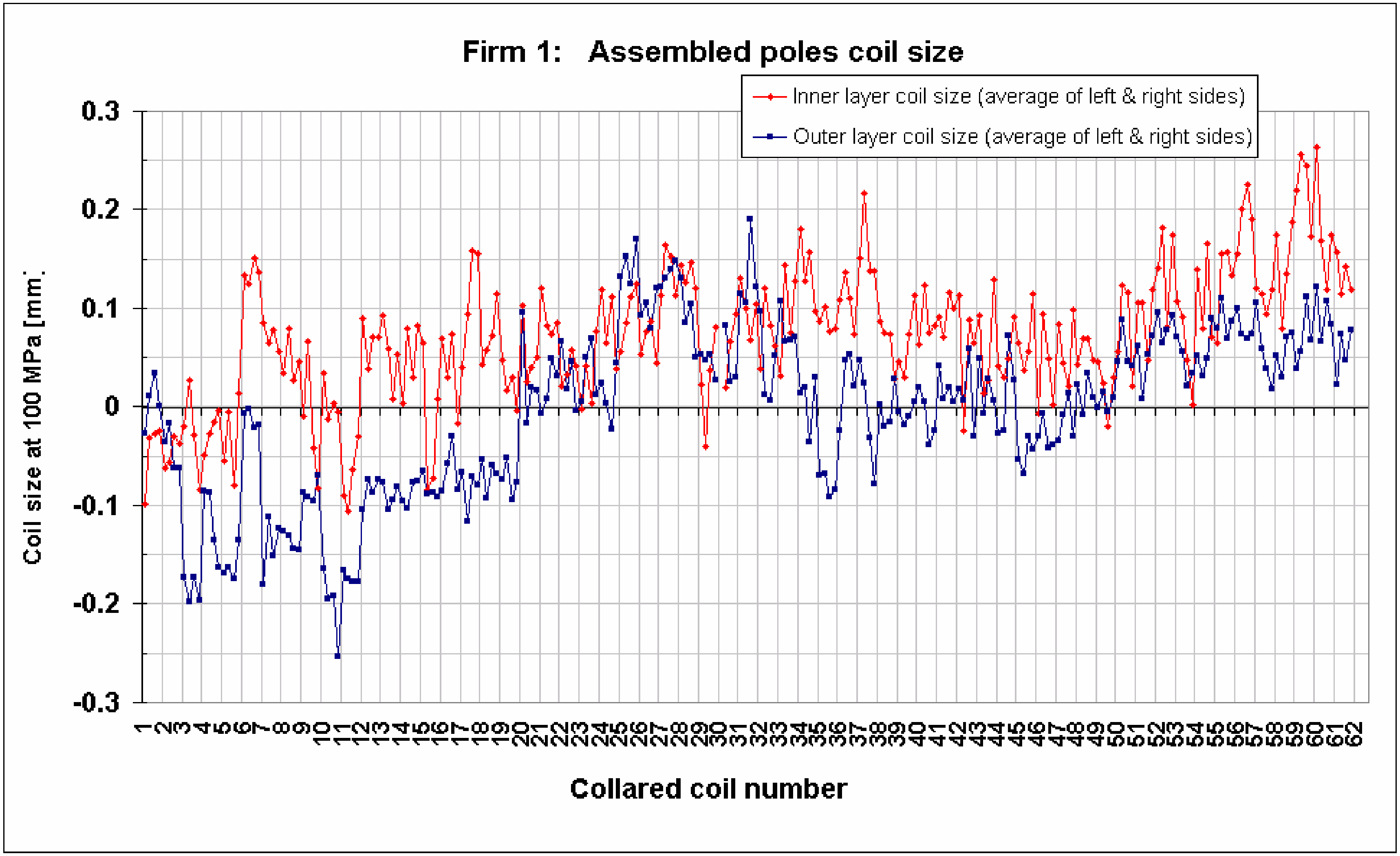

Fig. 1 Firm 1. Average coil size in the straight part of the assembled poles (248 poles).

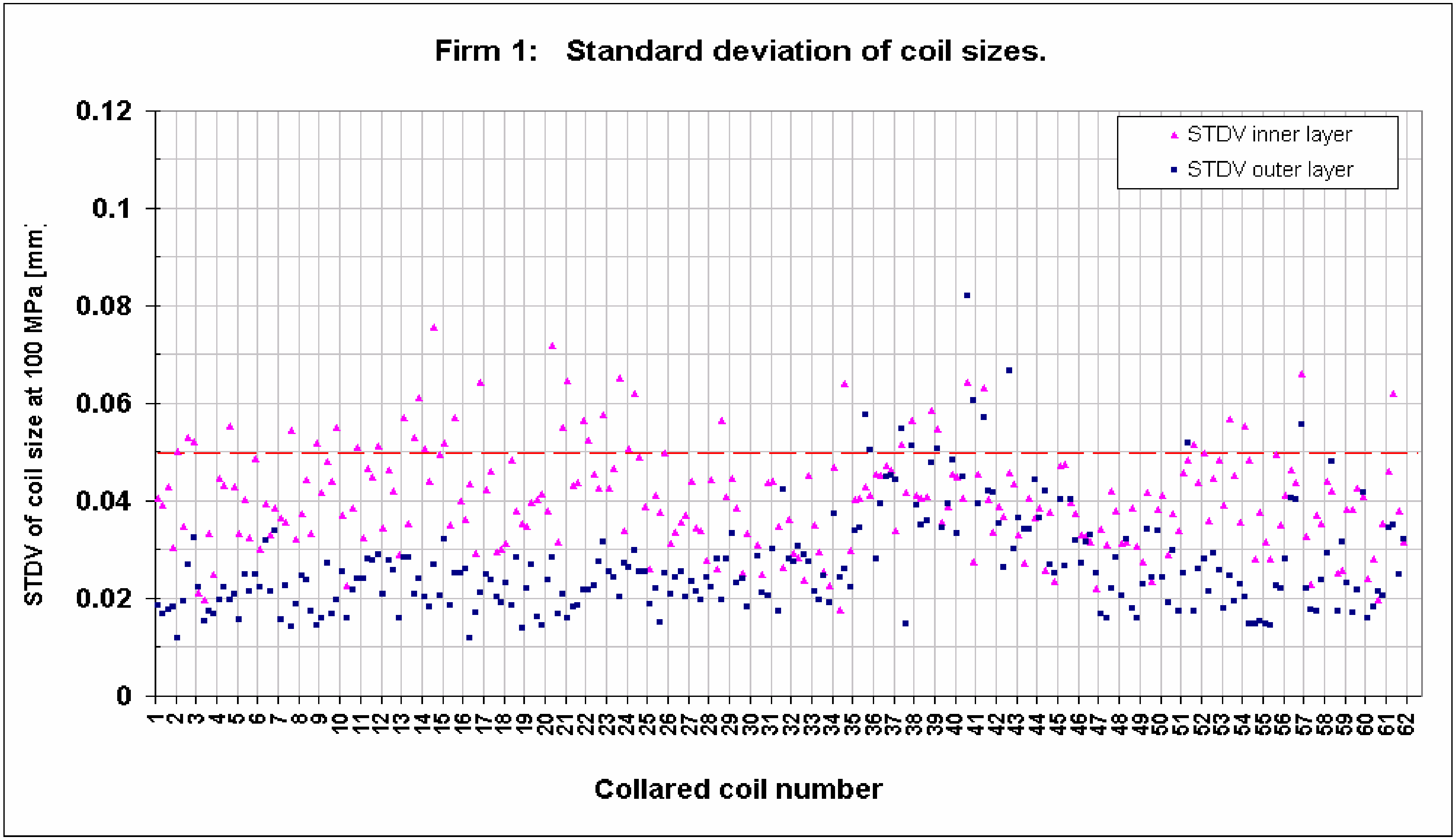

Fig. 2 Firm 1. Standard deviation of coil sizes measured in 15 positions along the coil (left and right coil sides in average). The area below the red dashed line in this figure is the allowed range for coil waviness.

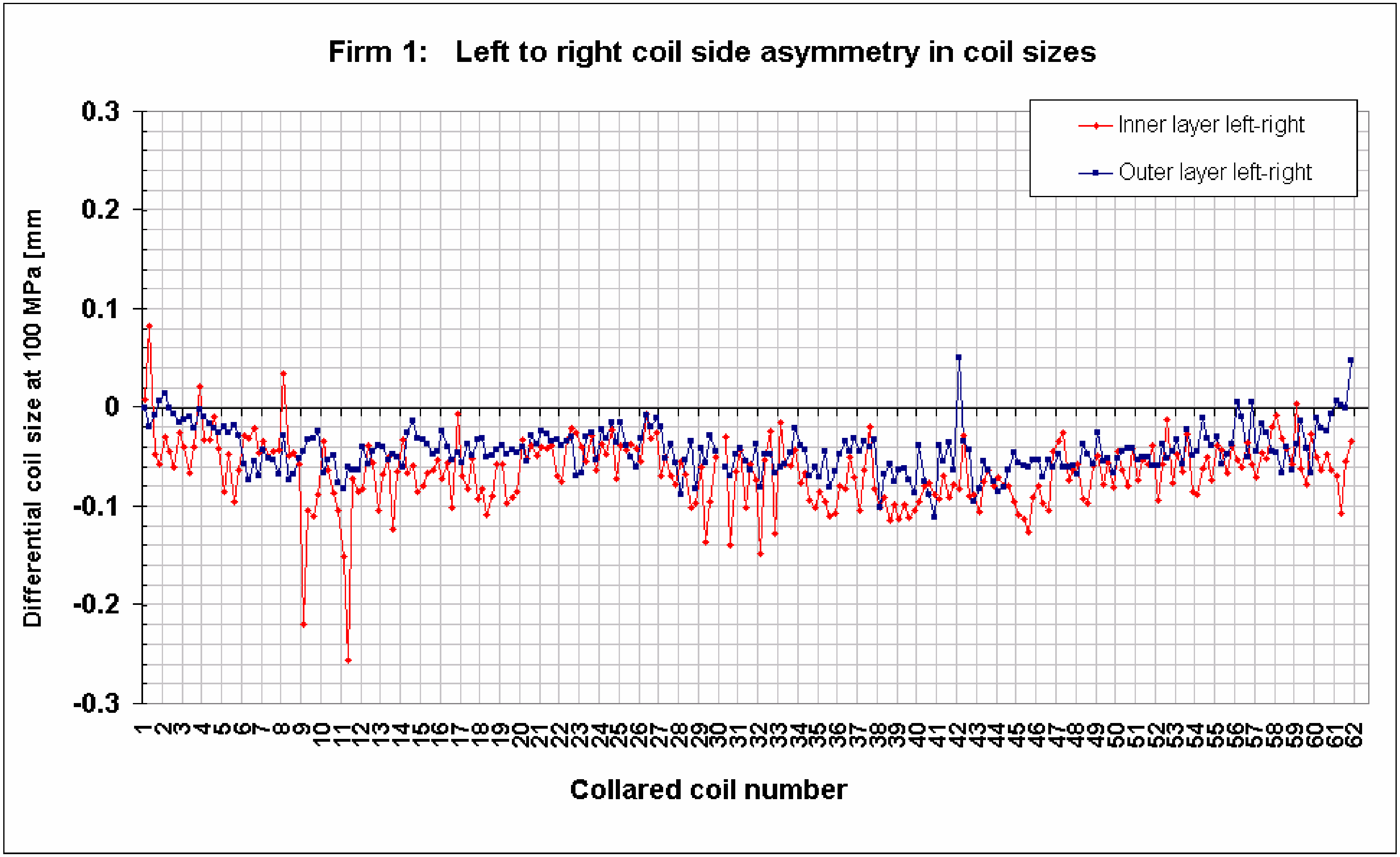

Fig. 3 Firm 1. Difference in the coil size between left and right sides of the coil on both layers.

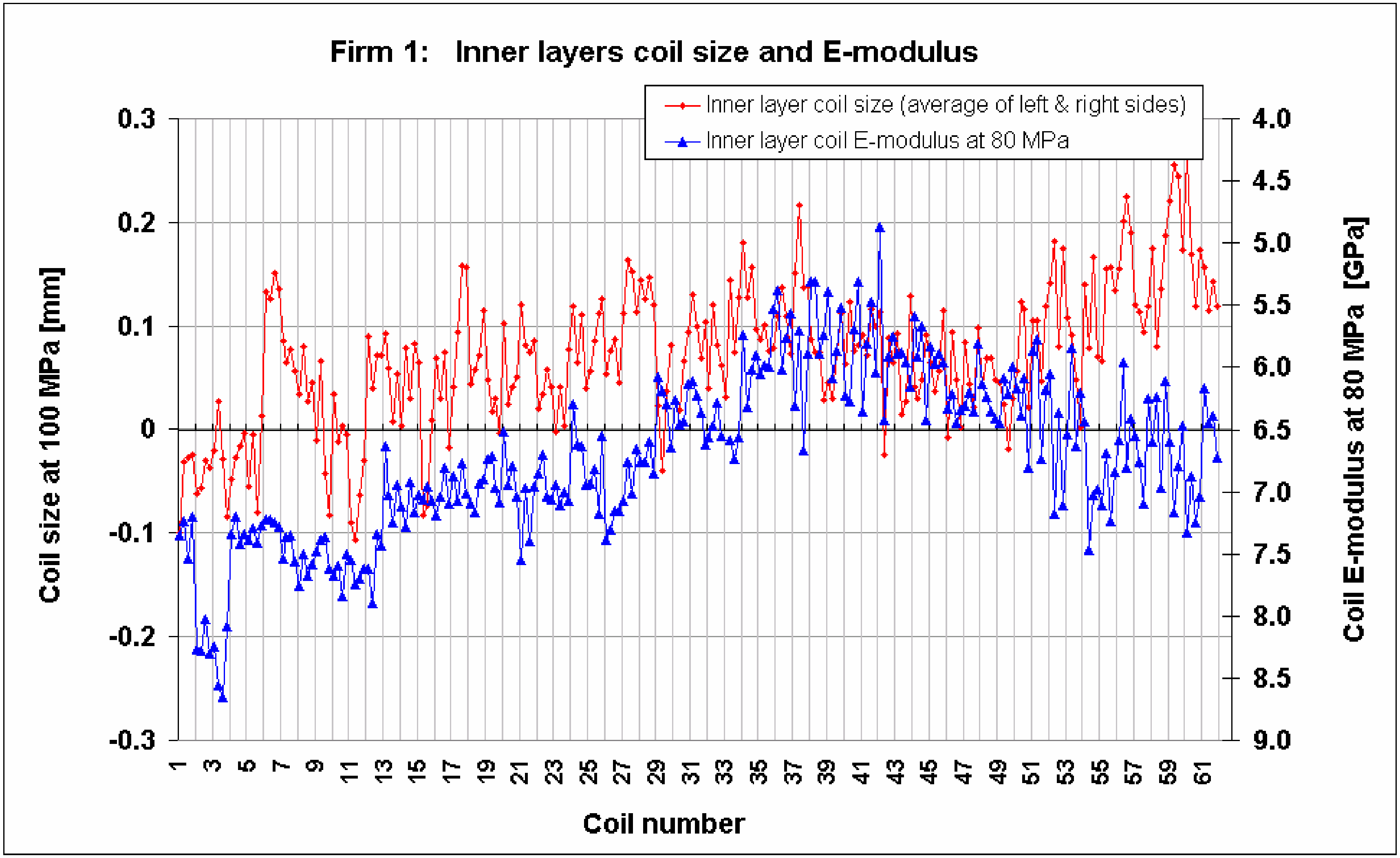

Fig. 4 Firm 1. Inner layer coil size (average) and E-modulus computed at 80 MPa.
(Data extracted from pole size measurements).

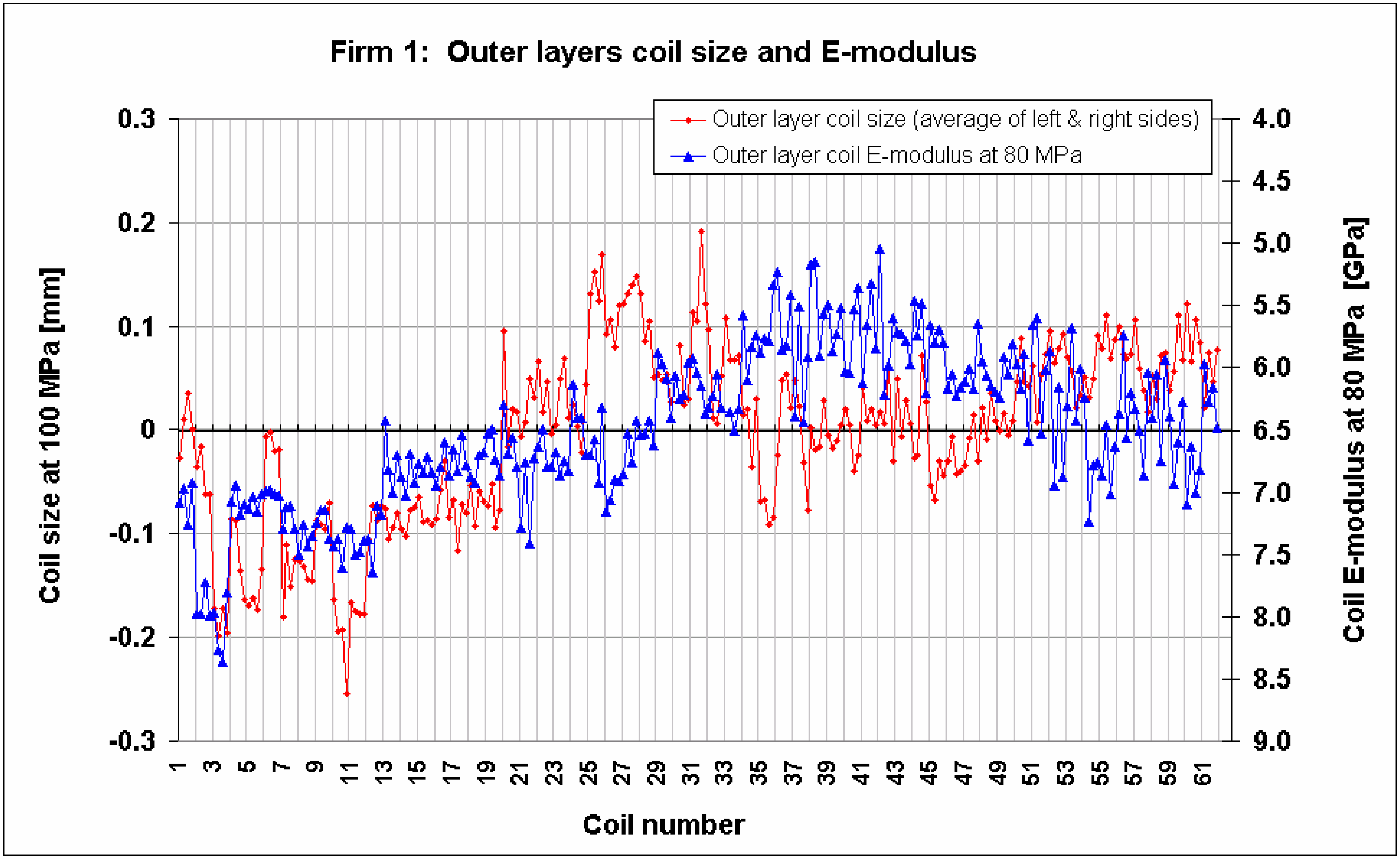

Fig. 5 Firm 1. Outer layer coil size (average) and E-modulus computed at 80 MPa. (Data extracted from pole size measurements).

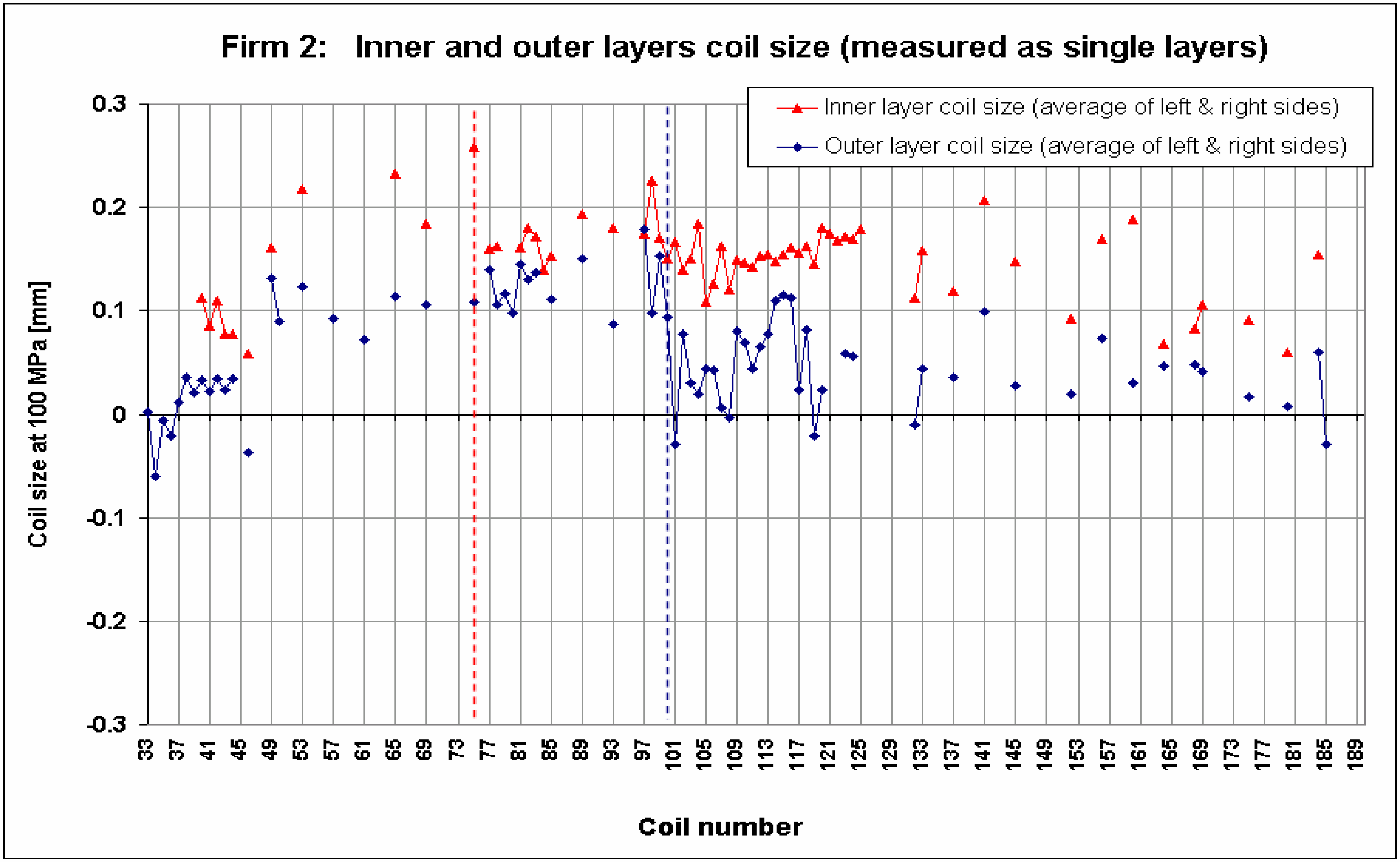

Fig. 6 Firm 2. Average coil size in the straight part of the inner and outer layers.

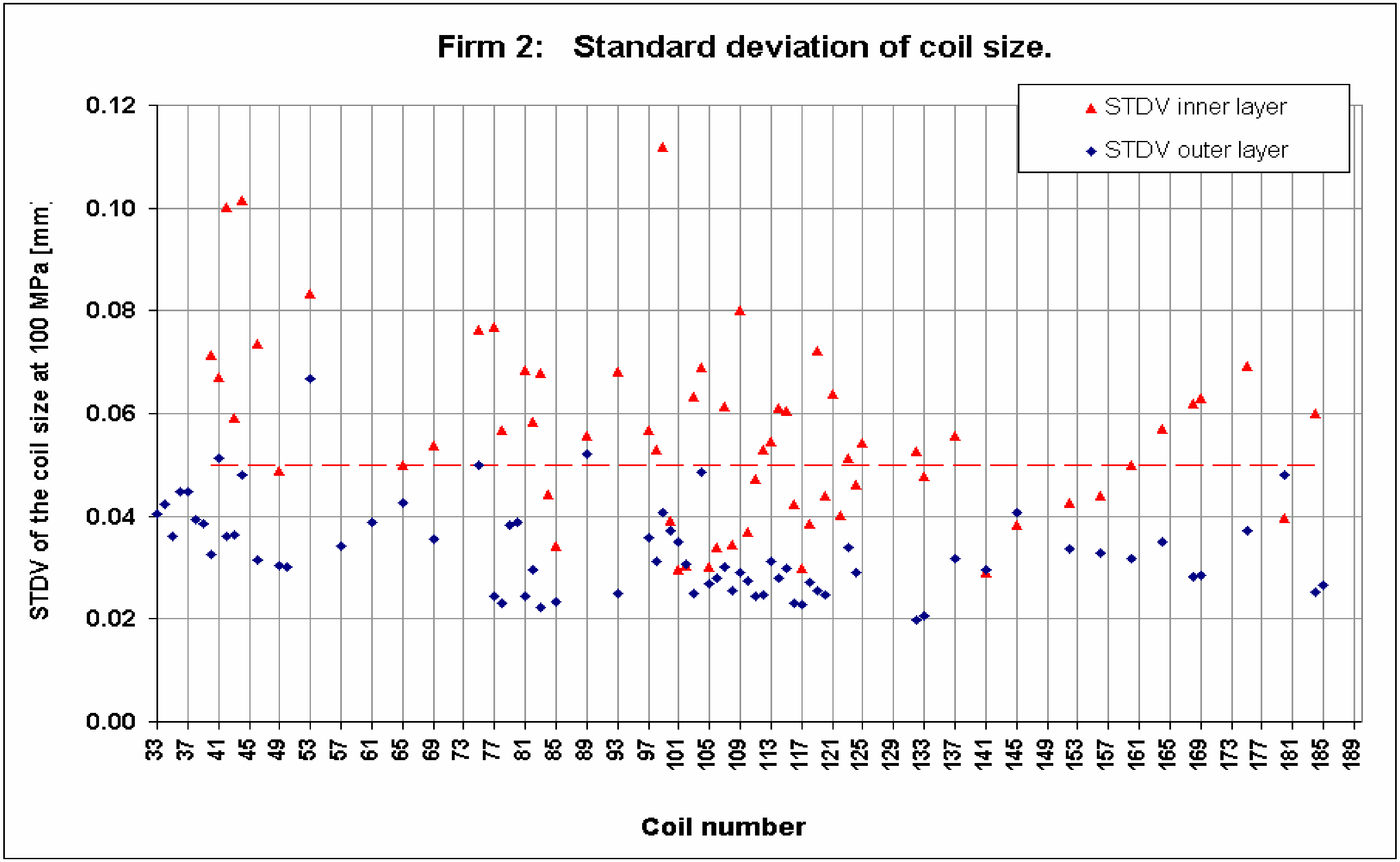

Fig. 7 Firm 2. Standard deviation of coil sizes measured in 15 positions along the coil (left and right coil sides in average). The area below the red dashed line in this figure is the allowed range for coil waviness.

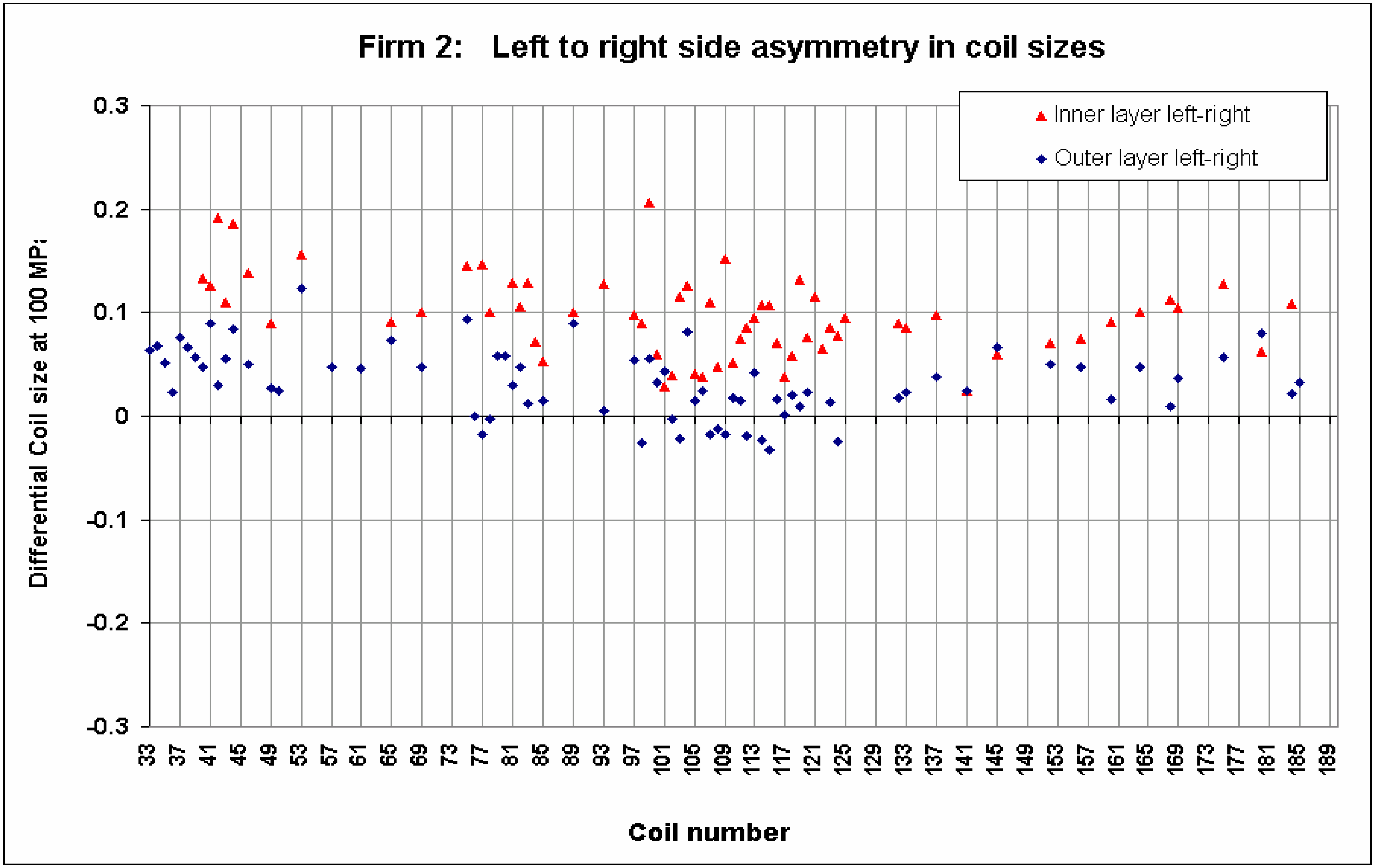

Fig. 8 Firm 2. Difference in the coil size between left and right sides of the coil on both layers.

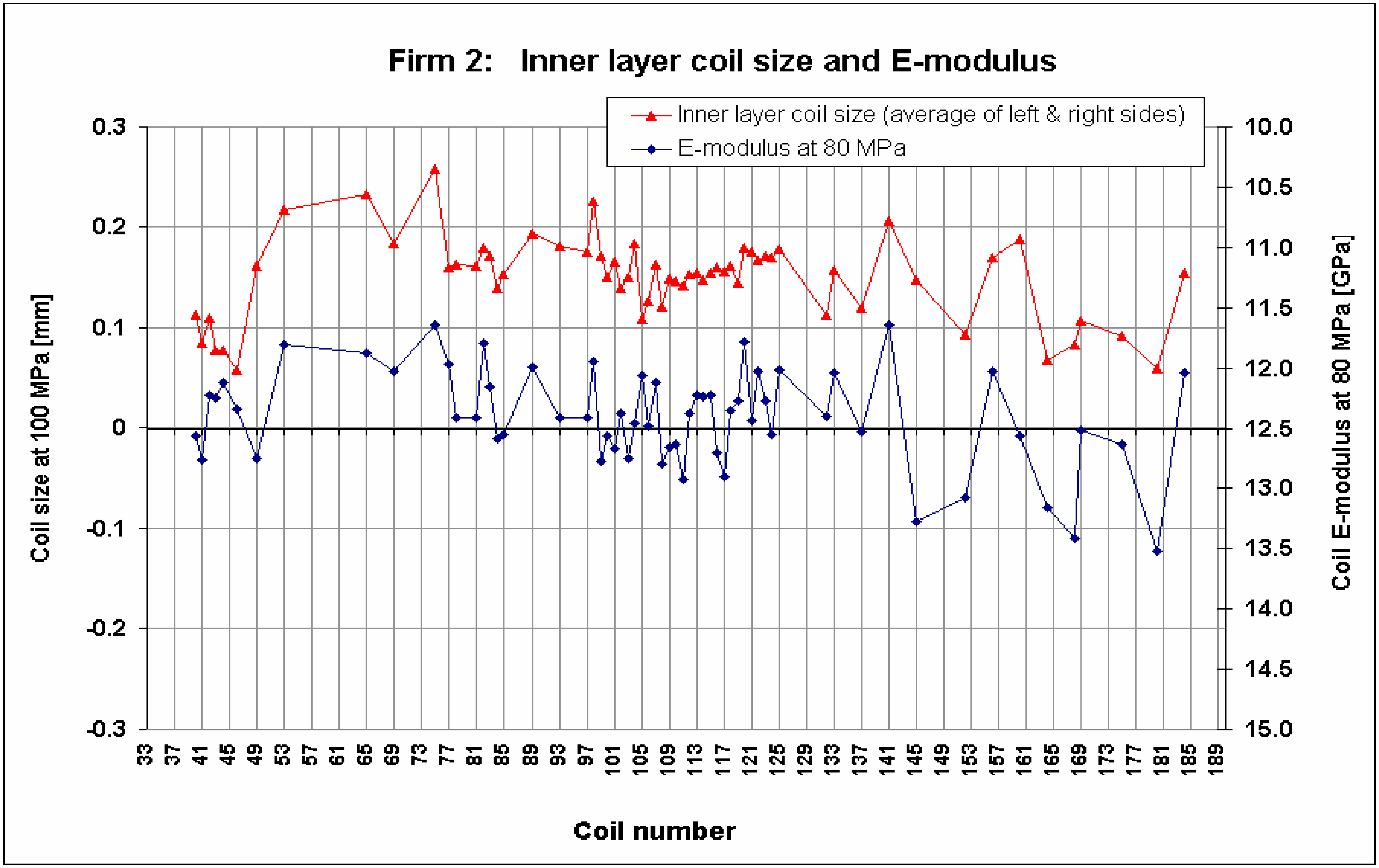

Fig. 9 Firm 2. Inner layer coil size (average) and E-modulus computed at 80 MPa.

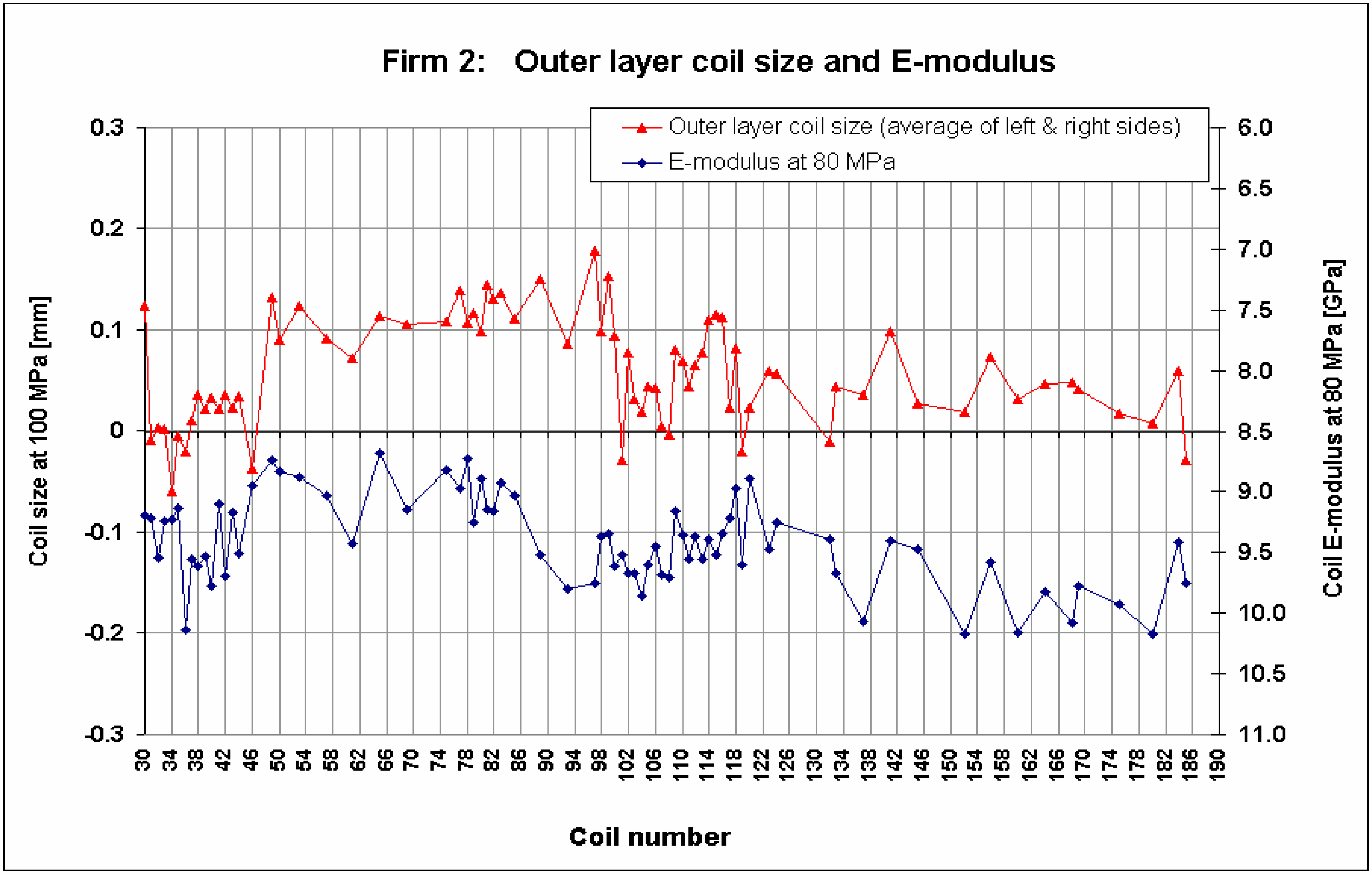

Fig. 10 Firm 2. Outer layer coil size (average) and E-modulus computed at 80 MPa.

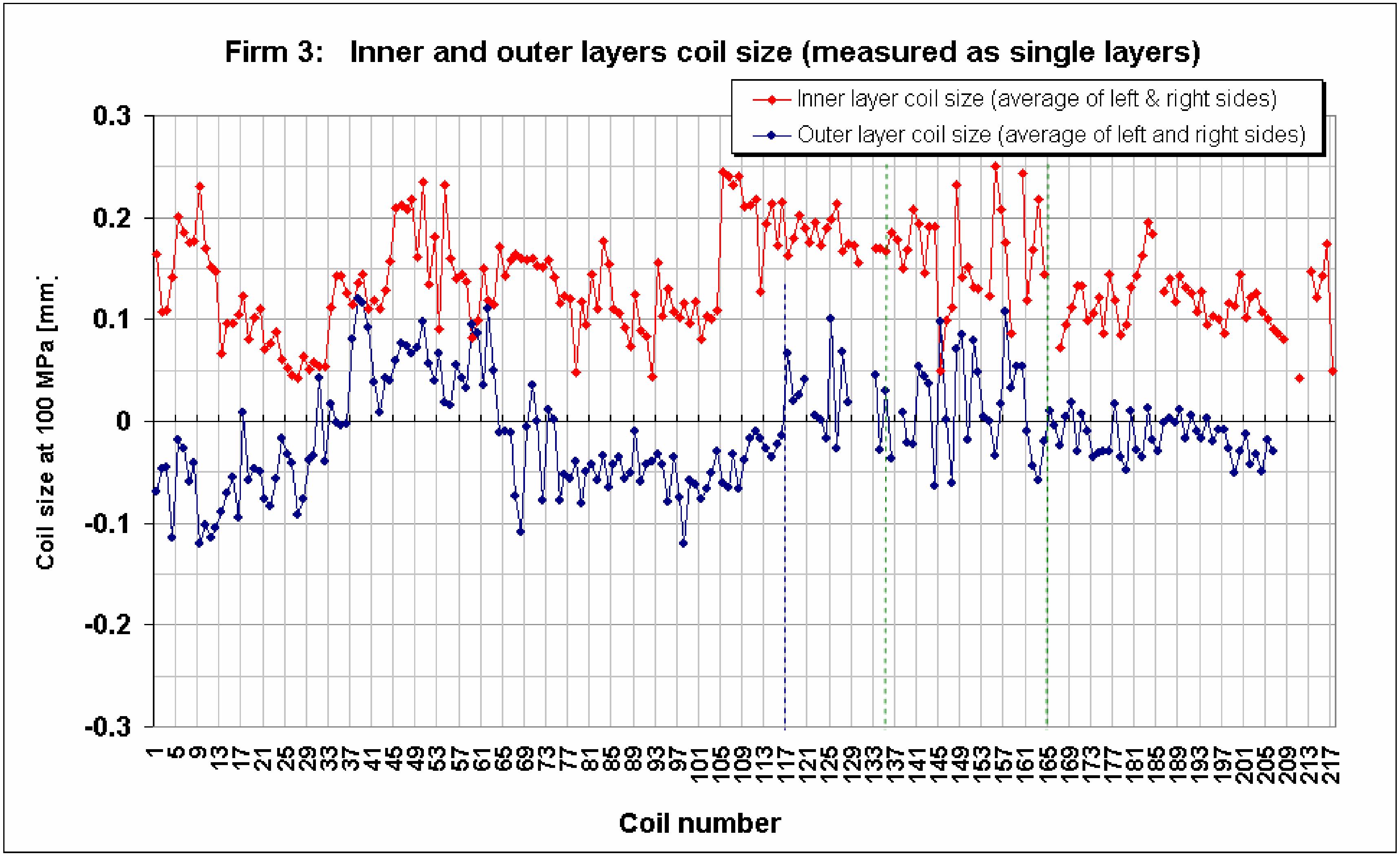

Fig. 11 Firm 3. Average coil size in the straight part of inner and outer layers.

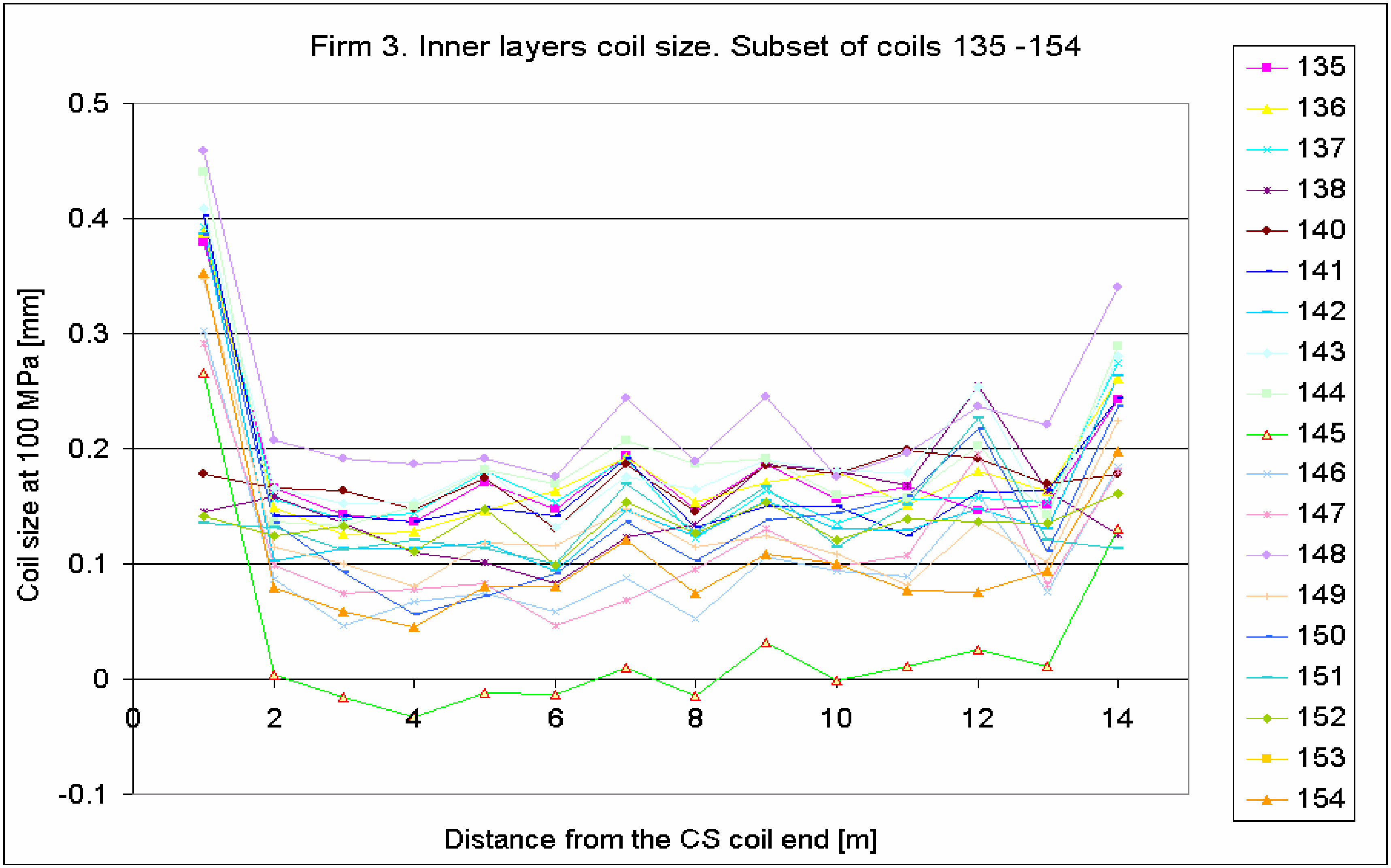

Fig. 12 Firm 3. Coil size variation along the coil for the subset of the inner layer coils 135-154.

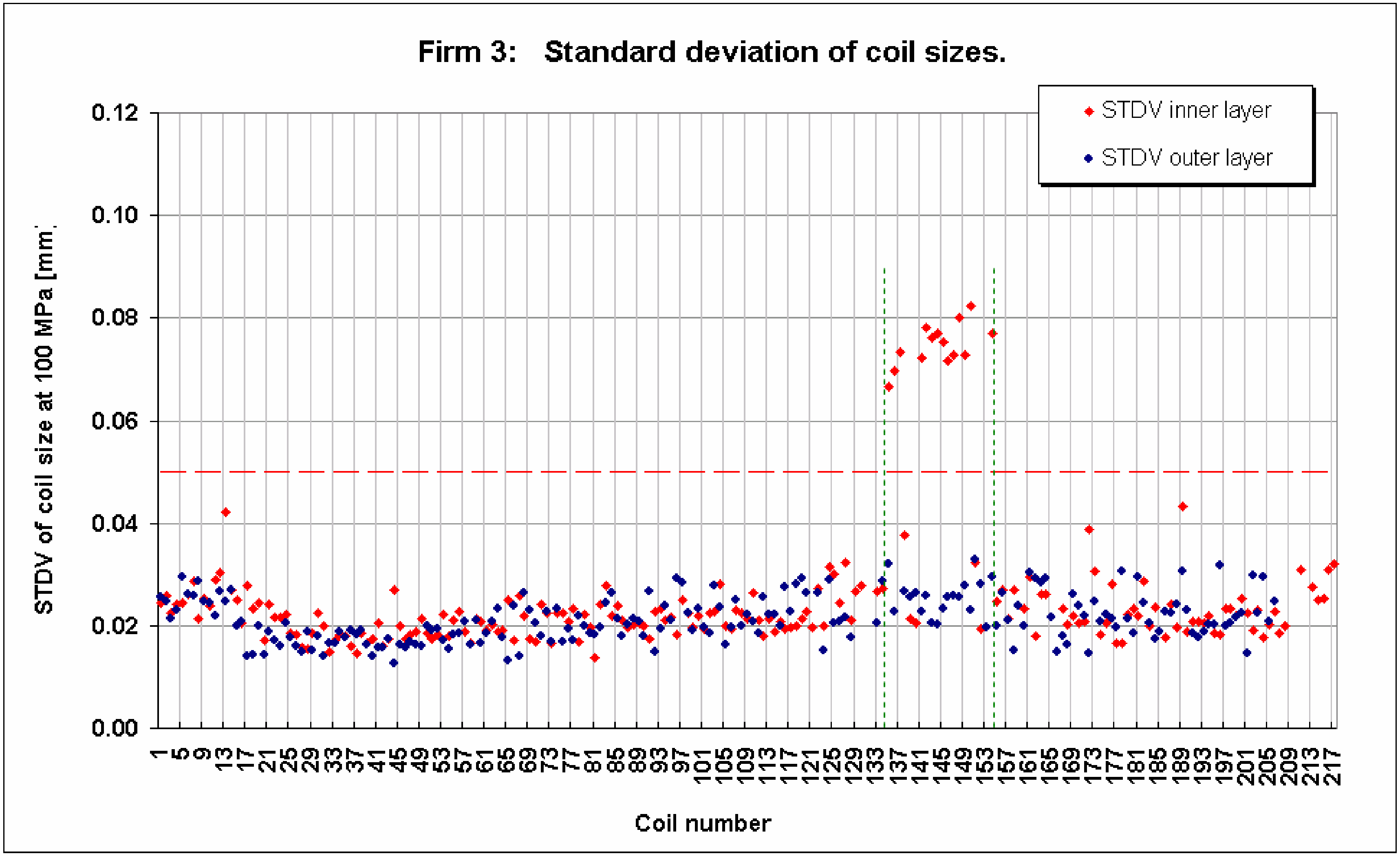

Fig.13 Firm 3. Standard deviation of coil sizes measured in 14 positions along the coil (left and right coil sides in average). The area below the red dashed line in this figure is the allowed range for coil waviness.

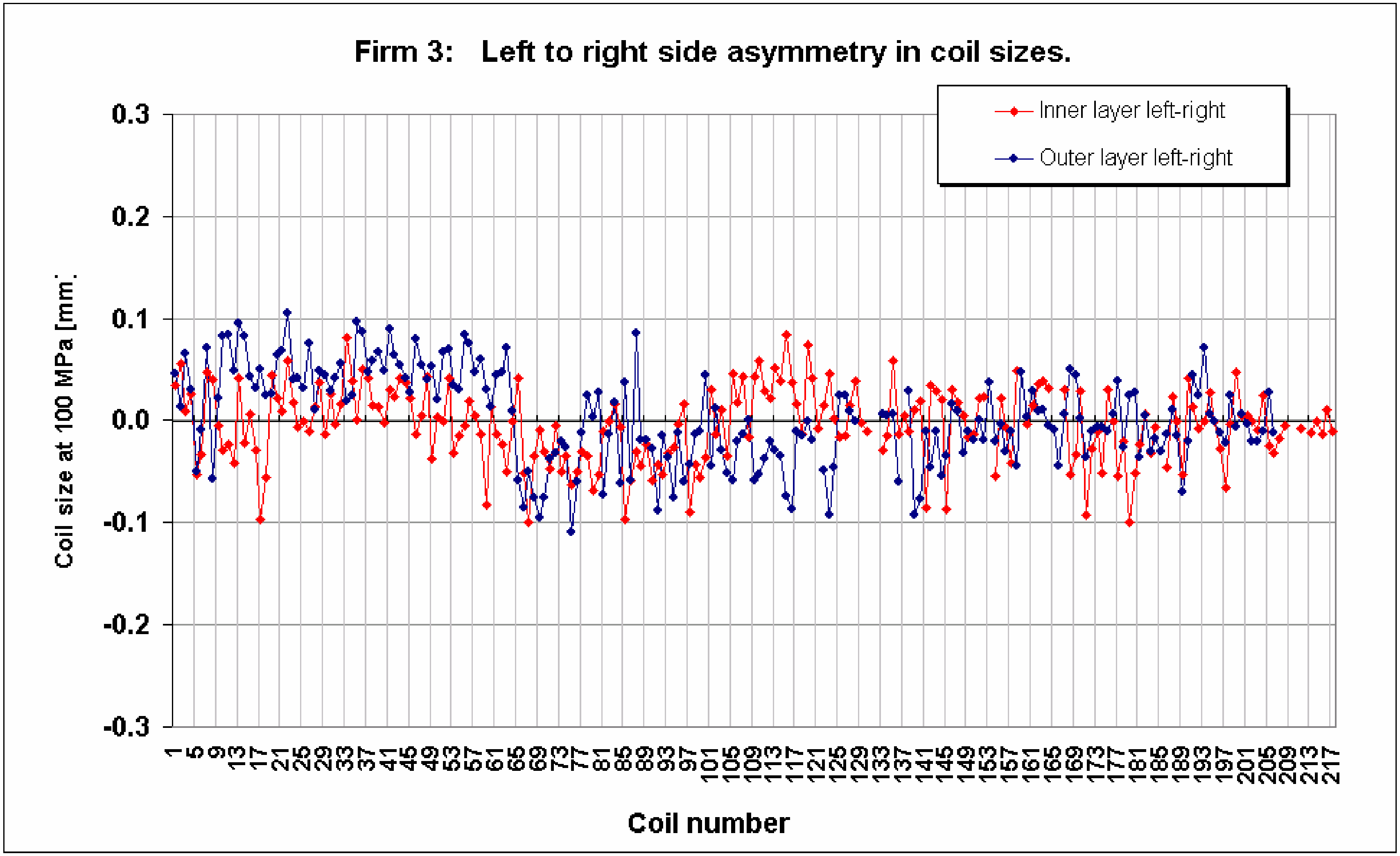

Fig.14 Firm 3. Difference in the coil size between left and right side of the coil on both layers.

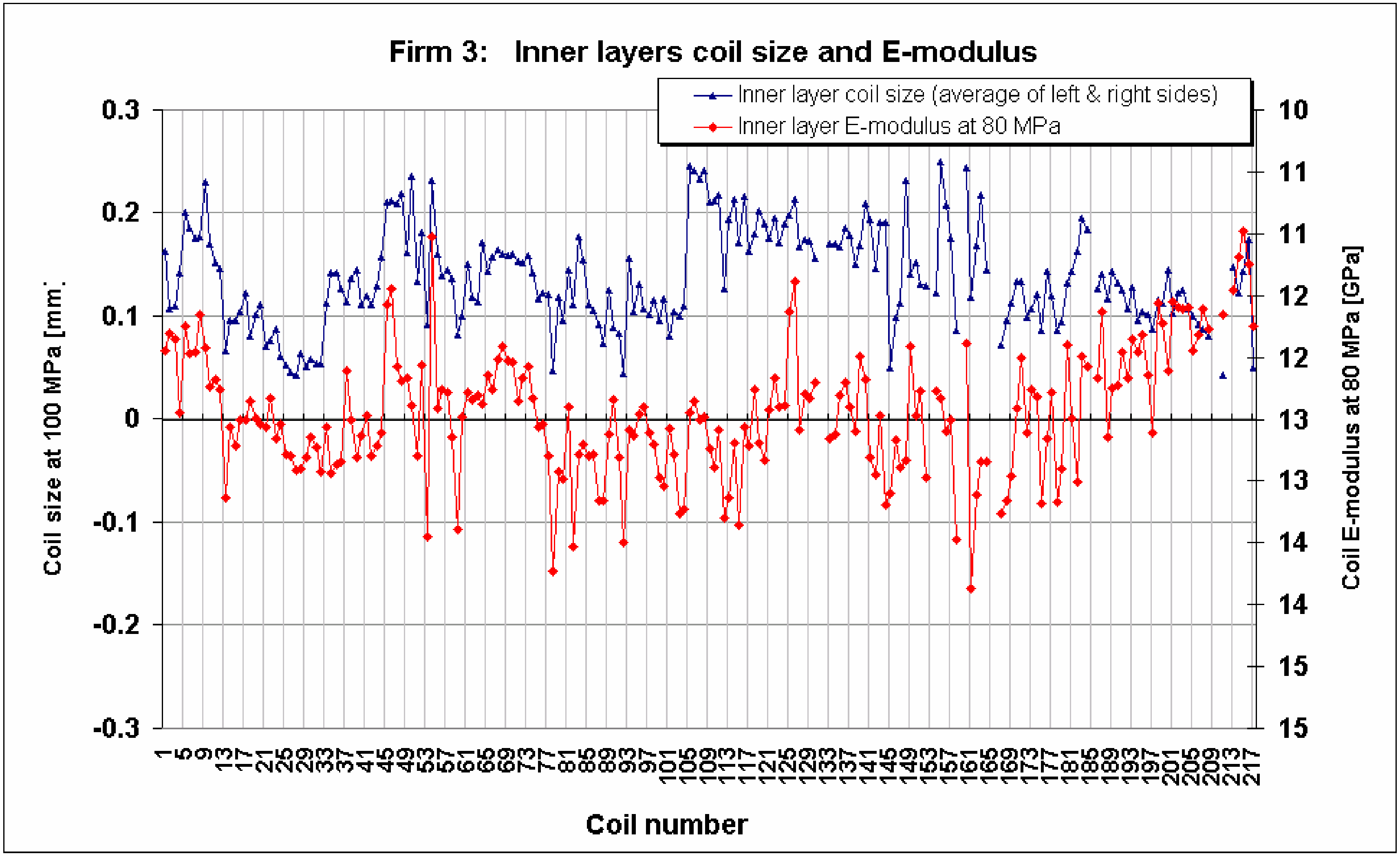

Fig. 15 Firm 3. Inner layer coil size (average) and E-modulus computed at 80 MPa.

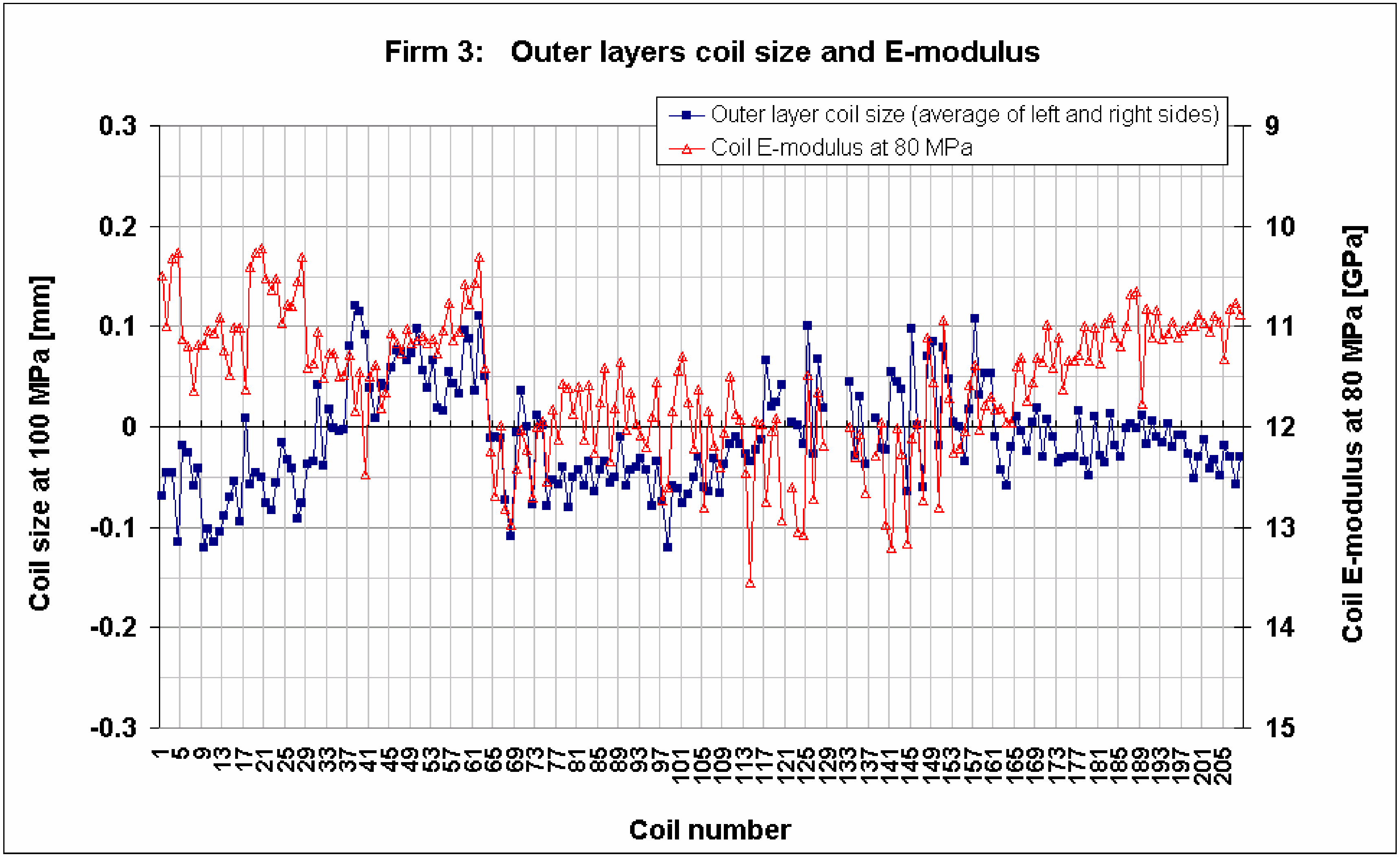

Fig. 16 Firm 3. Outer layer coil size (average) and E-modulus computed at 80 MPa.

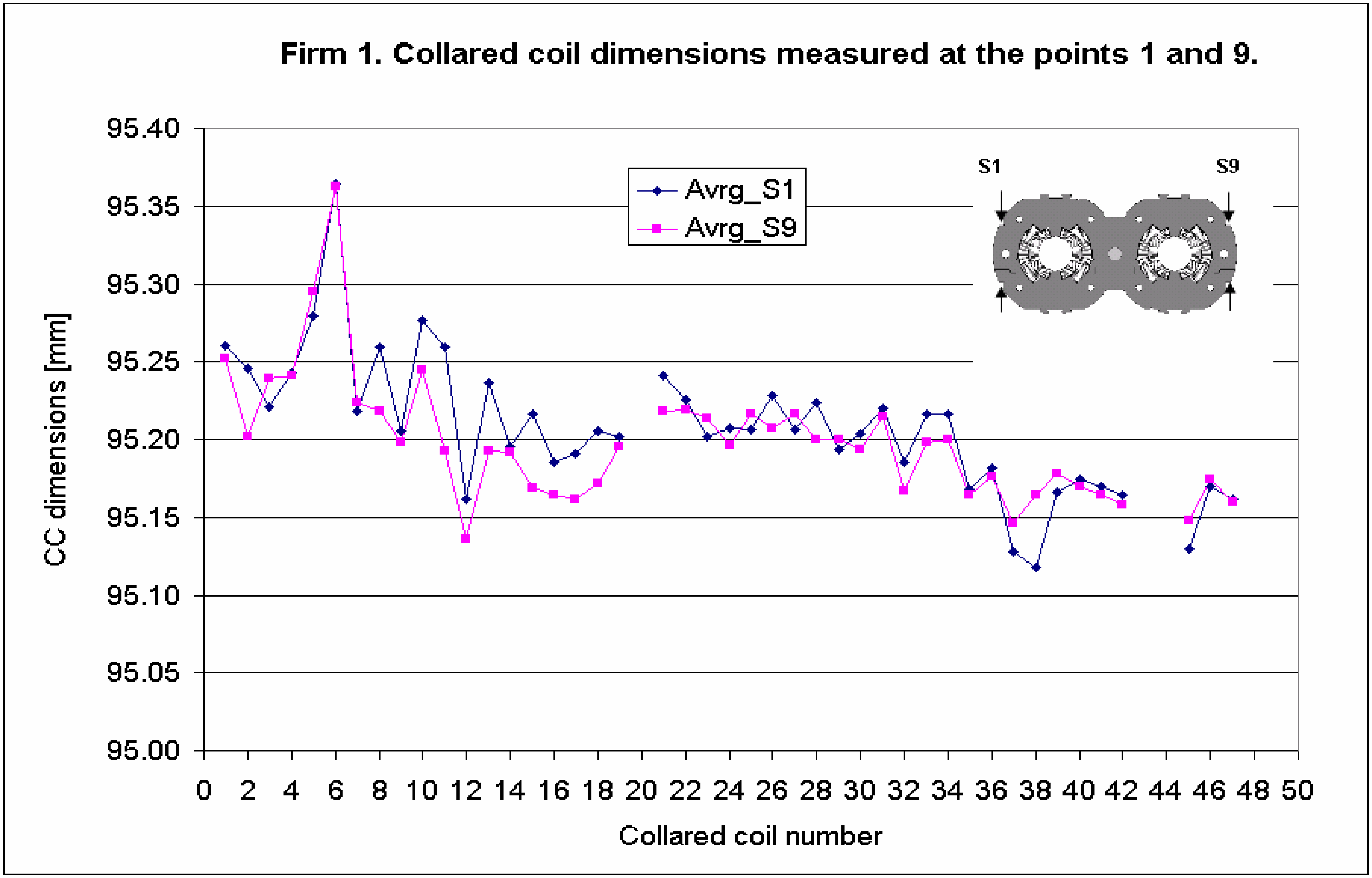

Fig. 17 Firm 1. Collared coil dimensions measured at the points S1 and S9.

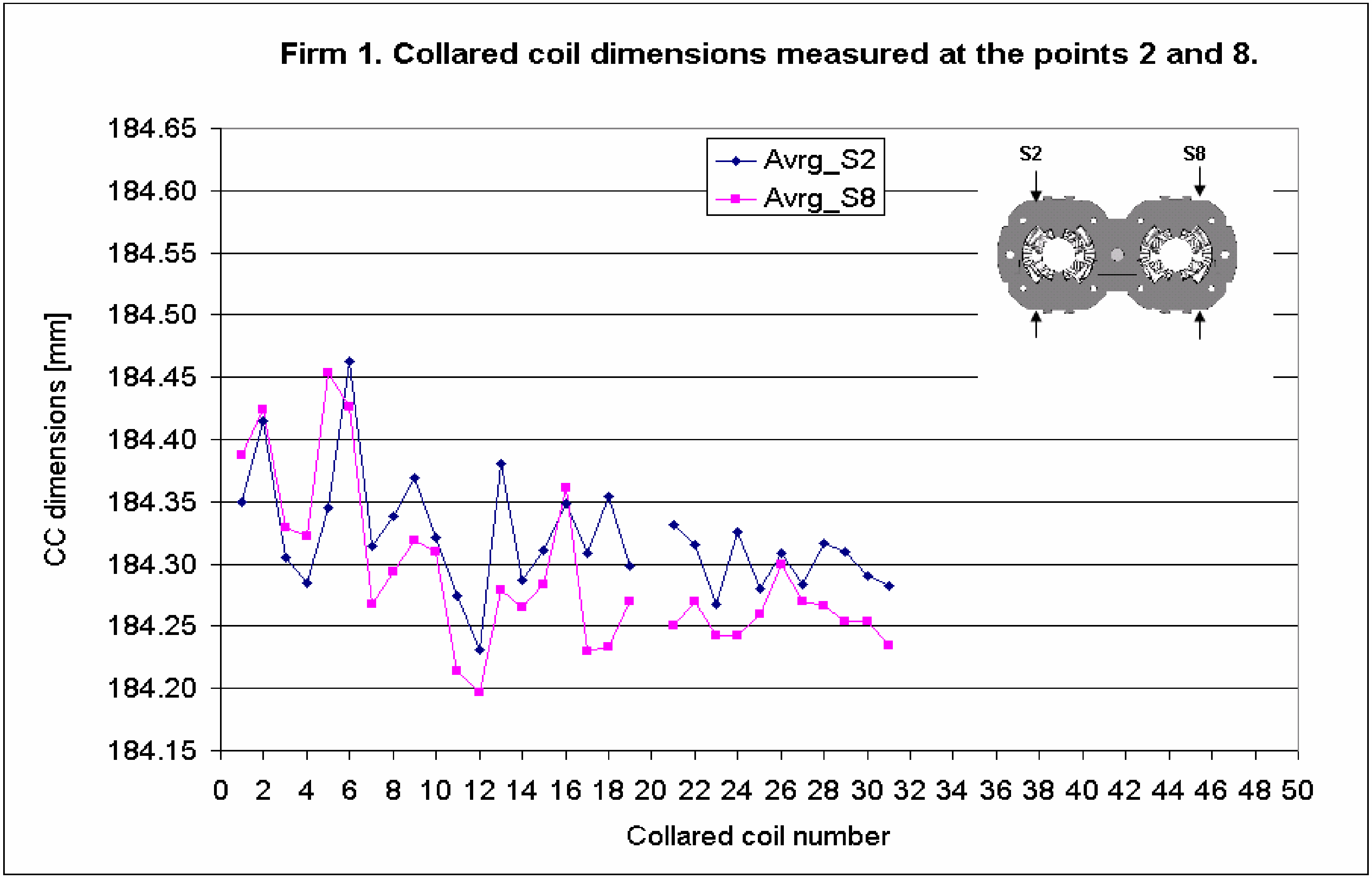

Fig. 18 Firm 1. Collared coil dimensions measured at the points S2 and S8.

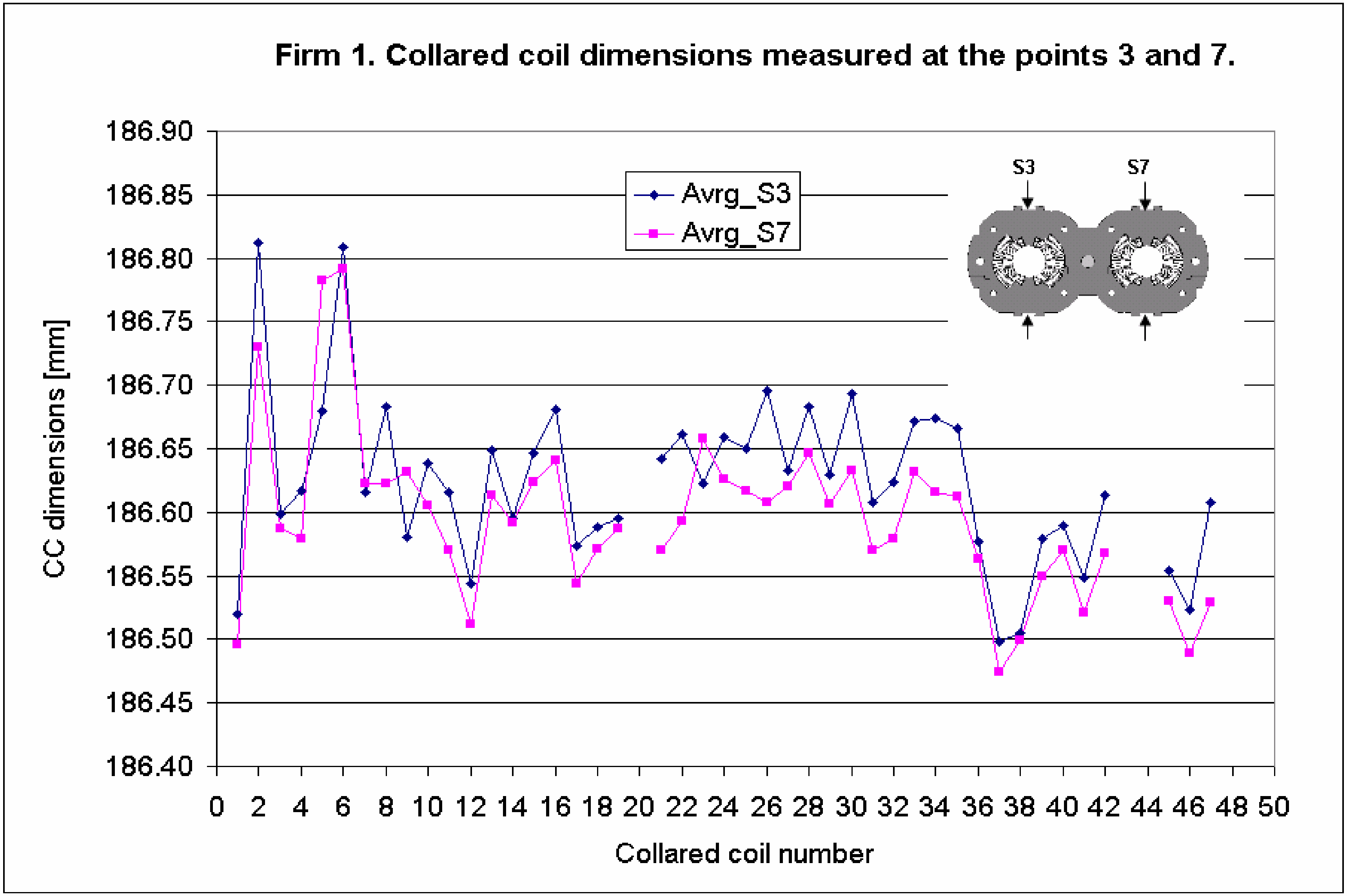

Fig. 19 Firm 1. Collared coil dimensions measured at the points S3 and S7.

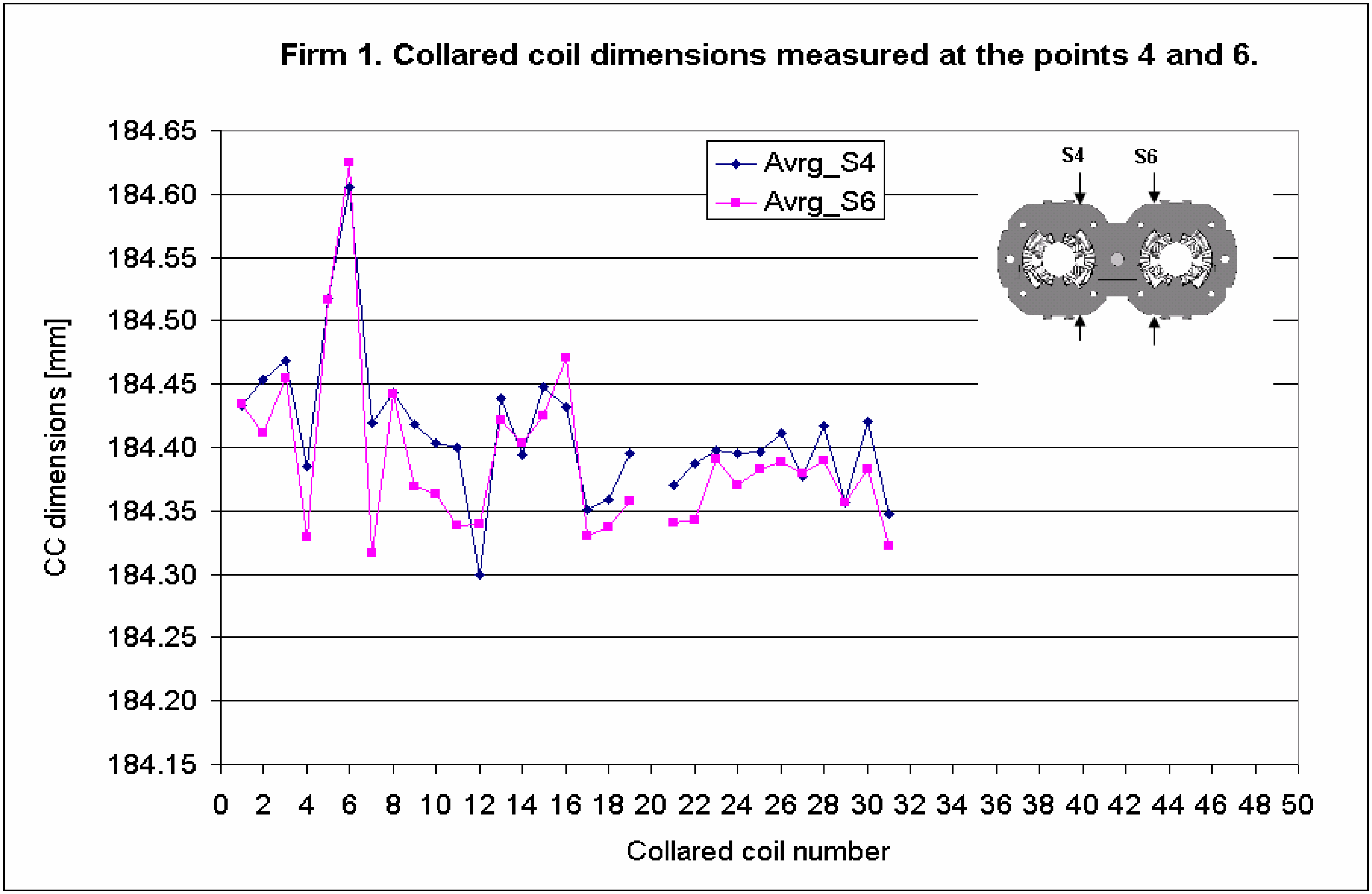

Fig. 20 Firm 1. Collared coil dimensions measured at the points S4 and S6.

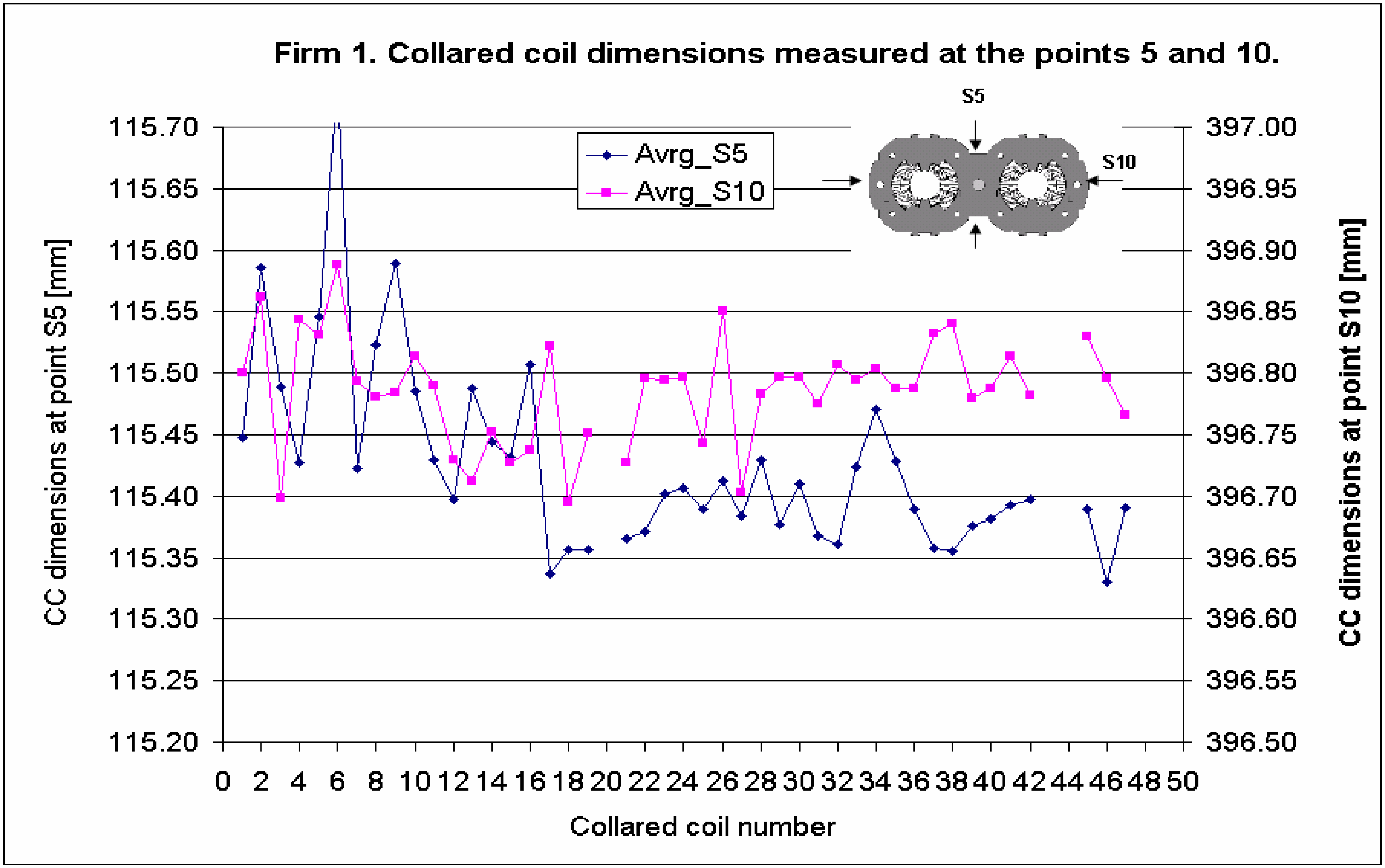

Fig. 21 Firm 1. Collared coil dimensions measured at the points S5 and S10.

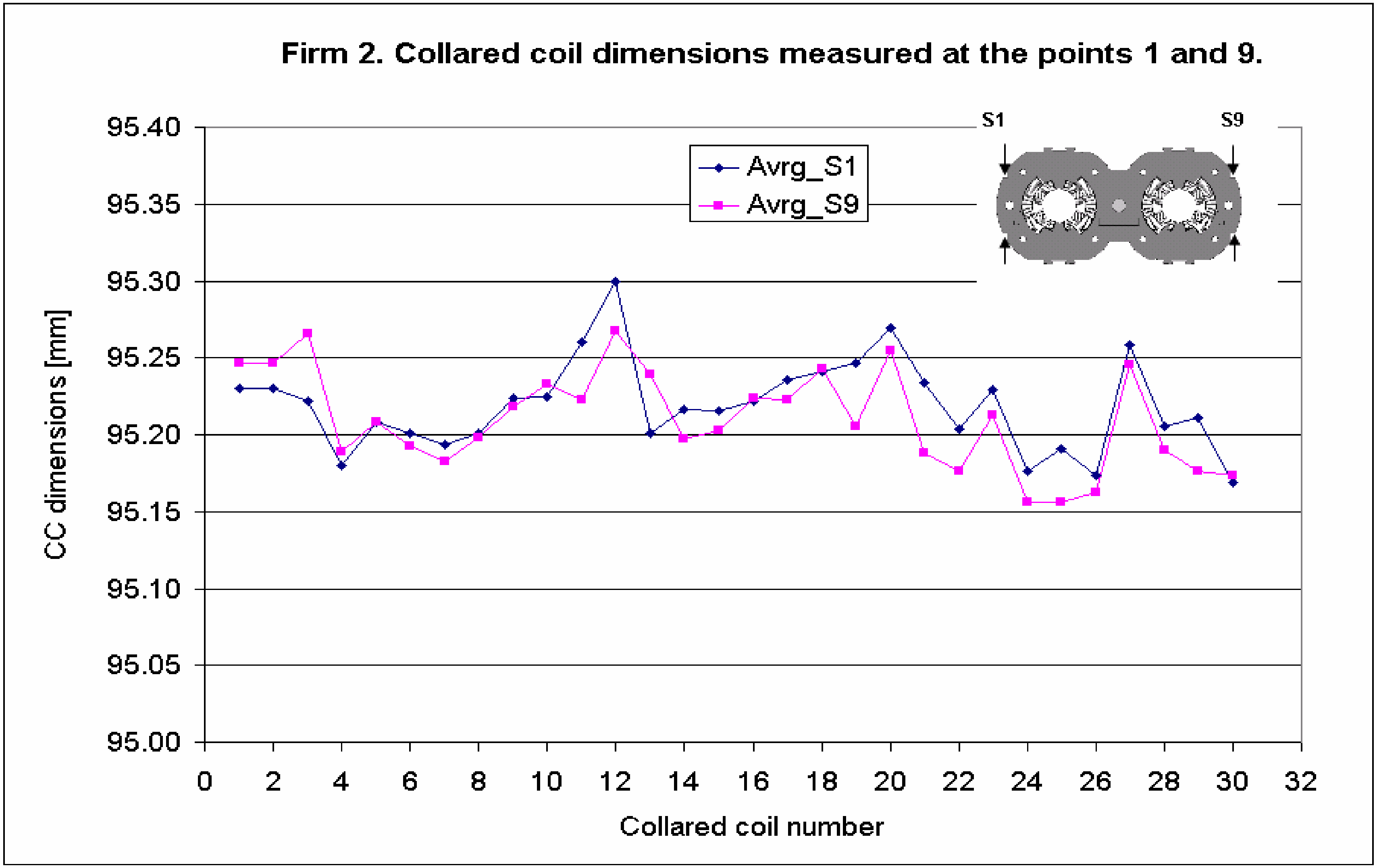

Fig. 22 Firm 2. Collared coil dimensions measured at the points S1 and S9.

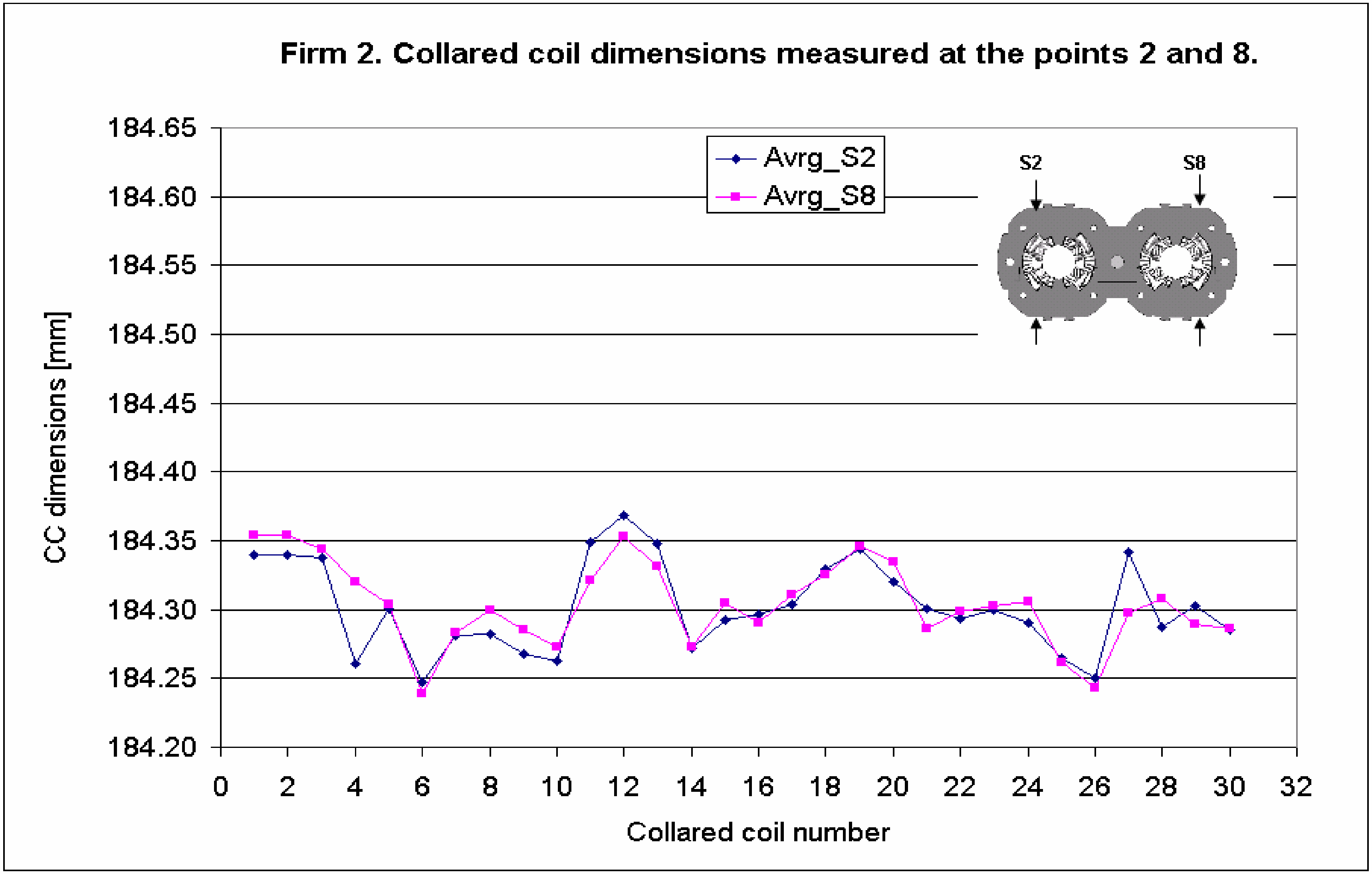

Fig. 23 Firm 2. Collared coil dimensions measured at the points S2 and S8.

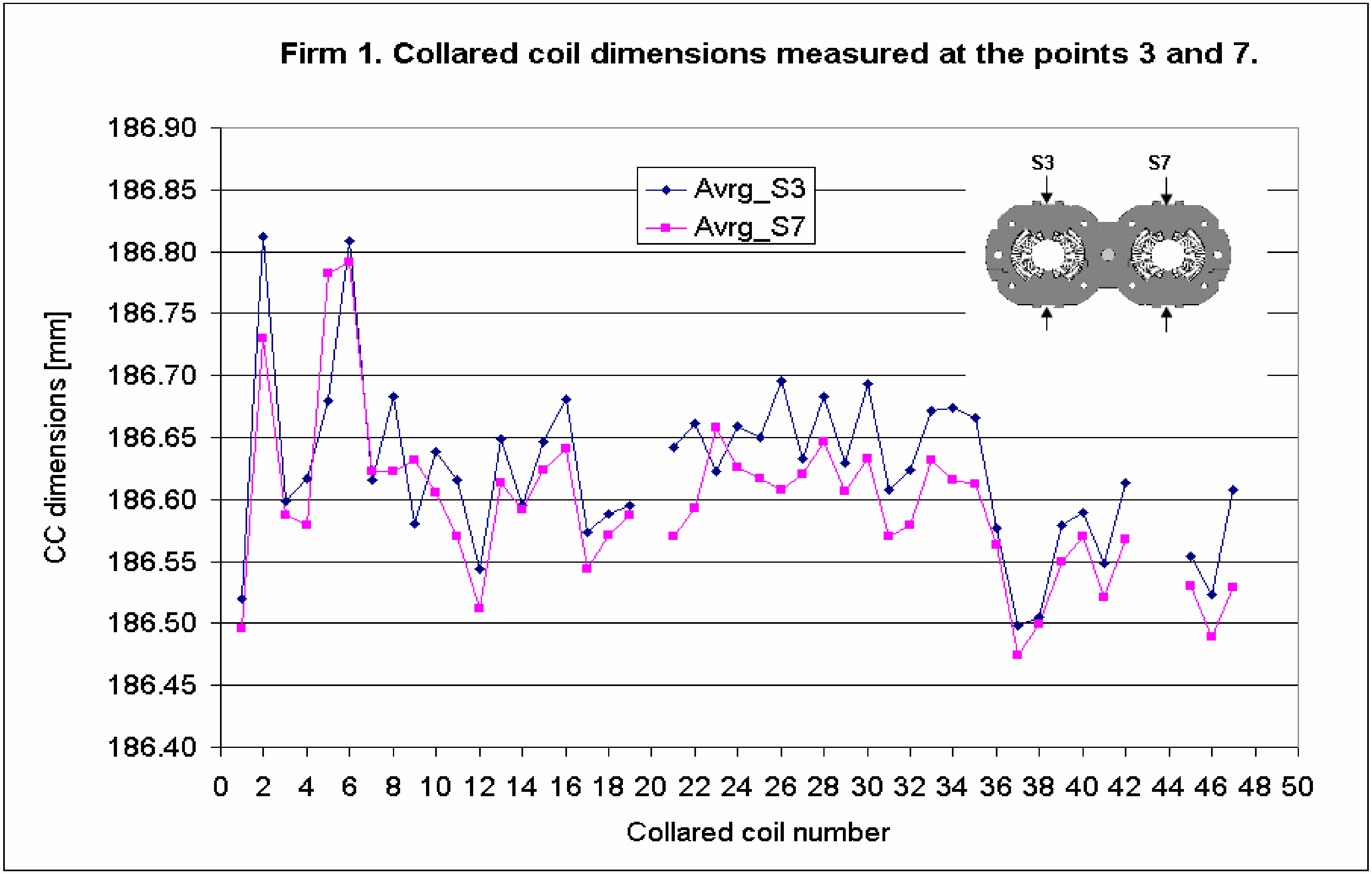

Fig. 24 Firm 2. Collared coil dimensions measured at the points S3 and S7.

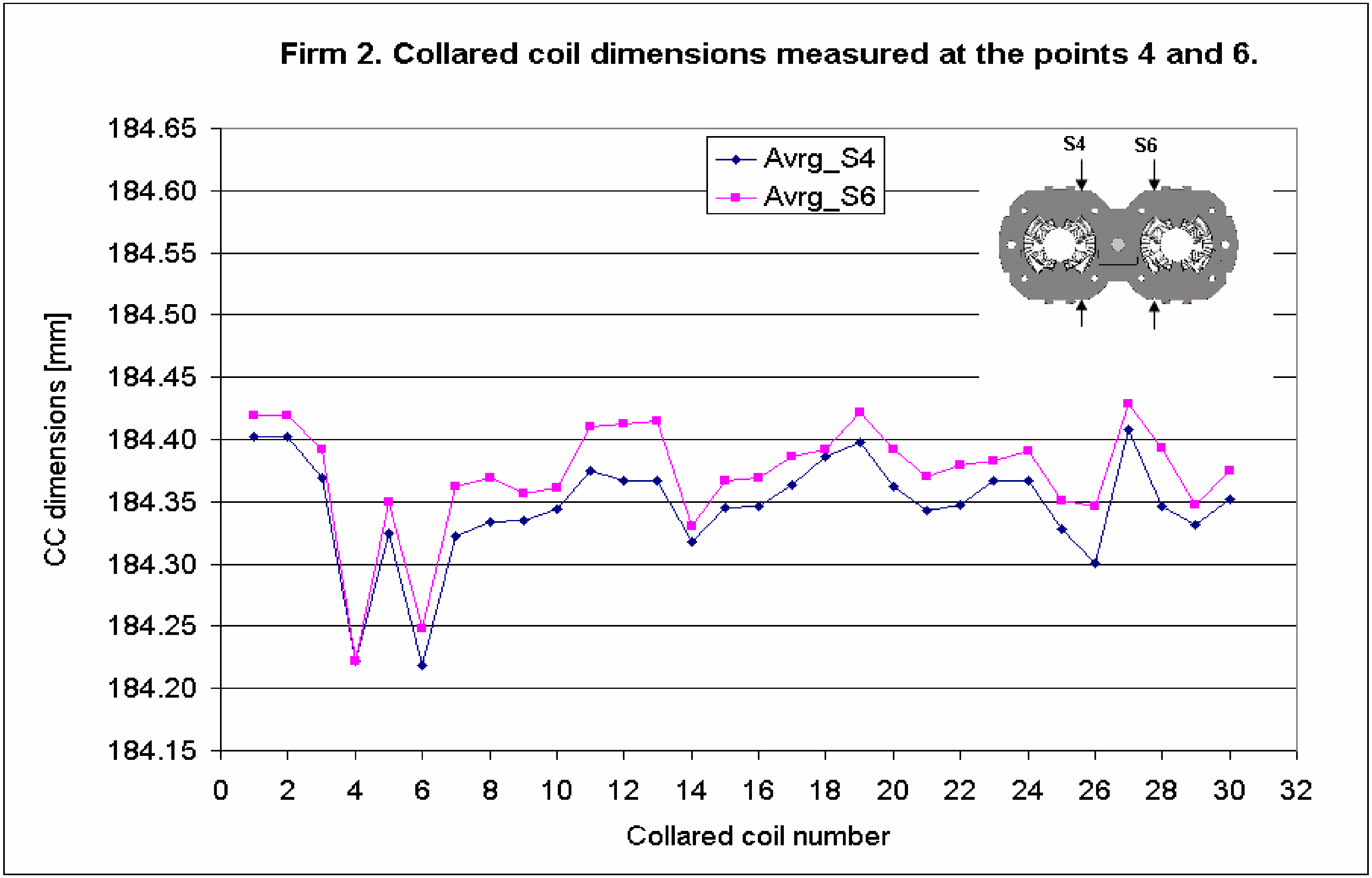

Fig. 25 Firm 2. Collared coil dimensions measured at the points S4 and S6.

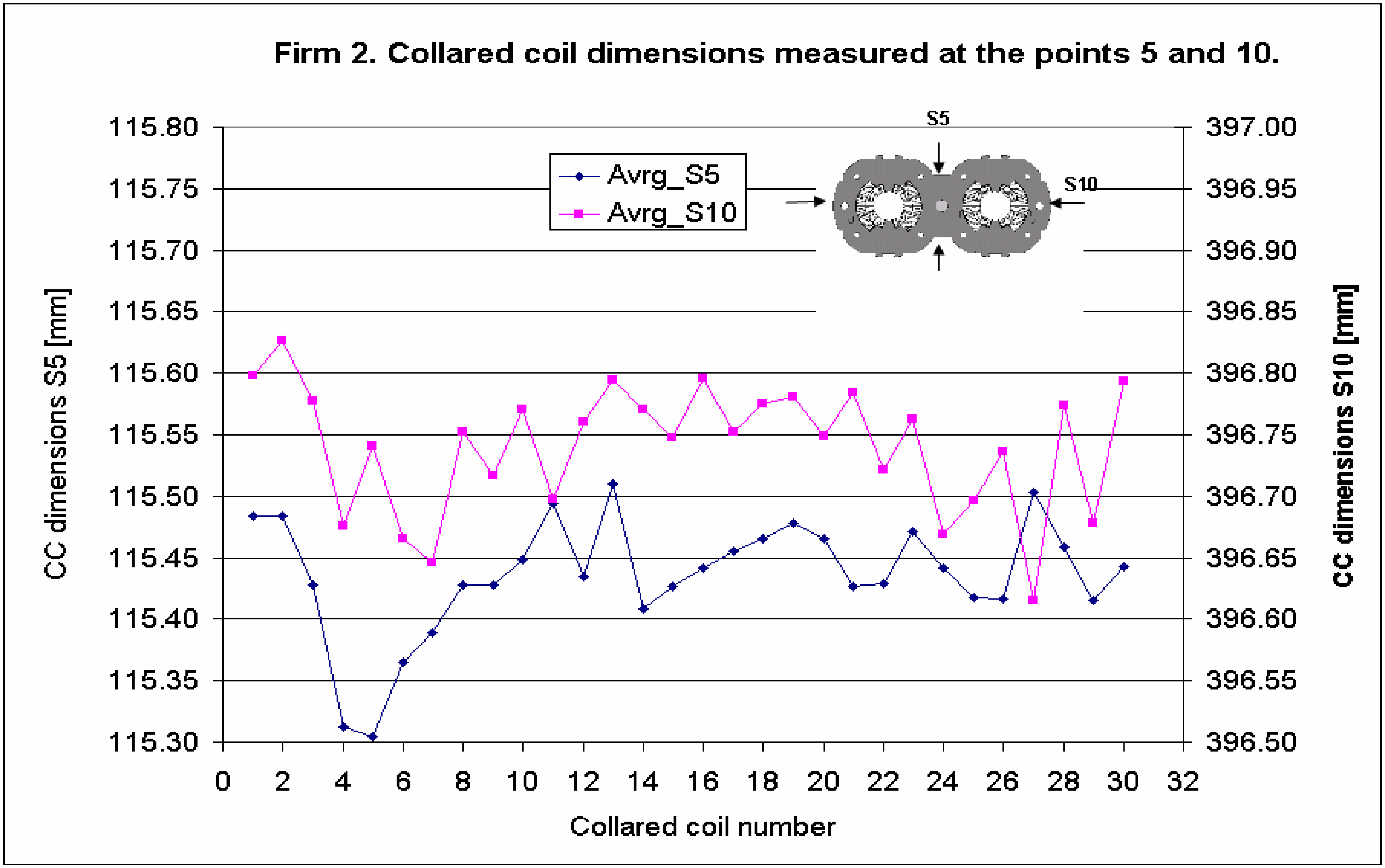

Fig. 26 Firm 2. Collared coil dimensions measured at the points S5 and S10.

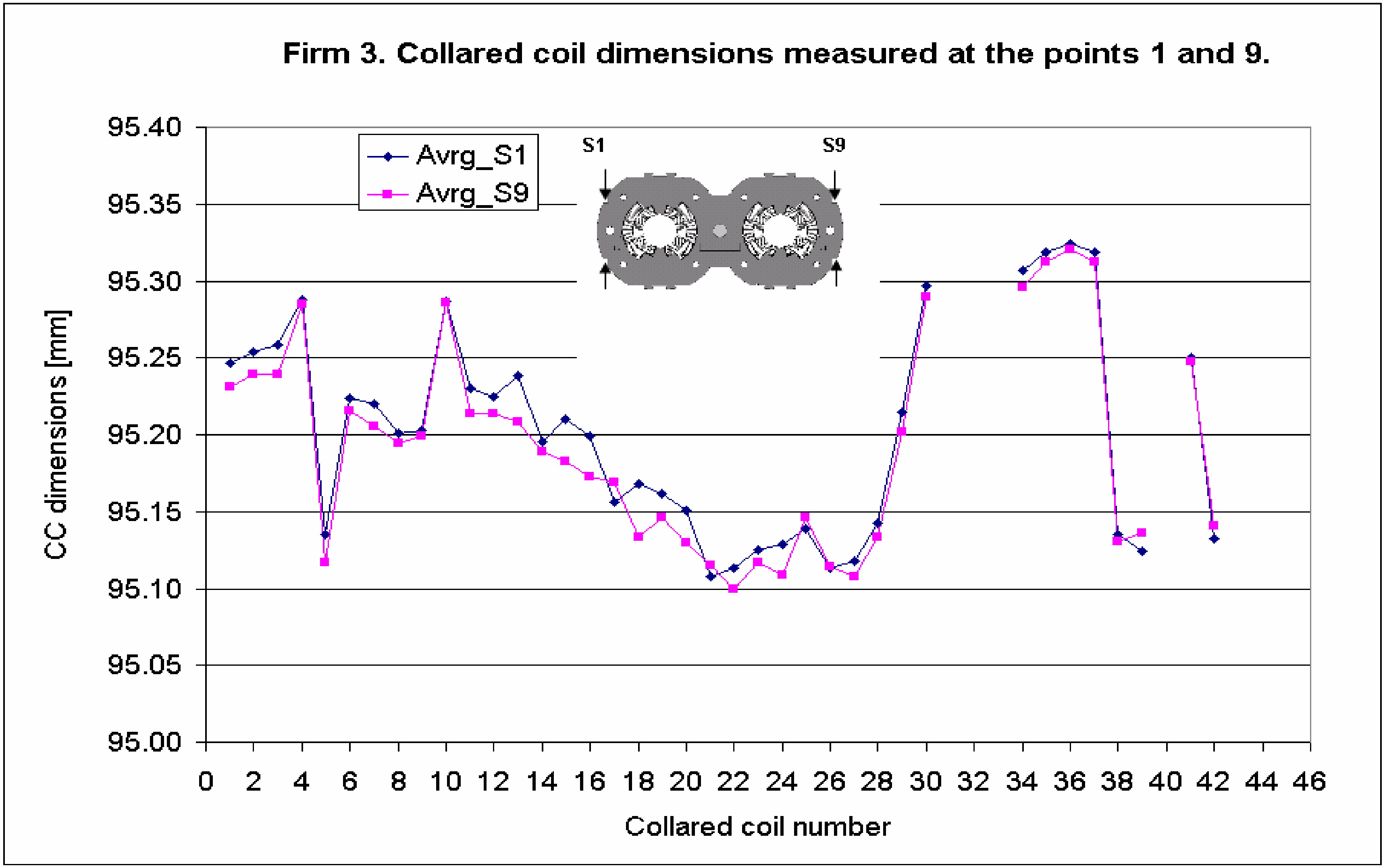

Fig. 27 Firm 3. Collared coil dimensions measured at the points S1 and S9.

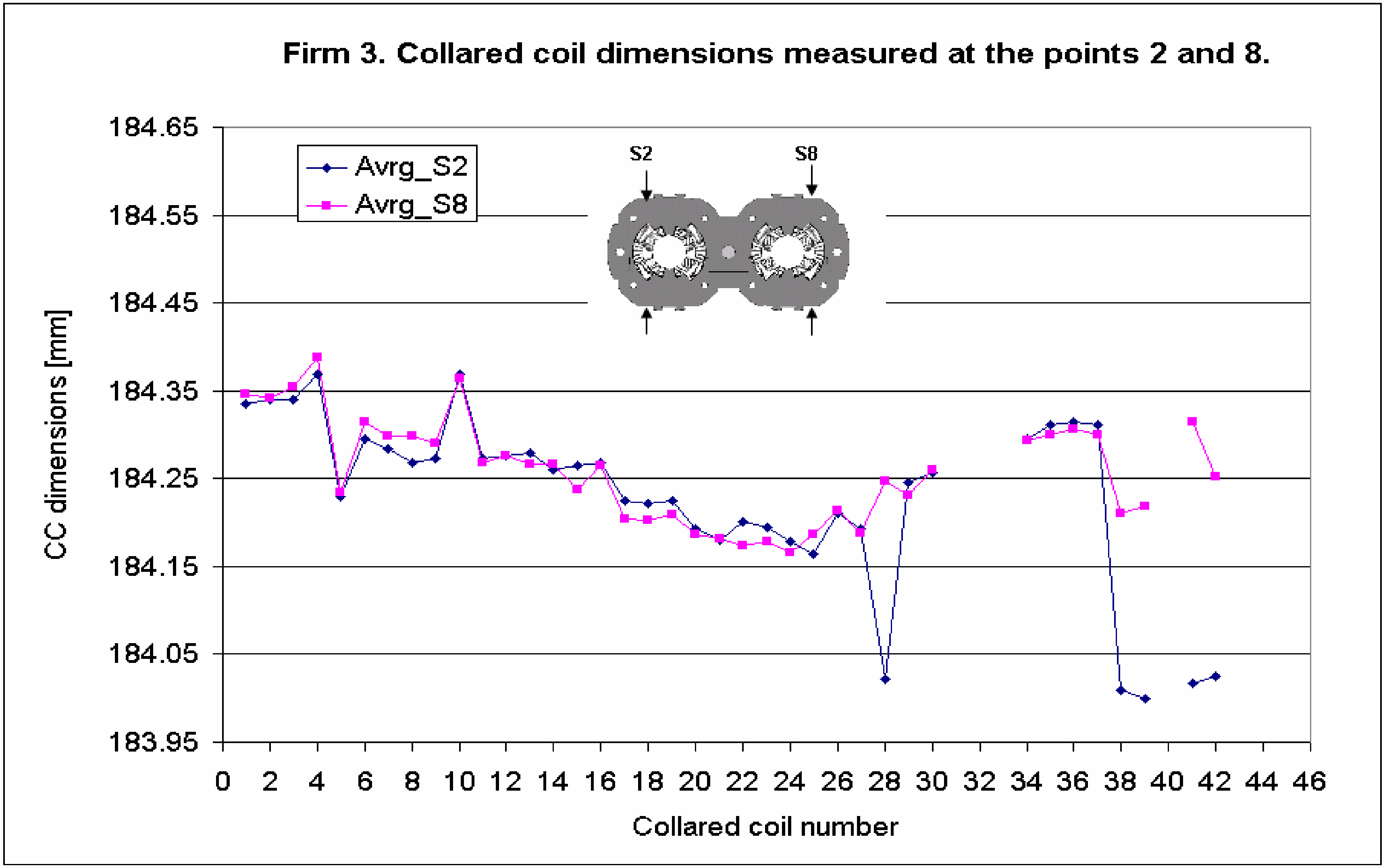

Fig. 28 Firm 3. Collared coil dimensions measured at the points S2 and S8.

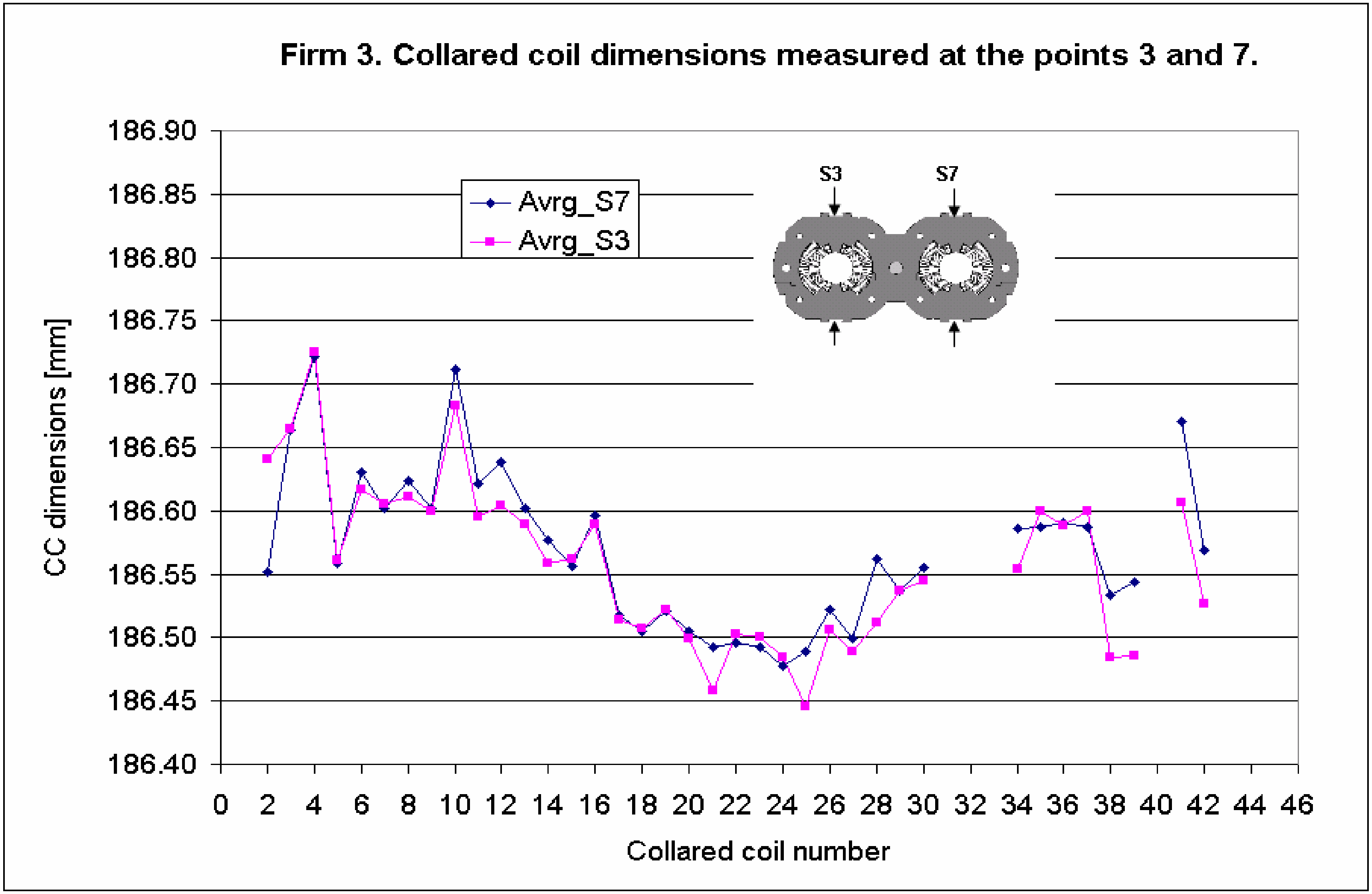

Fig. 29 Firm 3. Collared coil dimensions measured at the points S3 and S7.

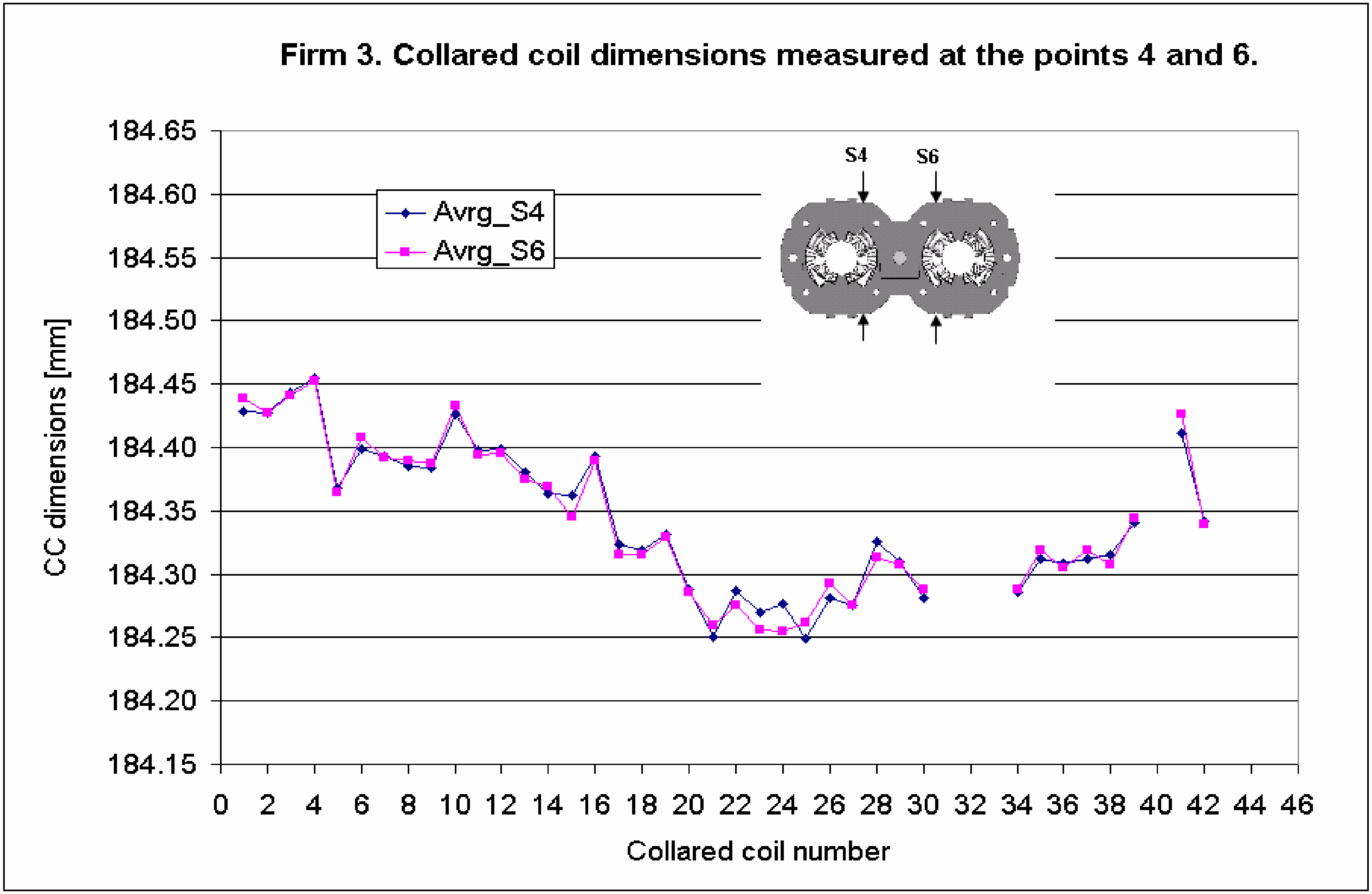

Fig. 30 Firm 3. Collared coil dimensions measured at the points S4 and S6.

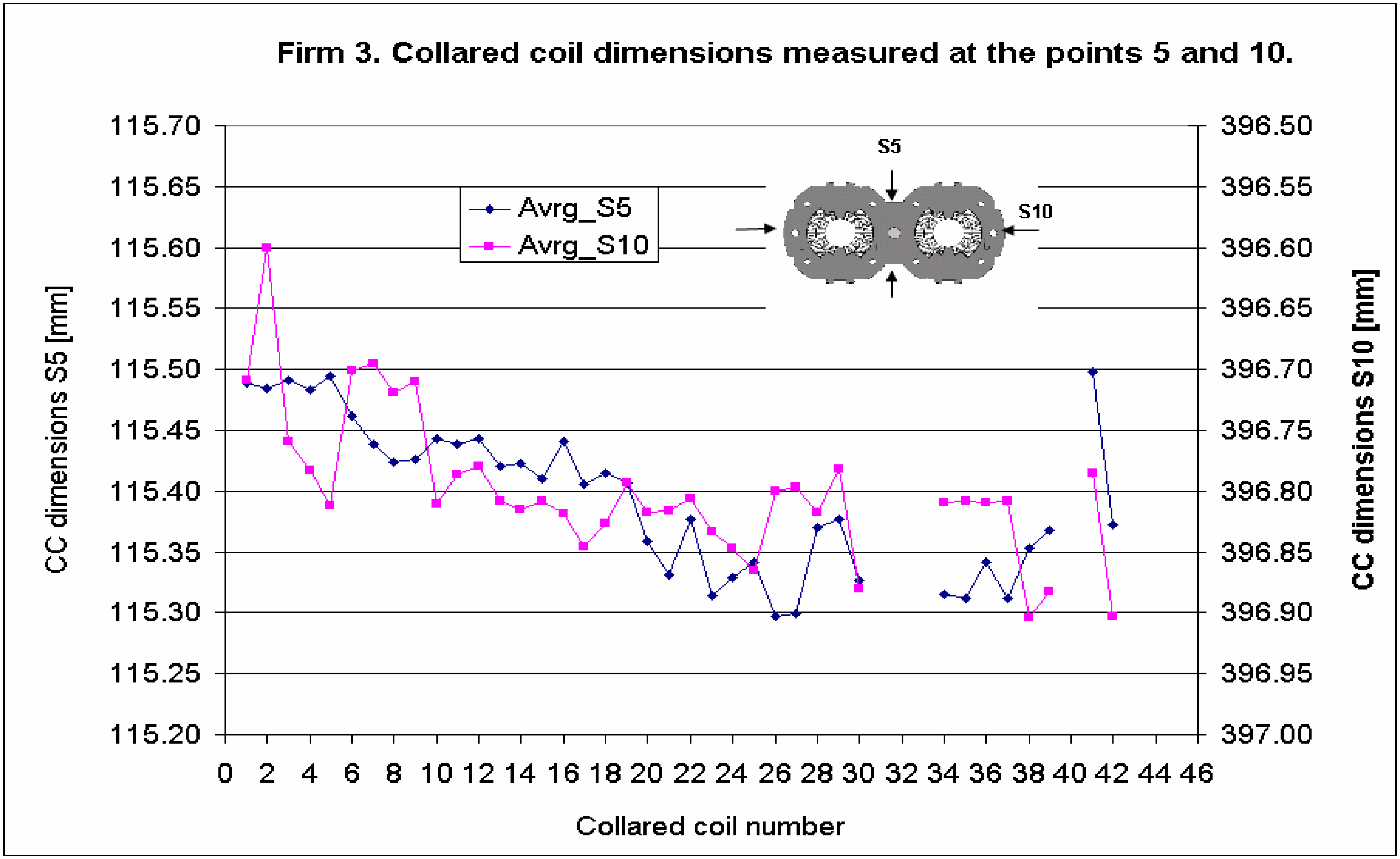

Fig. 31 Firm 3. Collared coil dimensions measured at the points S5 and S10 (notice that the scale for S10 axis is reversed).

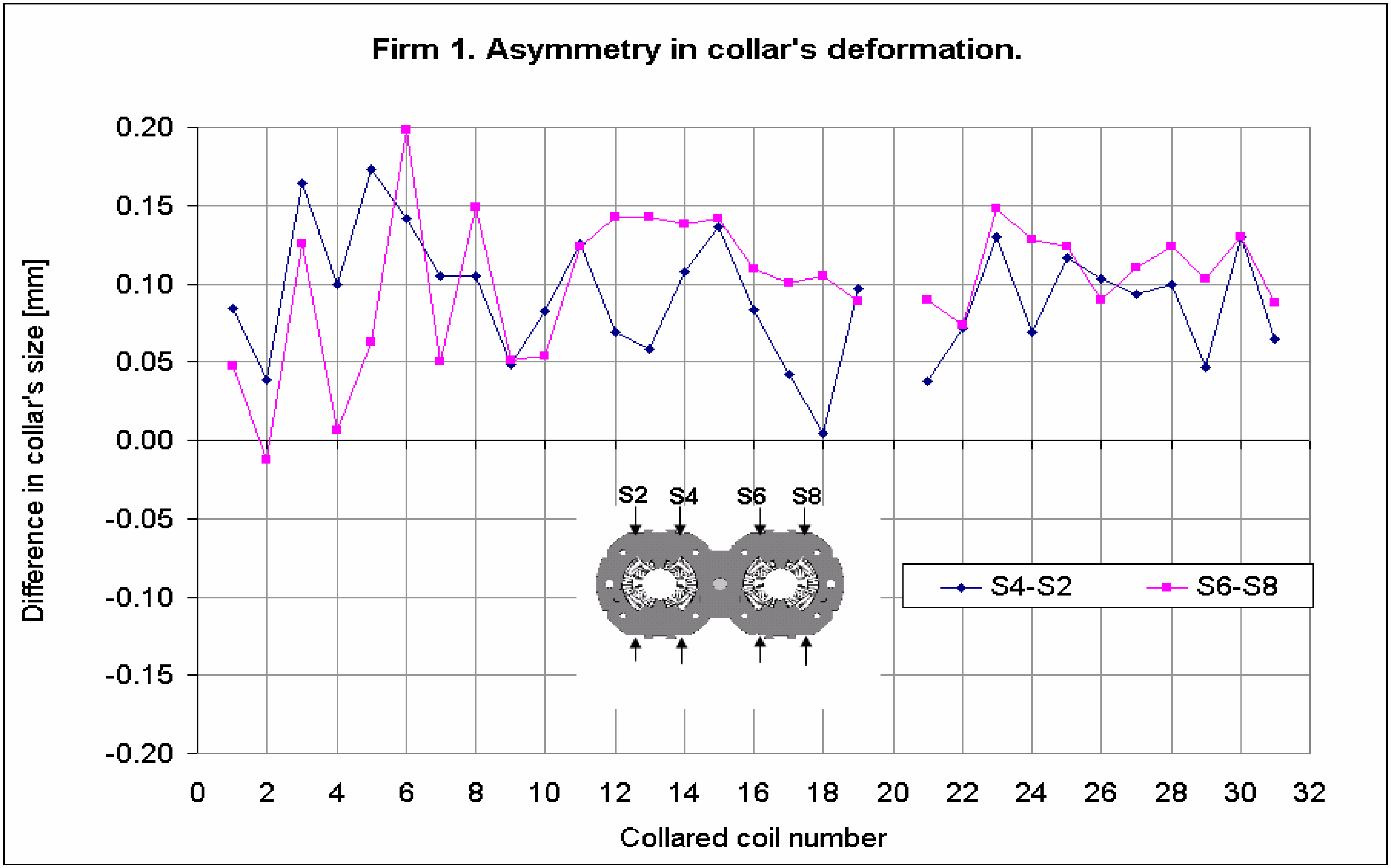

Fig. 32 Firm 1. Measured asymmetry in collared coil dimensions.

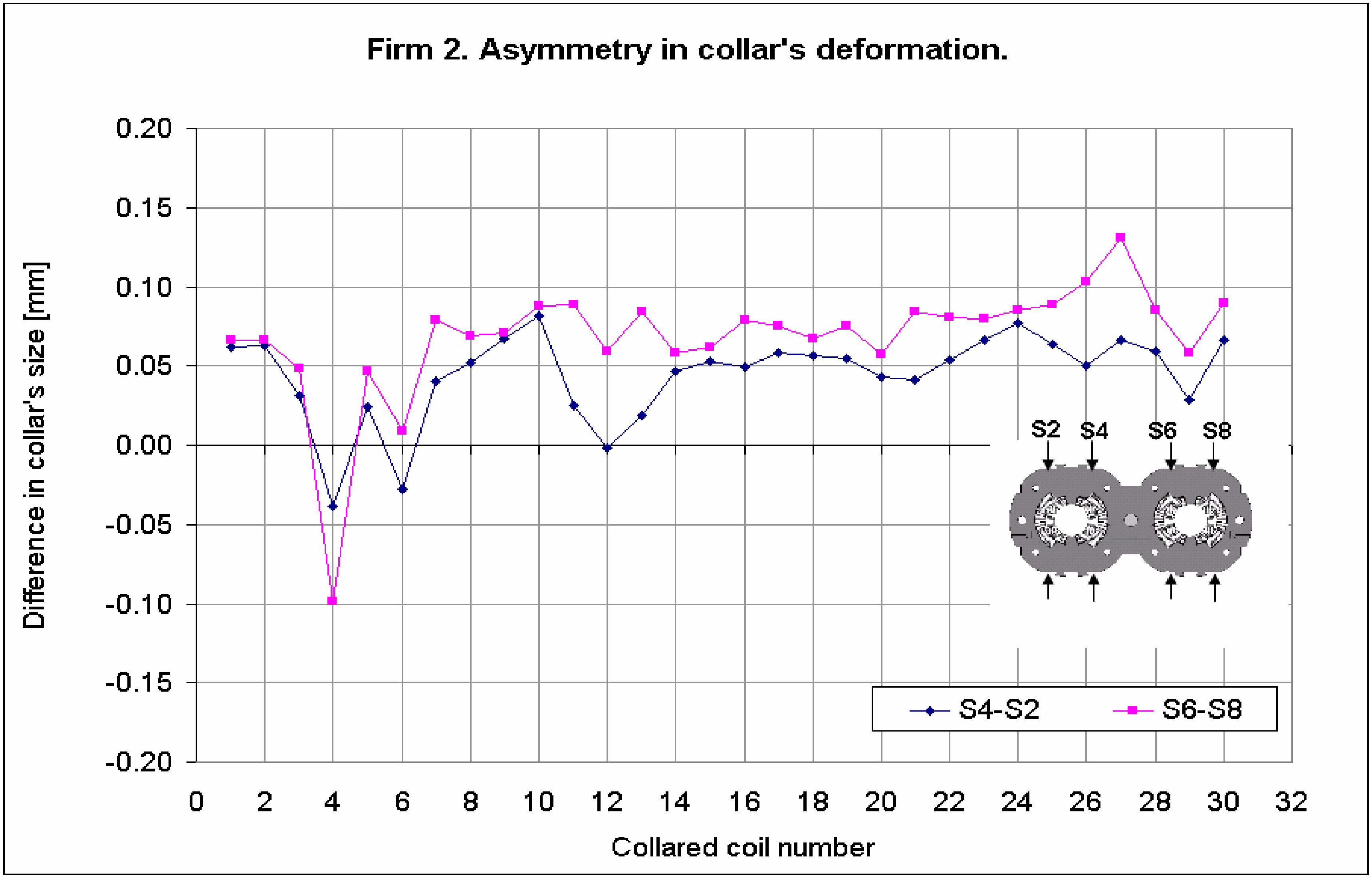

Fig. 33 Firm 2. Measured asymmetry in collared coil dimensions.

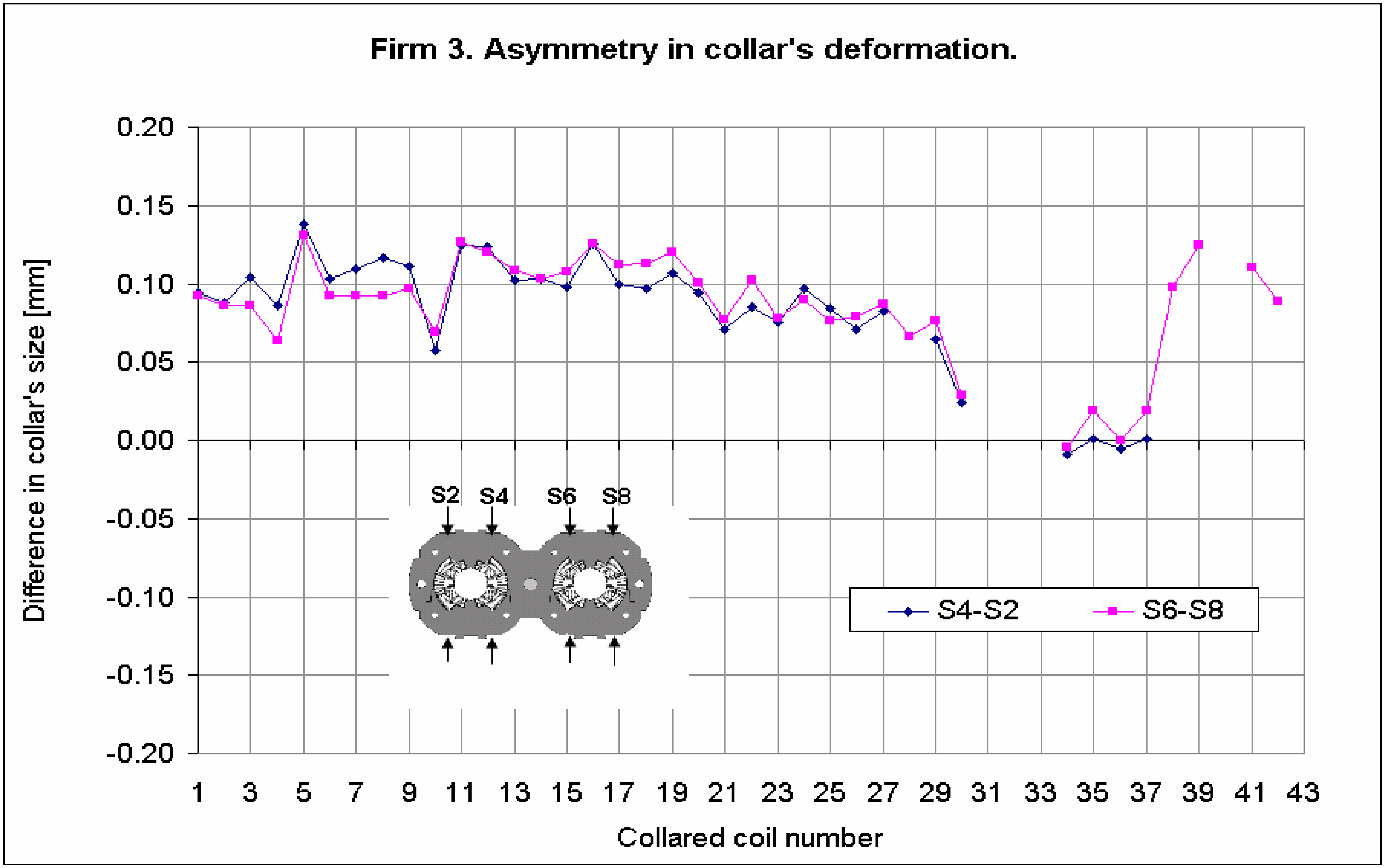

Fig. 34 Firm 3. Measured asymmetry in collared coil dimensions.

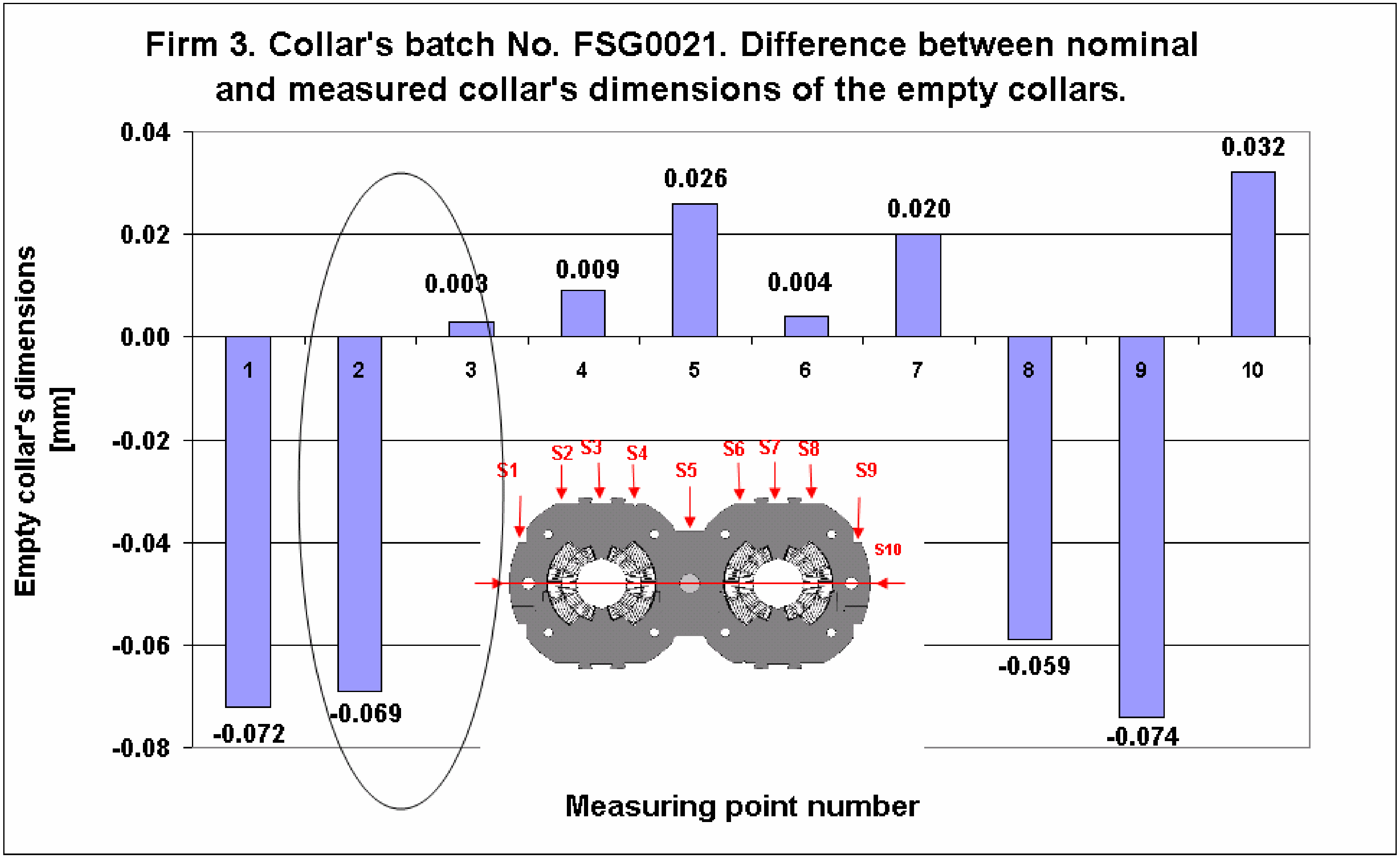

Fig. 35 Firm 3. Difference between nominal and measured dimensions of empty collars. The measurements were performed on the pre-assembled collar-pack, locked with the nominal collaring rods.

Acknowledgments

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