Report on mechanical measurements in the main LHC dipole collared coils: July-September 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, 289 (40 during last tree months) assembled poles have been produced and all measured.
- **Firm 2 (ANSALDO)** –Up to date, 244 inner and outer layers have been produced, but only 77 inner and 89 outer have been measured (typically, one inner and one outer layer per magnet are measured).
- **Firm 3 (NOELL)** – NOELL keeps measuring almost all produced coils layers. Up to date, 237 inner and 267 outer layers have been measured.

What is new:

Change of collared coil dimension measuring machine at ALSTOM. A new machine to measure collared coil dimensions is in use at Alstom starting from the CC-51. The new machine is rather similar to the ones at Noell and at Ansaldo and in principle does more accurate measurements, as it uses electronic sensors instead of analog in the old machine.

Trends in coil sizes. Periodic trends (with positive and negative slopes) are observed in the coils size data from all the firms.

Coil waviness. We present a standard deviation of coil size measured in many positions along the coil for tree firms. There is an important increase of coil waviness in the outer layers coils of the last 5 pole sets at firm 1, which could be related to the measuring machine.

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 coils 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).
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. There is an important increase of coil waviness in the outer layers coils of the last 5 pole sets at firm 1, which could be related to the measuring machine: the limitations which comes from the measuring machine are not allow to measure the coils at 100 MPa pressure (a standard pressure for raw data treatment at CERN for all the firms), but around 80 MPa. It was noticed that for some coils at firm 1, the shape of strain-displacement curve is not normal, and during the post-processing of raw data the extrapolations to 100 MPa pressure are fails.
The difference in coil size between the left and right sides of coils is shown in figure 3. A large variation in left-to-right side coil asymmetry on the outer layer coil size in the last 5 pole sets, is probably related to the measuring machine. 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. About 60 inner and 60 outer layers have been produced over last tree months, but only 26: 12 inner layers and 14 outer layers were measured. The variation in the coil size in the inner and outer layers coils of series production stays in the range of ±0.1 mm. We remind, that at firm 2 starting from the inner layer № 75 (red dashed line in fig. 6) and from the outer layer № 98 (blue dashed line in fig. 6) the coils are cured with extra shims of 0.1 mm in the curing mould.
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 coil waviness on the inner layer is systematically higher then on the outer layers.
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. About 30 inner and 60 outer layers have been measured in last 3 months out of ~160 produced over the same period. The data on coil size of the inner layers at firm 3 shows an important jump in the coils for CC-74. We can't say about the trend on the inner layer, as only data for a few coils is available.
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 12. Here we see that most of the coils (apart the inner layers №135-154 with the problem mentioned in a previous report) are well inside the allowed tolerances range (red dashed line in figure 12). 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 13. Here, the difference appears to be around zero in average.
In figures 14 and 15, 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 16 ÷ 21 the CC dimensions for measuring points S1-10 are shown (each plot gives the data on two symmetrical points). A new machine to measure collared coil dimensions is in use at Alstom starting from the CC-51 (the collared coils 44 and 48 are also were measured with the new system). The new machine is rather similar to the ones at Noell and at Ansaldo and in principle does more accurate measurements, as it uses electronic sensors instead of analog in the old machine. At the same time a new measuring procedure was set: the coils CC are measured in 14 longitudinal positions, where 6 are in the straight part of the coil. Following CERN request, the measuring points are also re-arranged: instead of points S5 and S7, the measurements are now performed at the points S2 and S6, as the data on these points is more reliable for analysis.

Firm 2. In figures 21 ÷ 25 the CC dimensions for measuring points S1-10 are shown (each plot gives the data on two symmetrical points). At firm 2, for the collared coils of the series, the CC dimensions are measured in 11 pre-defined positions along the coil, where 4 positions are taken in the straight part of the coil.

Firm 3. In figures 26 ÷ 30 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).

The problem with the reading of the sensor at the points S2, mentioned in the previous report was investigated and found that sensor was working out of its range. The problem was fixed and starting from the CC 55 the data from this sensor is consistent.

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 31÷33 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 a new machine and measuring procedure are in use at firm 1 starting from the CC 51 (also CC 44 and 48). For the magnets 32-50 there no measurements had done at the measuring points S2, S4, S6 and S8.

Firm 3. The data on measuring points S2 and S4 from the CC 28 and CC 38-54 is dropped due to the problem with sensor S2 (fixed after CC-54).

Acknowledgments

We wish to acknowledge B. Bellesia, M. Cornelis, A. Devred, P. Fessia, A. Musso, M. Modena, G. De Rijk, L. Rossi, W. Scandale, F. Savary, and E. Todesco for comments, discussions and valuable help.

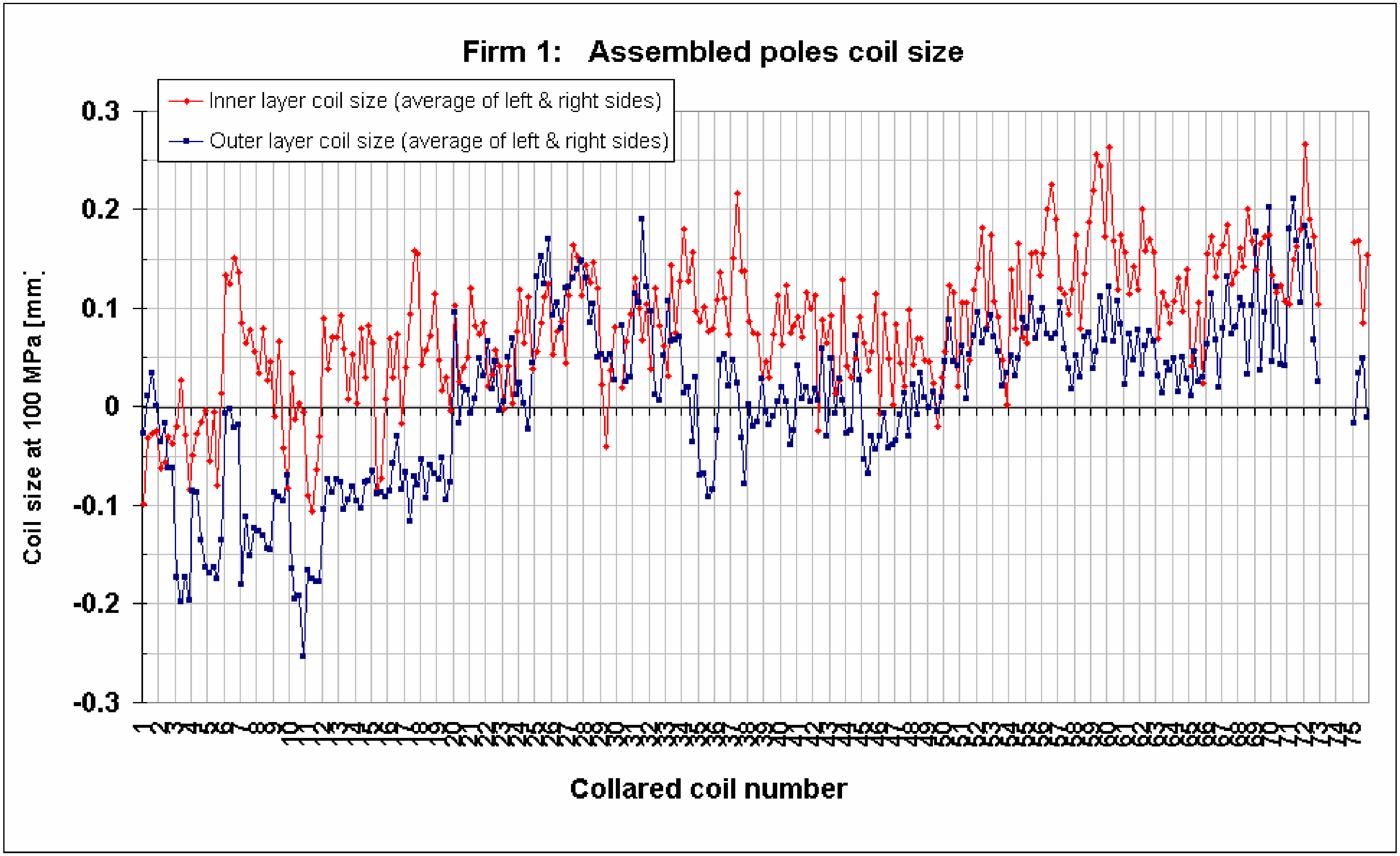

Fig. 1 Firm 1. Average coil size in the straight part of the assembled poles (248 poles).

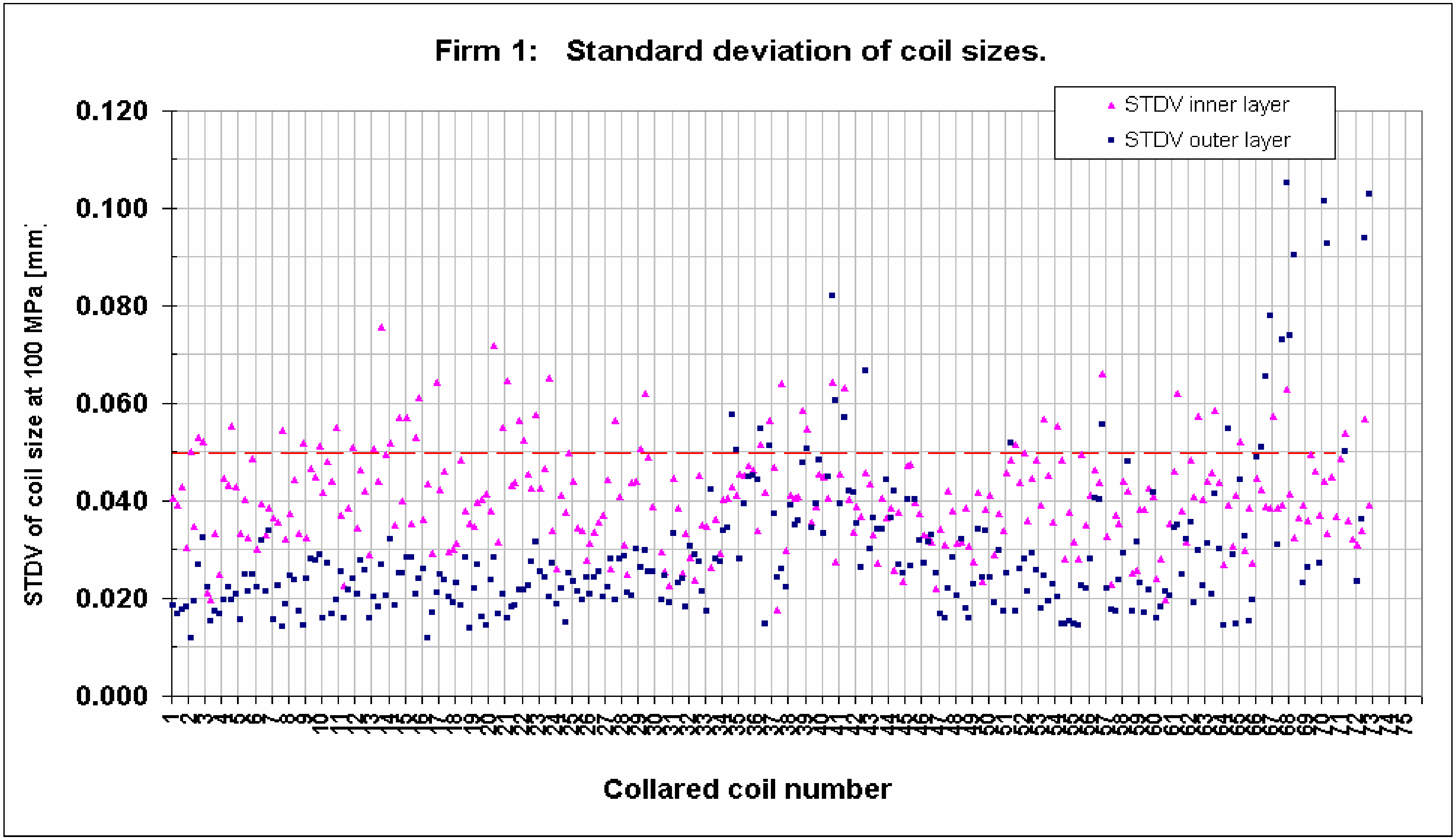

Fig. 2 Firm 1. Standard deviation of coil sizes measured in 15 positions along the coil (left and right coil sides in average). The area below the red dashed line in this figure is the allowed range for coil waviness.

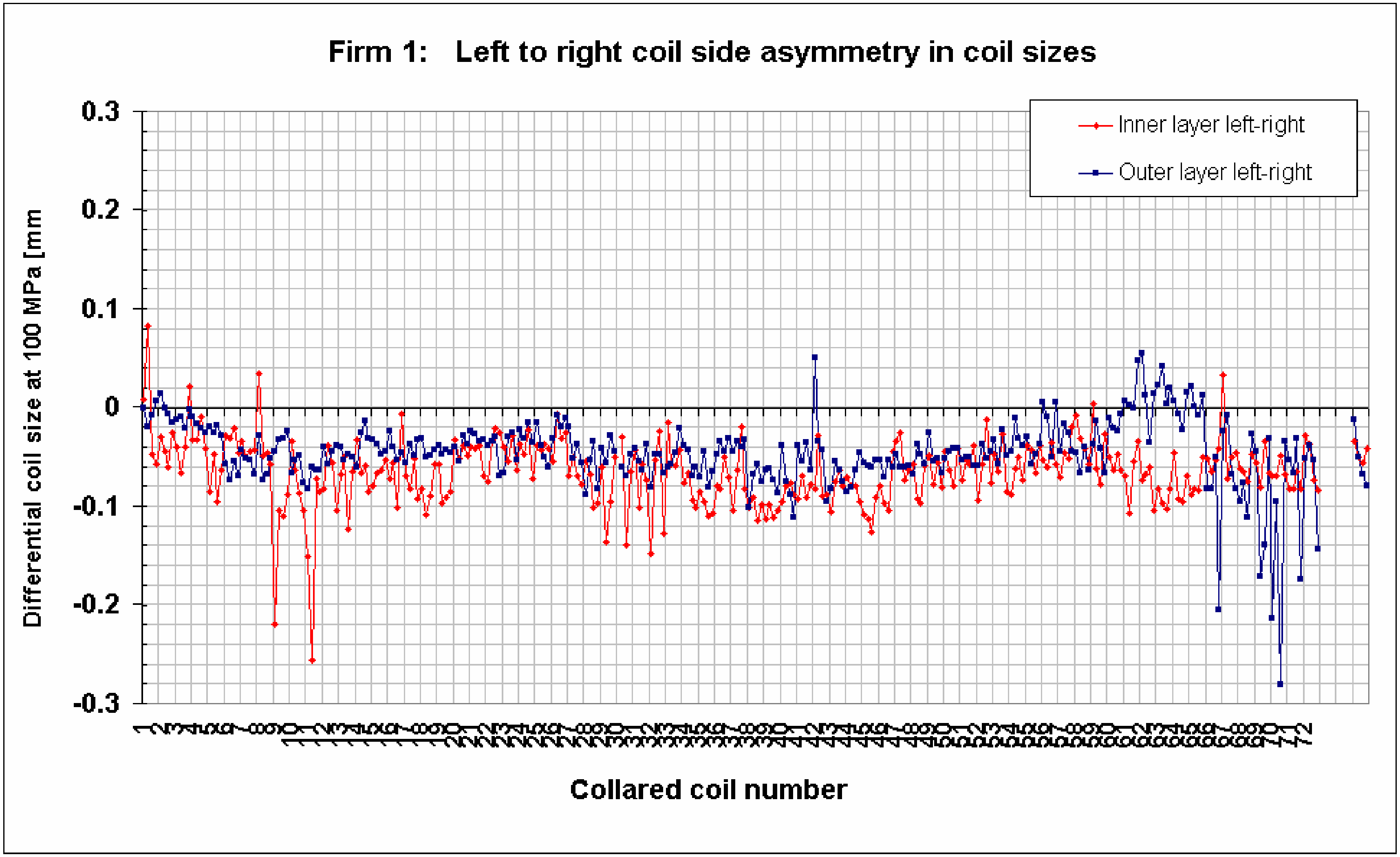

Fig. 3 Firm 1. Difference in the coil size between left and right sides of the coil on both layers.

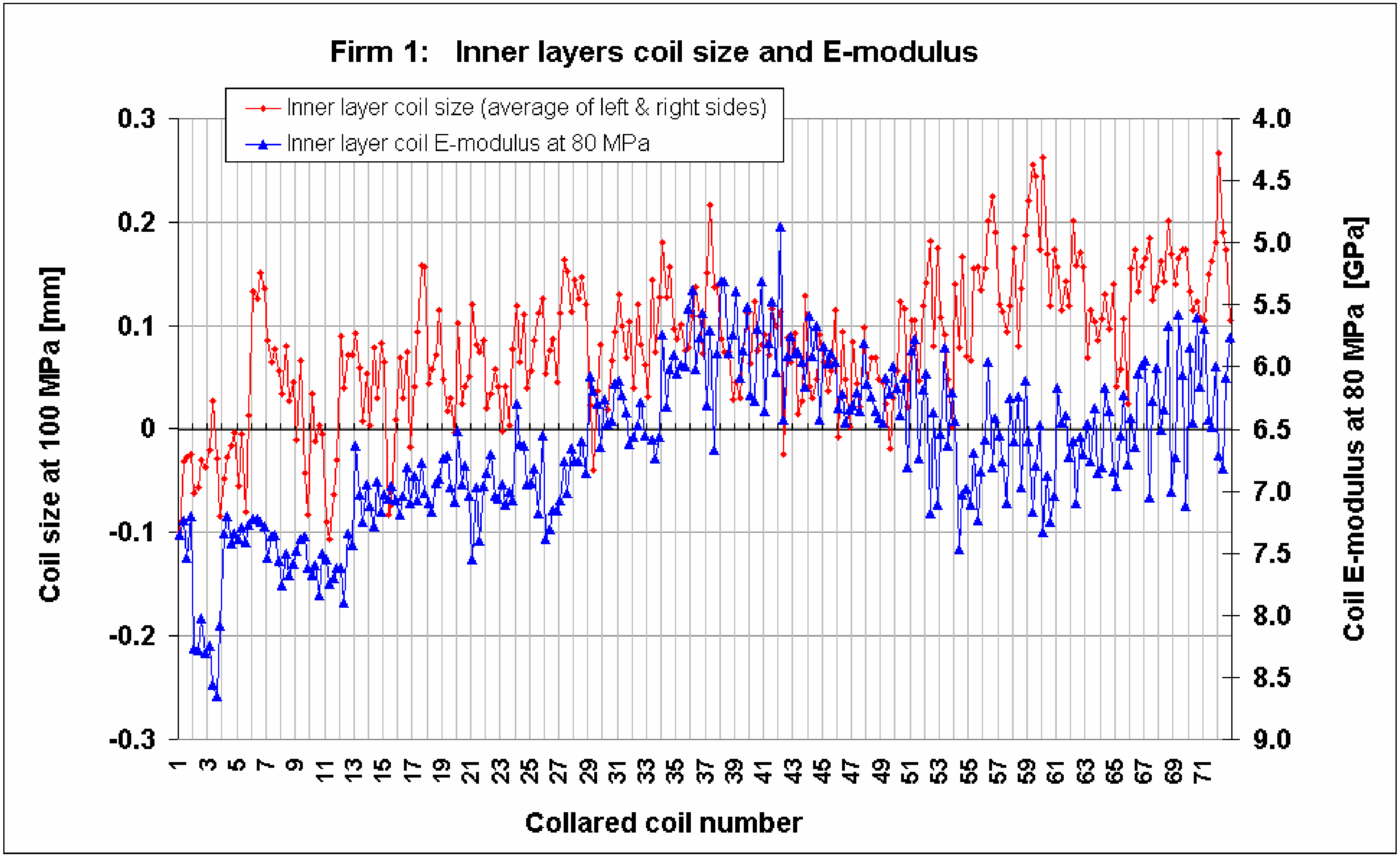

Fig. 4 Firm 1. Inner layer coil size (average) and E-modulus computed at 80 MPa.
(Data extracted from pole size measurements).

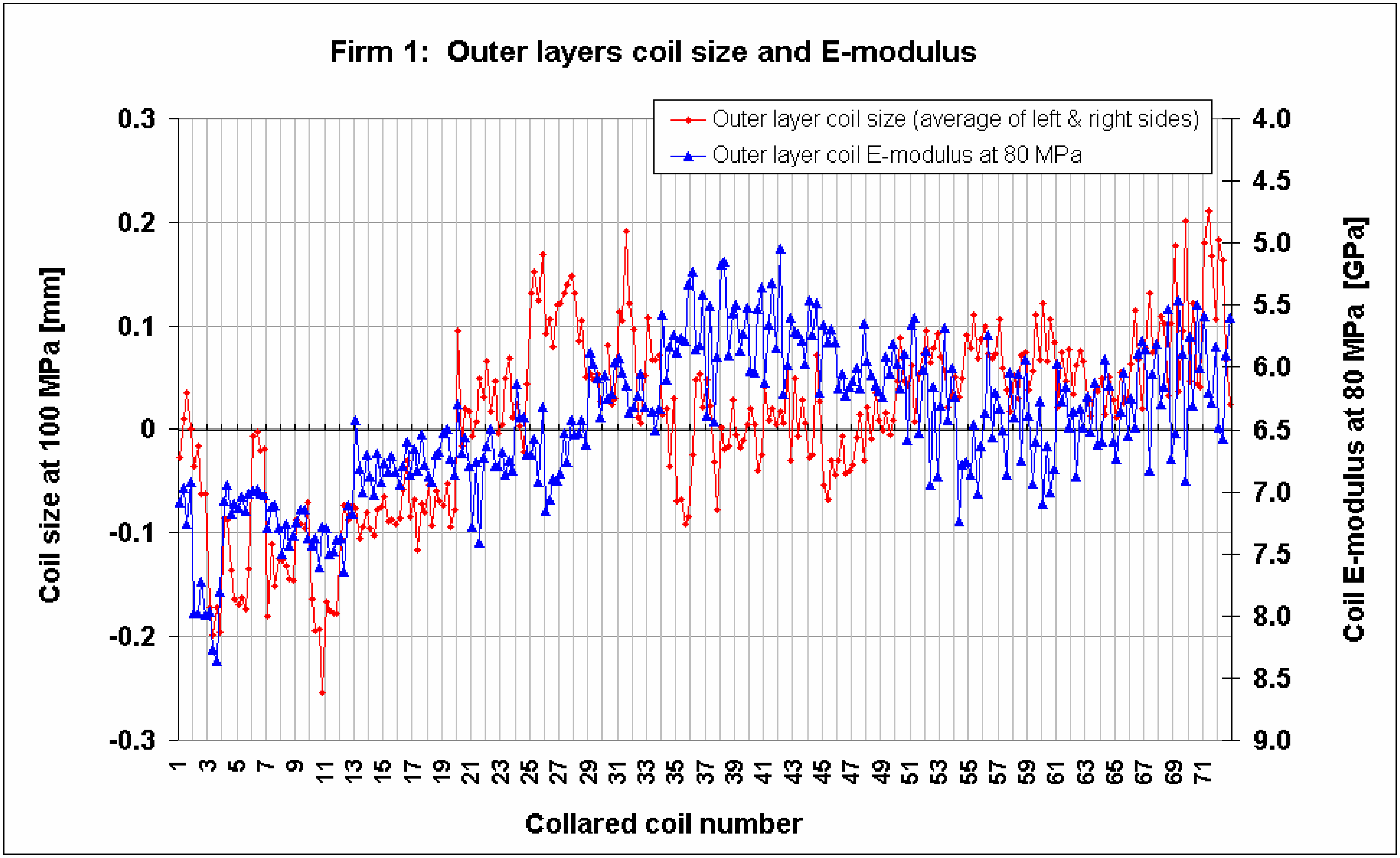

Fig. 5 Firm 1. Outer layer coil size (average) and E-modulus computed at 80 MPa. (Data extracted from pole size measurements).

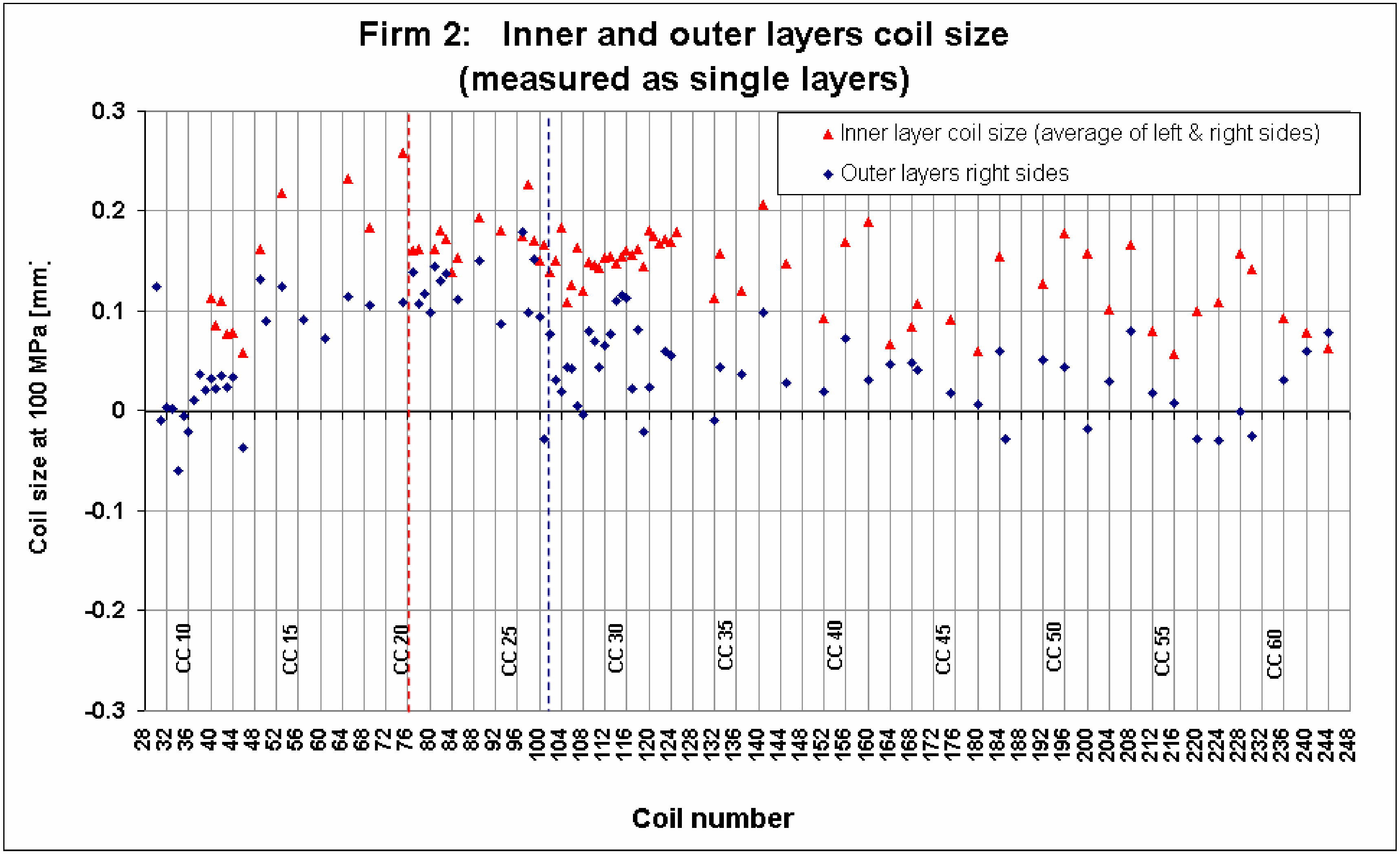

Fig. 6 Firm 2. Average coil size in the straight part of the inner and outer layers.

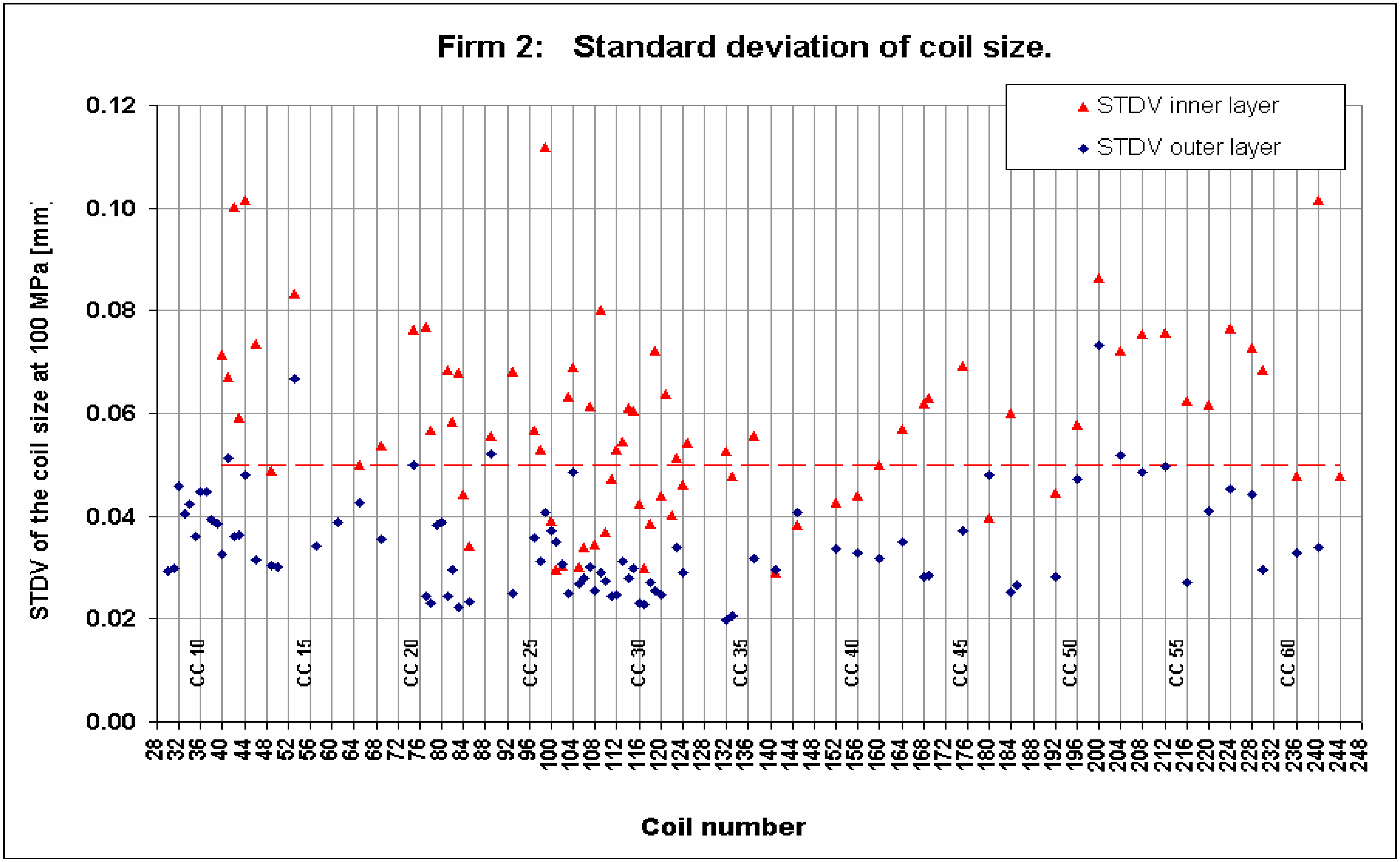

Fig. 7 Firm 2. Standard deviation of coil sizes measured in 15 positions along the coil (left and right coil sides in average). The area below the red dashed line in this figure is the allowed range for coil waviness.

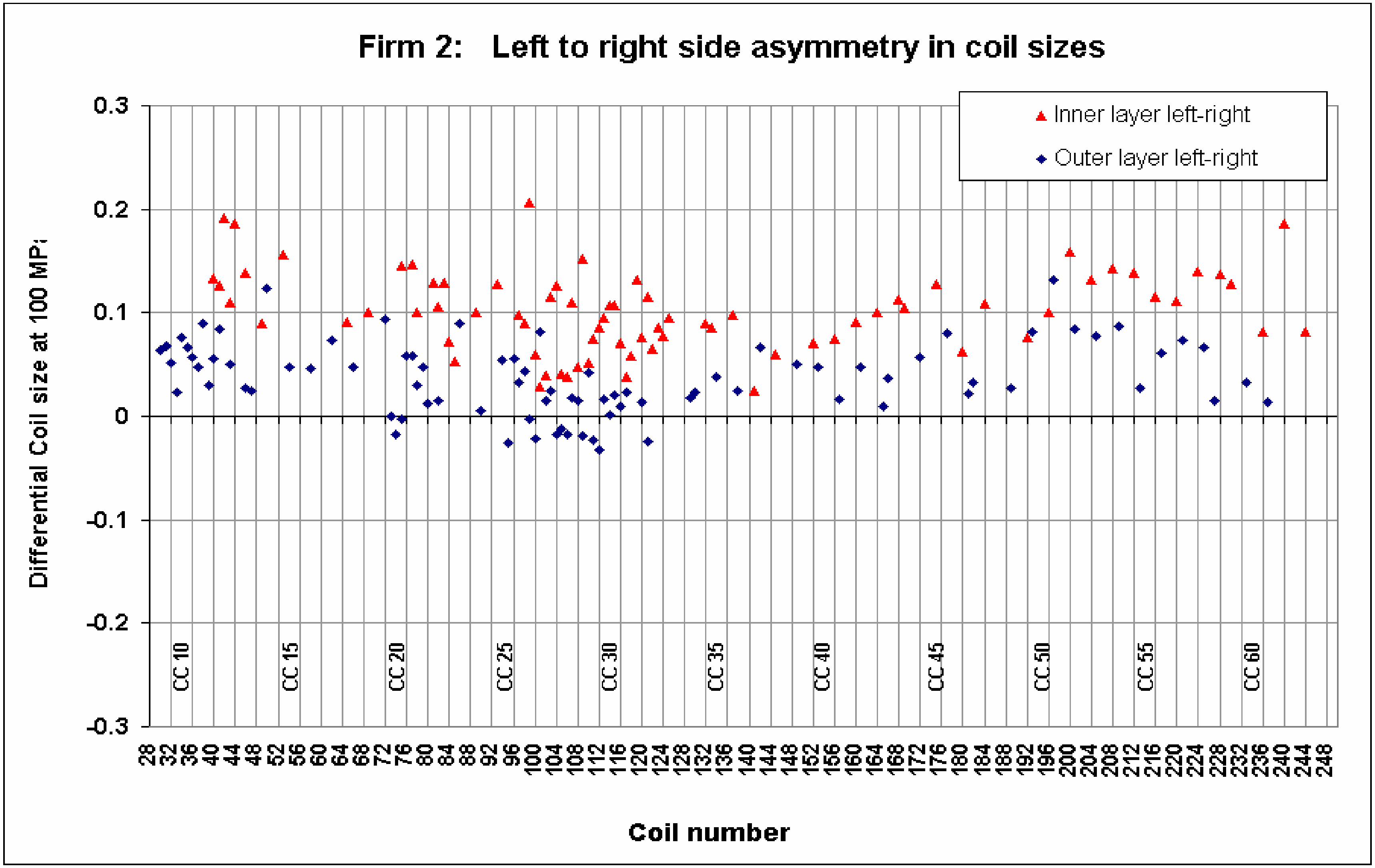

Fig. 8 Firm 2. Difference in the coil size between left and right sides of the coil on both layers.

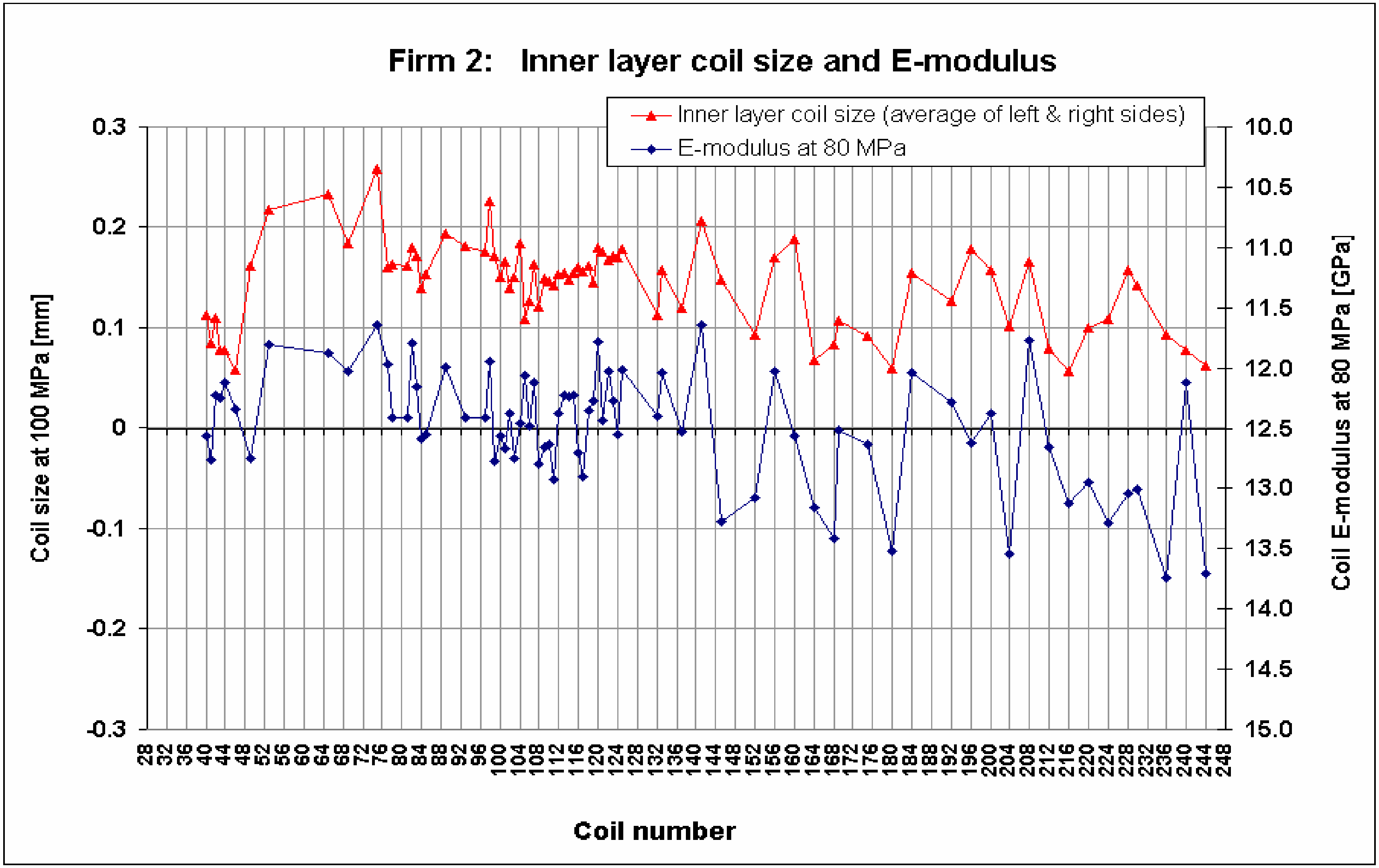

Fig. 9 Firm 2. Inner layer coil size (average) and E-modulus computed at 80 MPa.

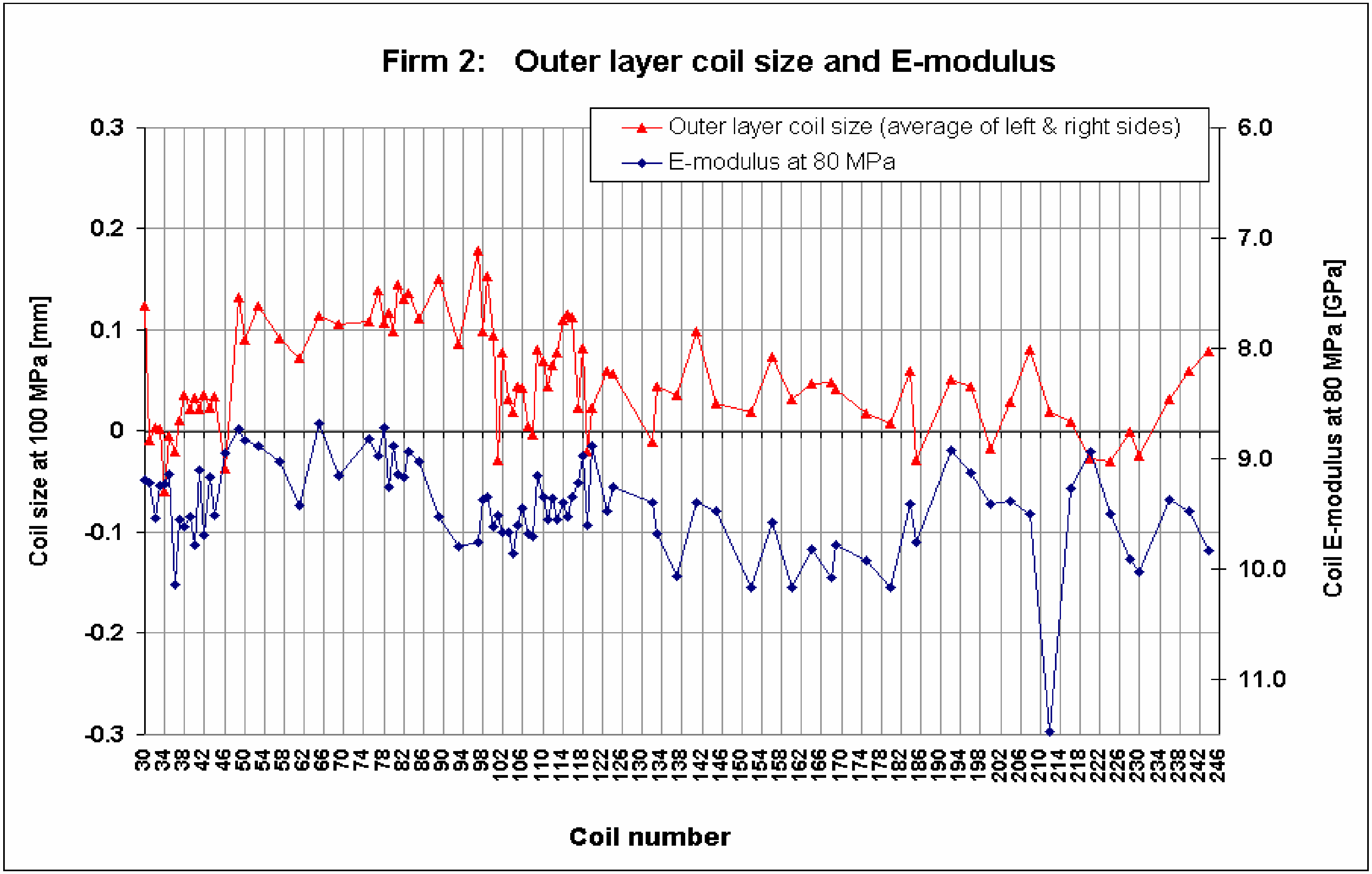

Fig. 10 Firm 2. Outer layer coil size (average) and E-modulus computed at 80 MPa.

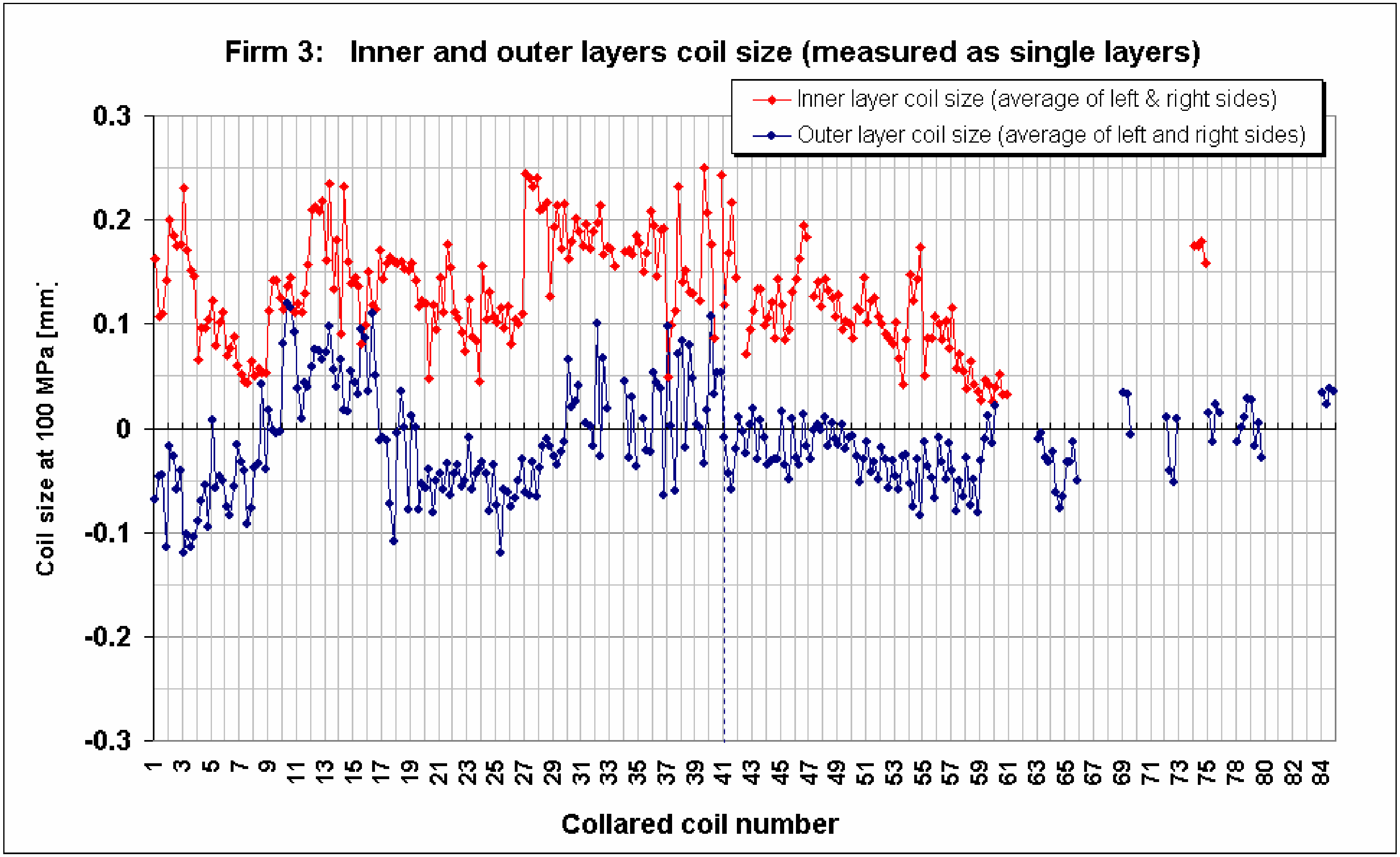

Fig. 11 Firm 3. Average coil size in the straight part of inner and outer layers.

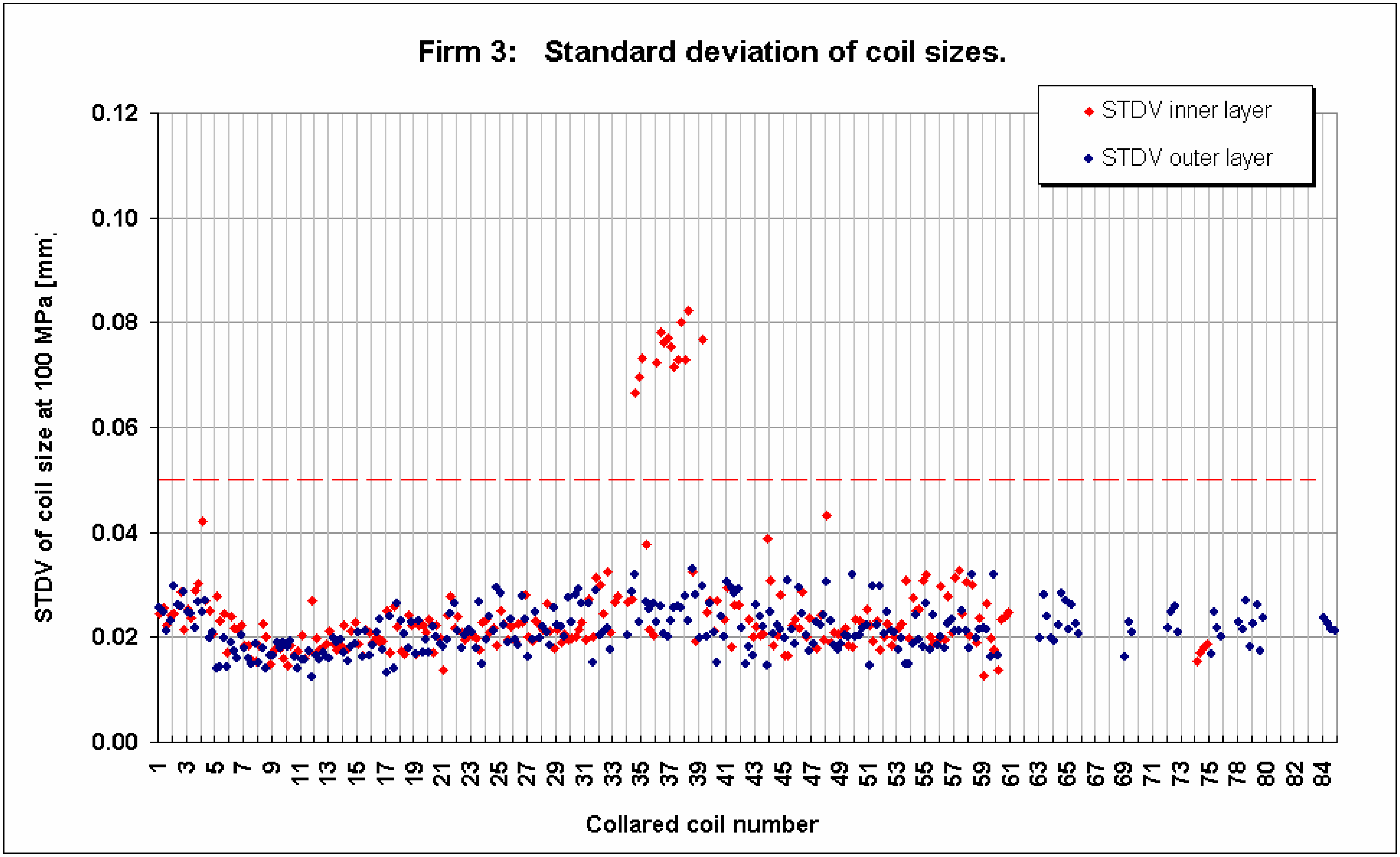

Fig.12 Firm 3. Standard deviation of coil sizes measured in 14 positions along the coil (left and right coil sides in average). The area below the red dashed line in this figure is the allowed range for coil waviness.

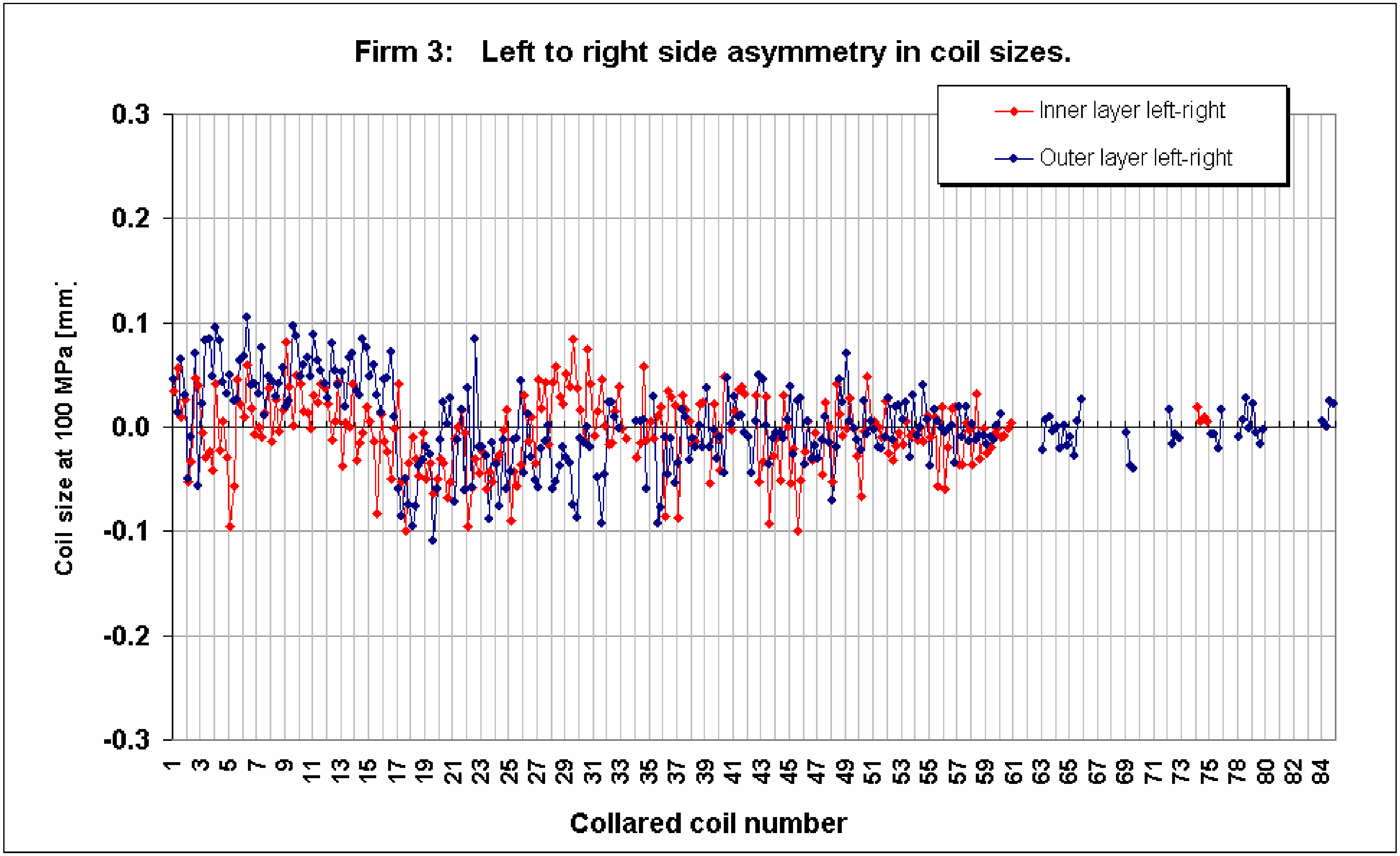

Fig.13 Firm 3. Difference in the coil size between left and right side of the coil on both layers.

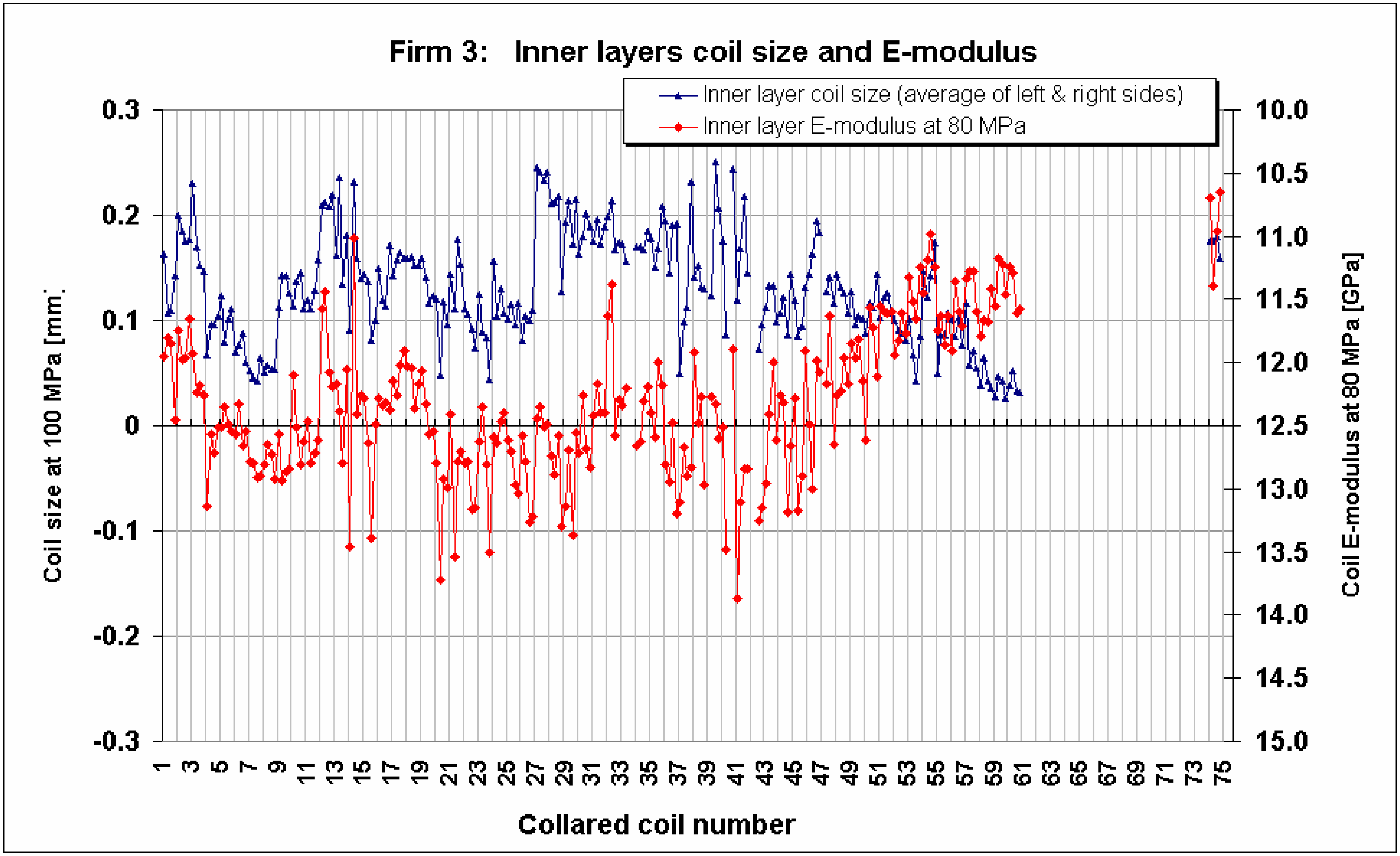

Fig. 14 Firm 3. Inner layer coil size (average) and E-modulus computed at 80 MPa.

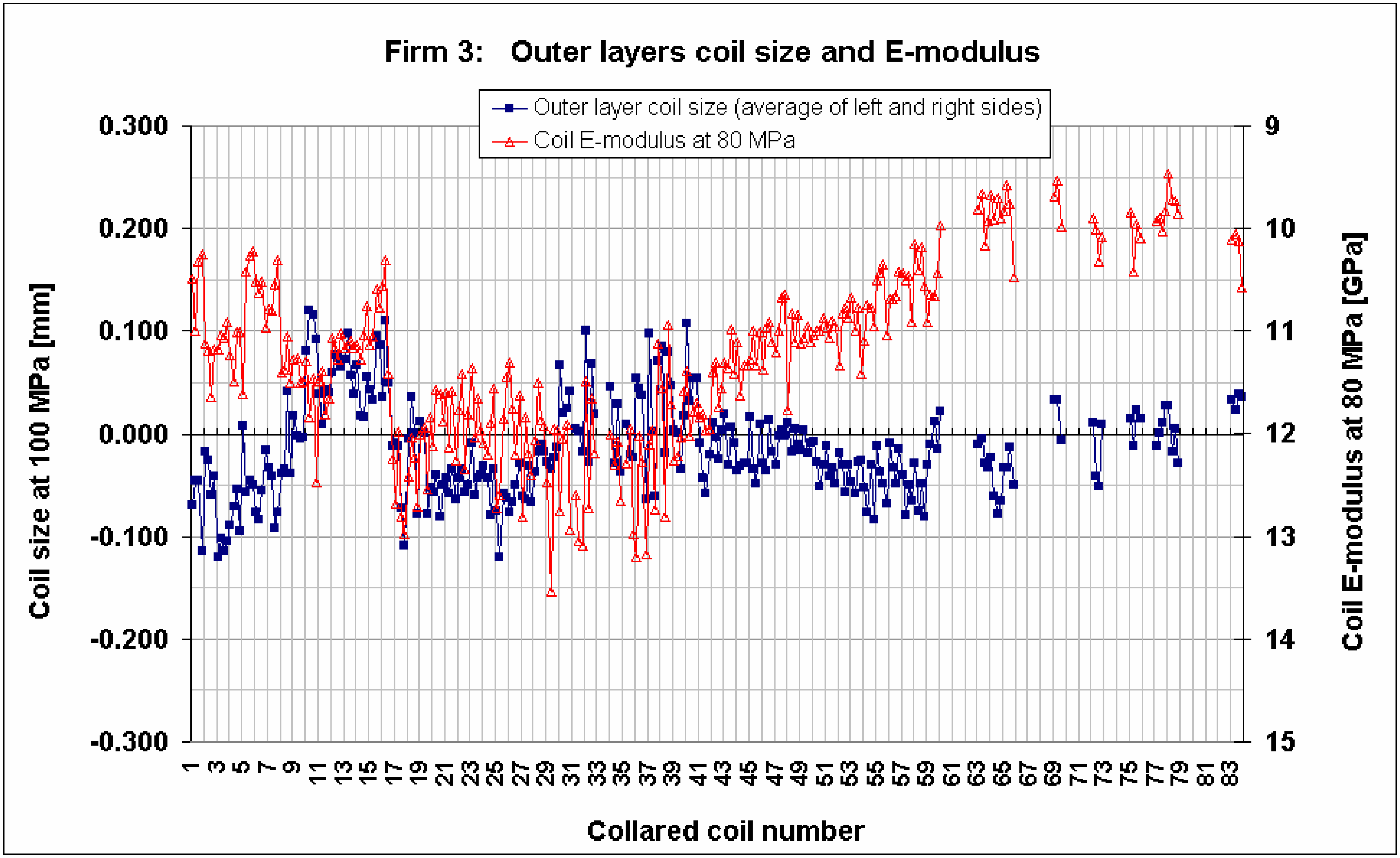

Fig. 15 Firm 3. Outer layer coil size (average) and E-modulus computed at 80 MPa.

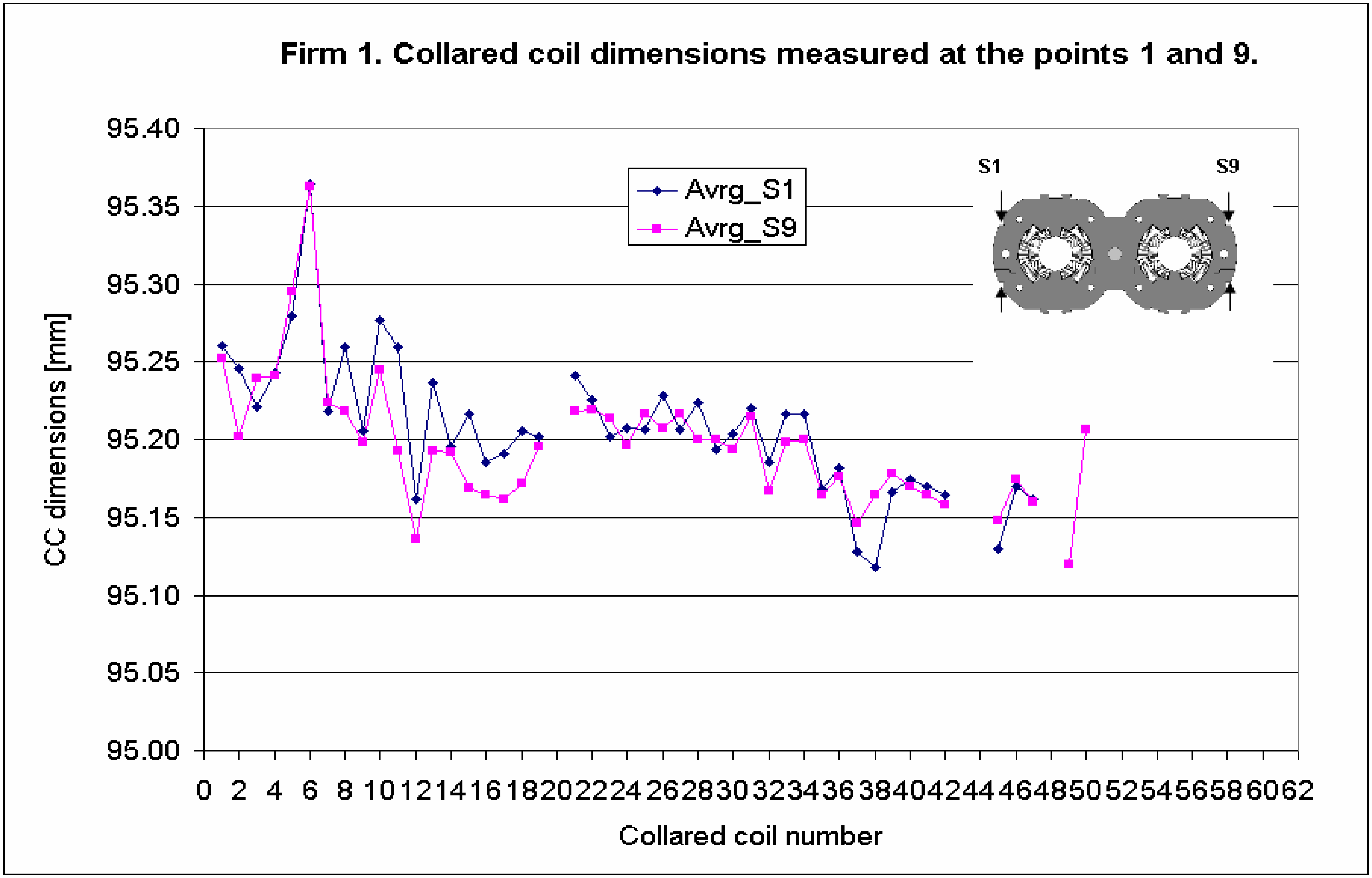

Fig. 16 Firm 1. Collared coil dimensions measured at the points S1 and S9.

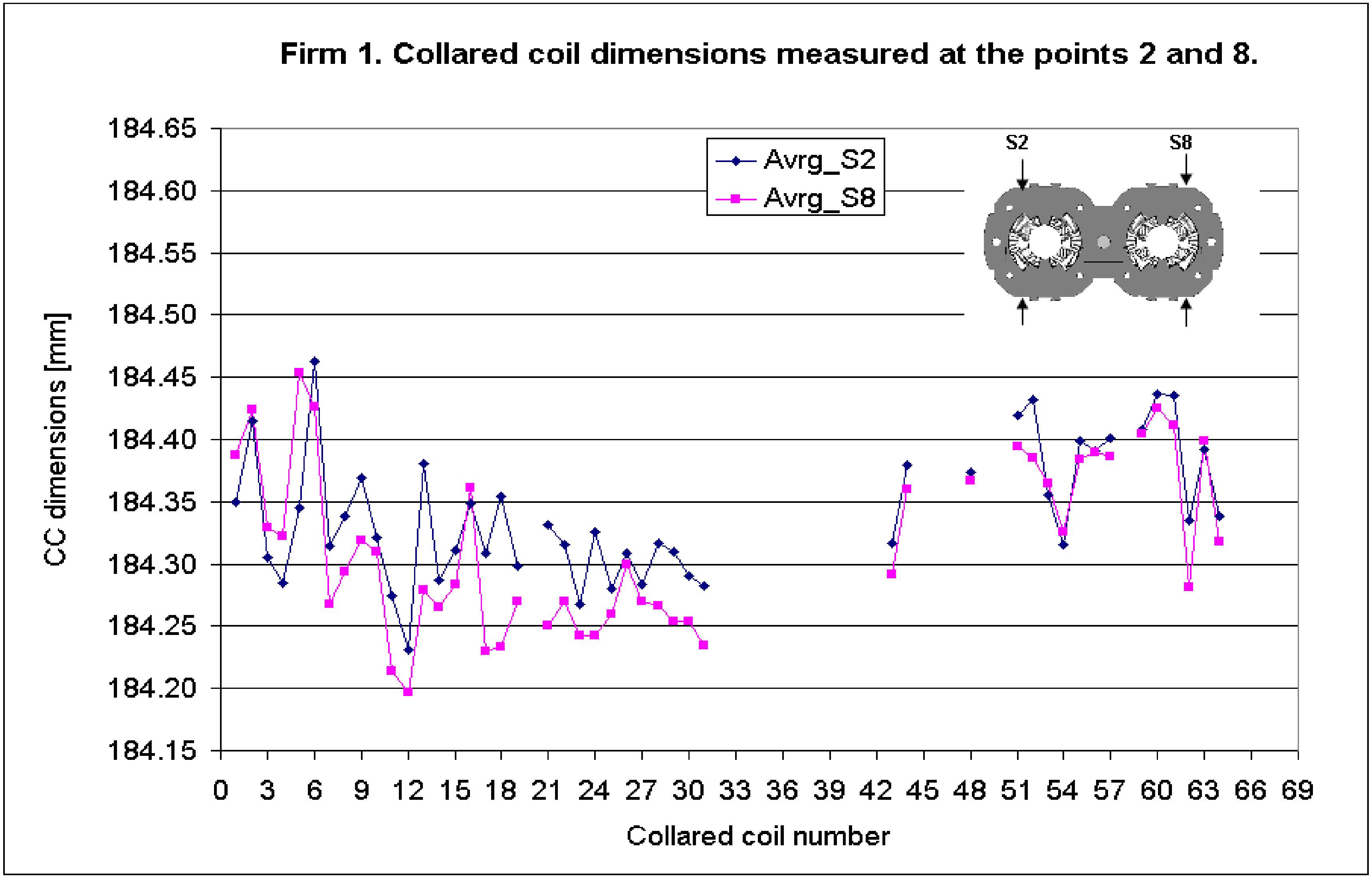

Fig. 17 Firm 1. Collared coil dimensions measured at the points S2 and S8.

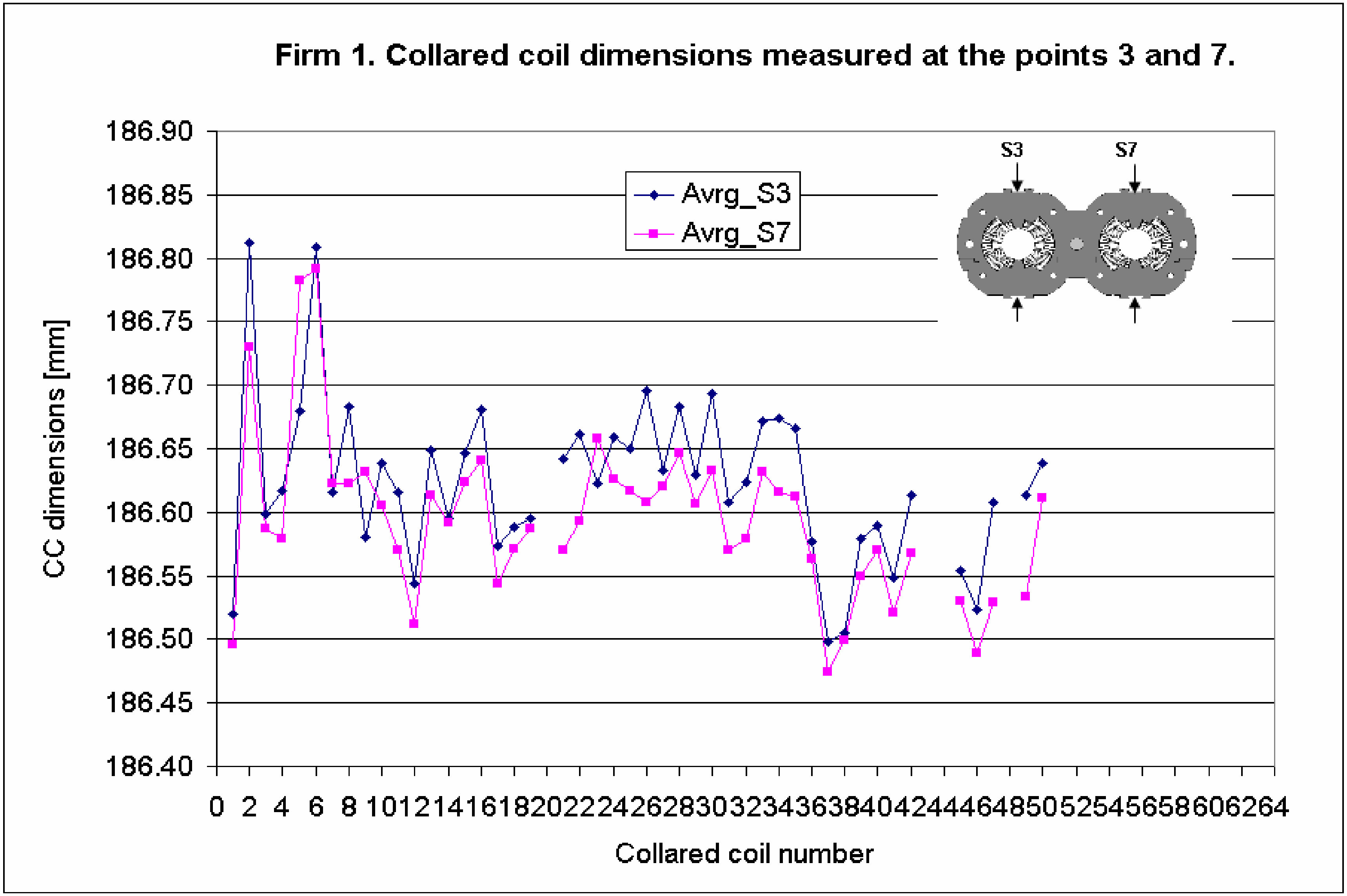

Fig. 18 Firm 1. Collared coil dimensions measured at the points S3 and S7.

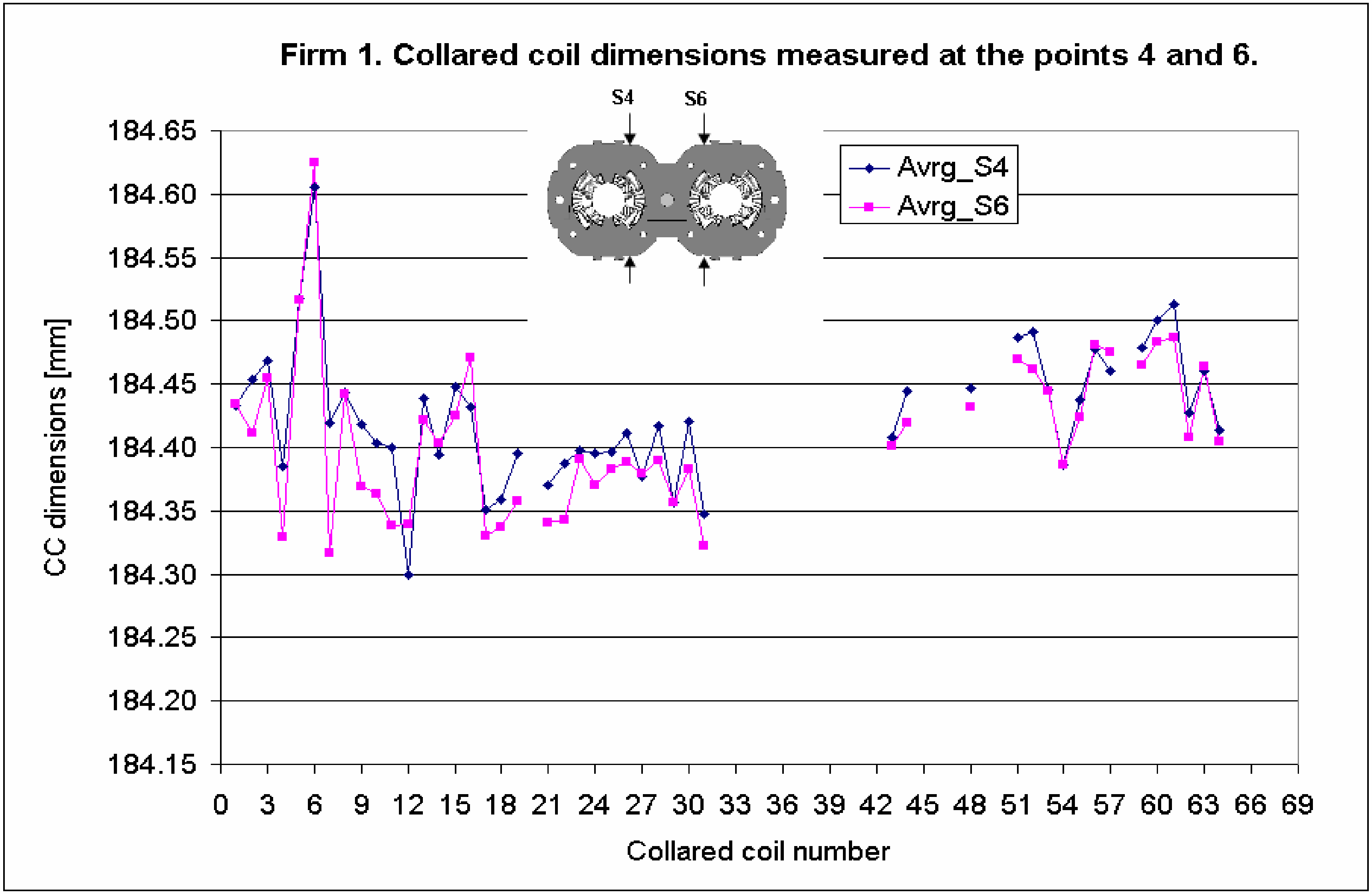

Fig. 19 Firm 1. Collared coil dimensions measured at the points S4 and S6.

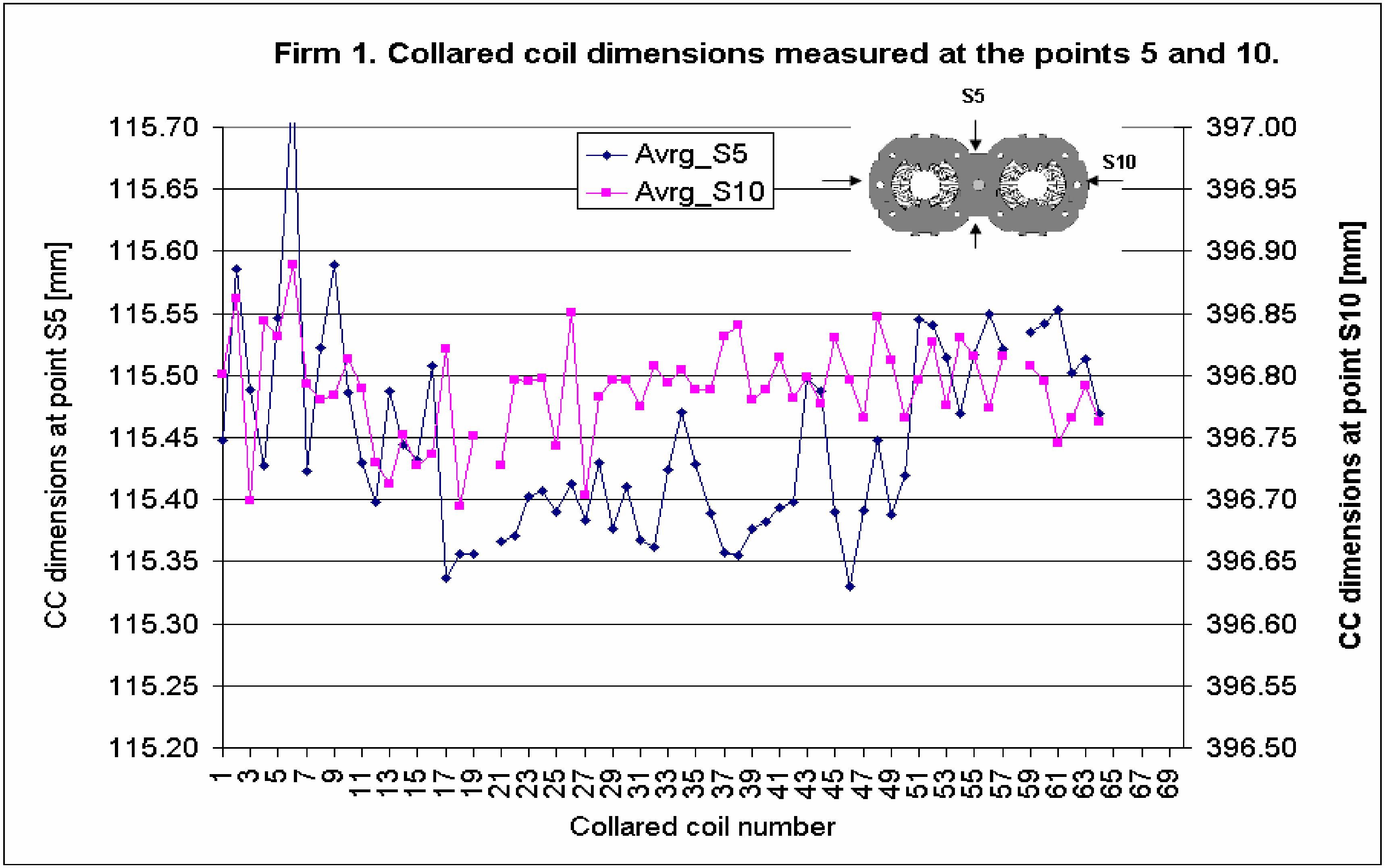

Fig. 20 Firm 1. Collared coil dimensions measured at the points S5 and S10.

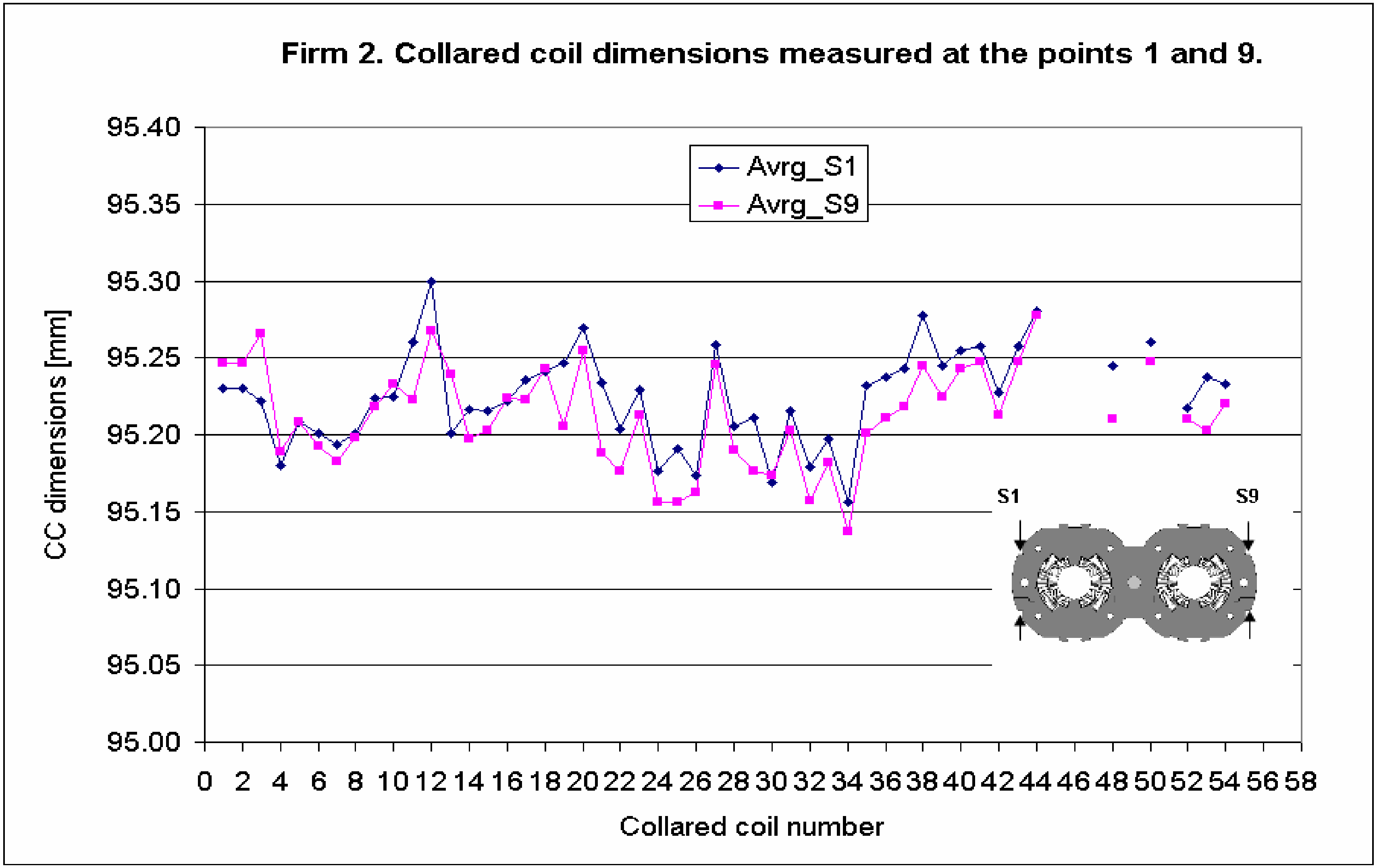

Fig. 21 Firm 2. Collared coil dimensions measured at the points S1 and S9.

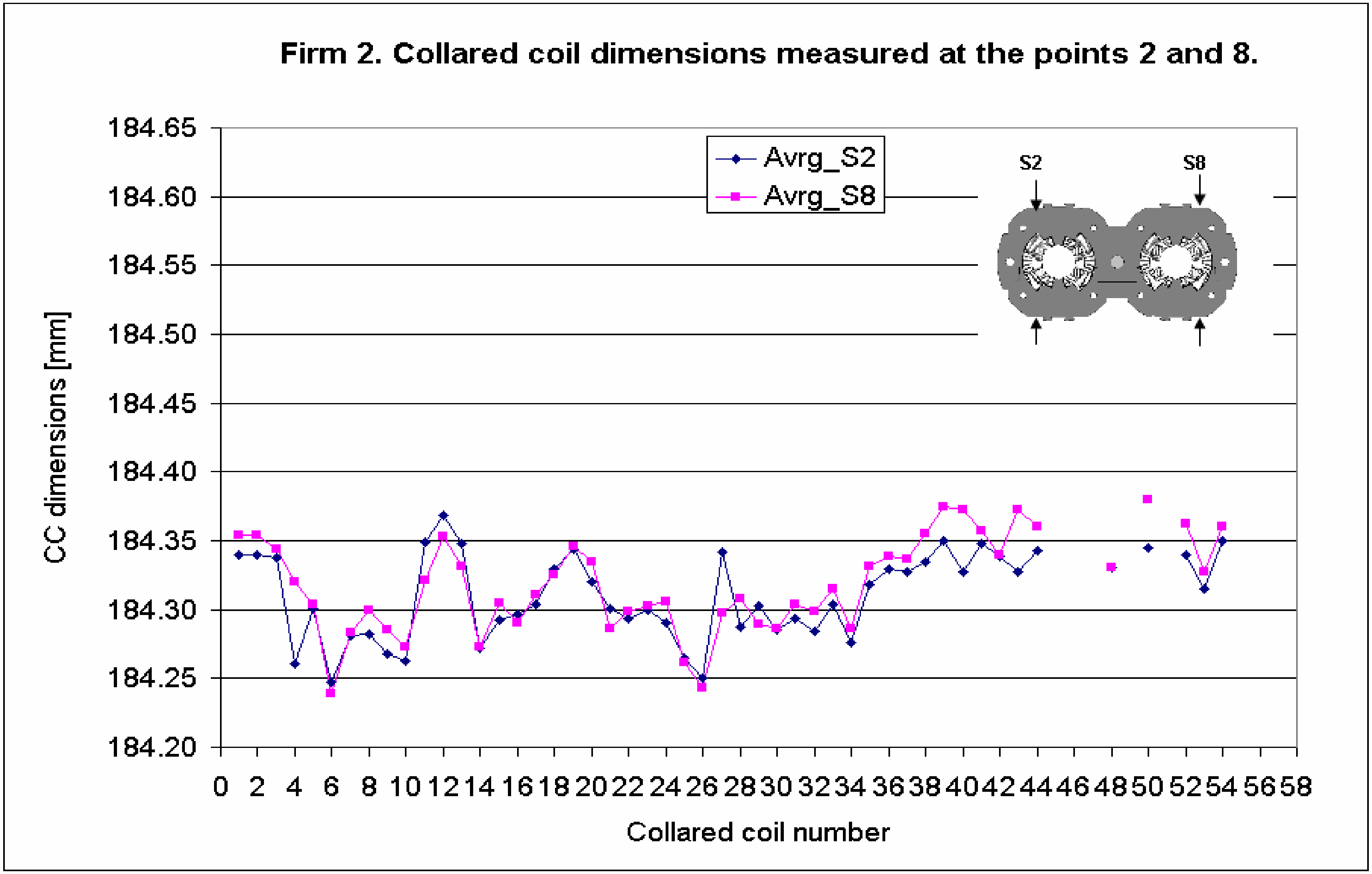

Fig. 22 Firm 2. Collared coil dimensions measured at the points S2 and S8.

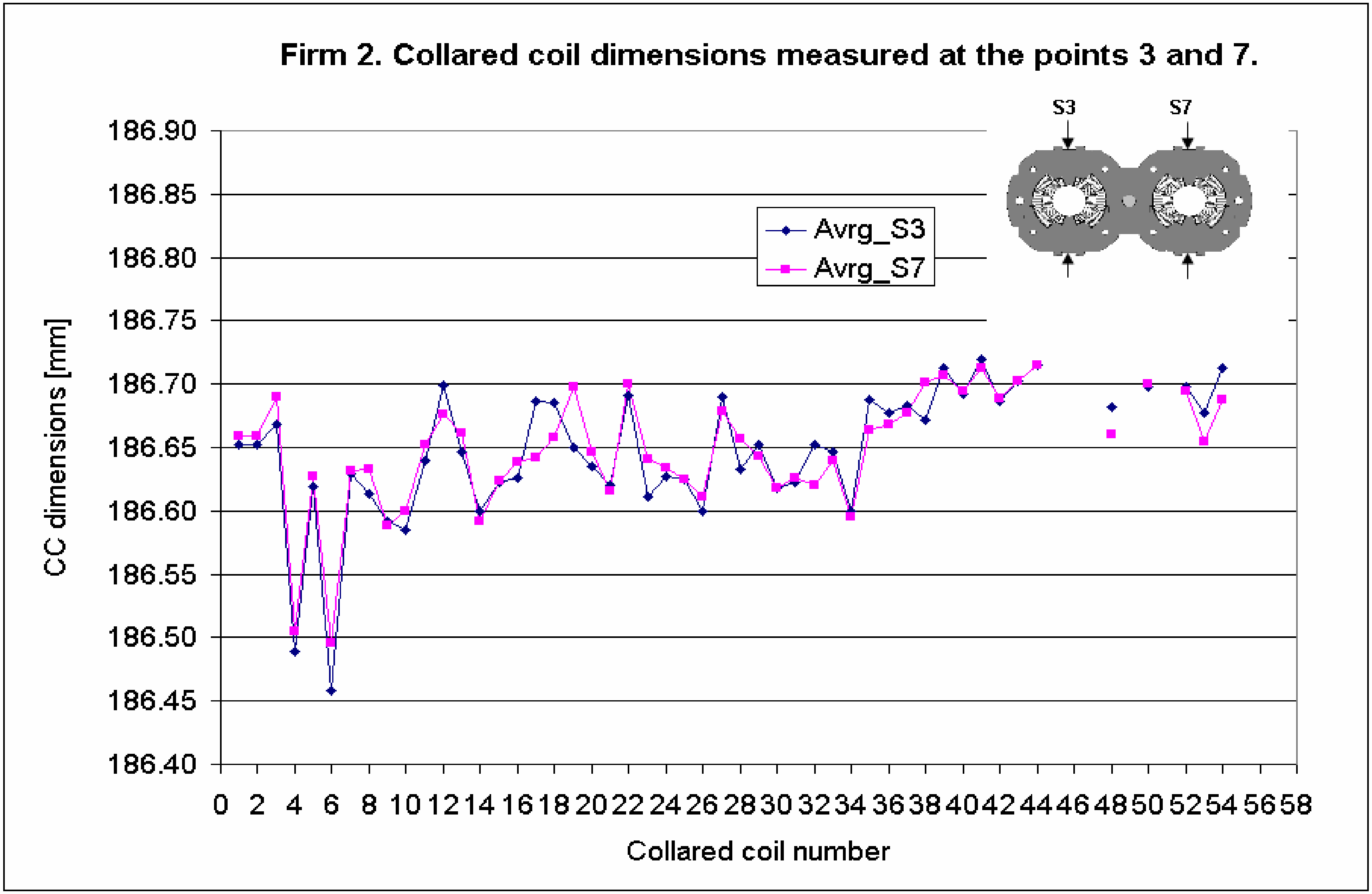

Fig. 23 Firm 2. Collared coil dimensions measured at the points S3 and S7.

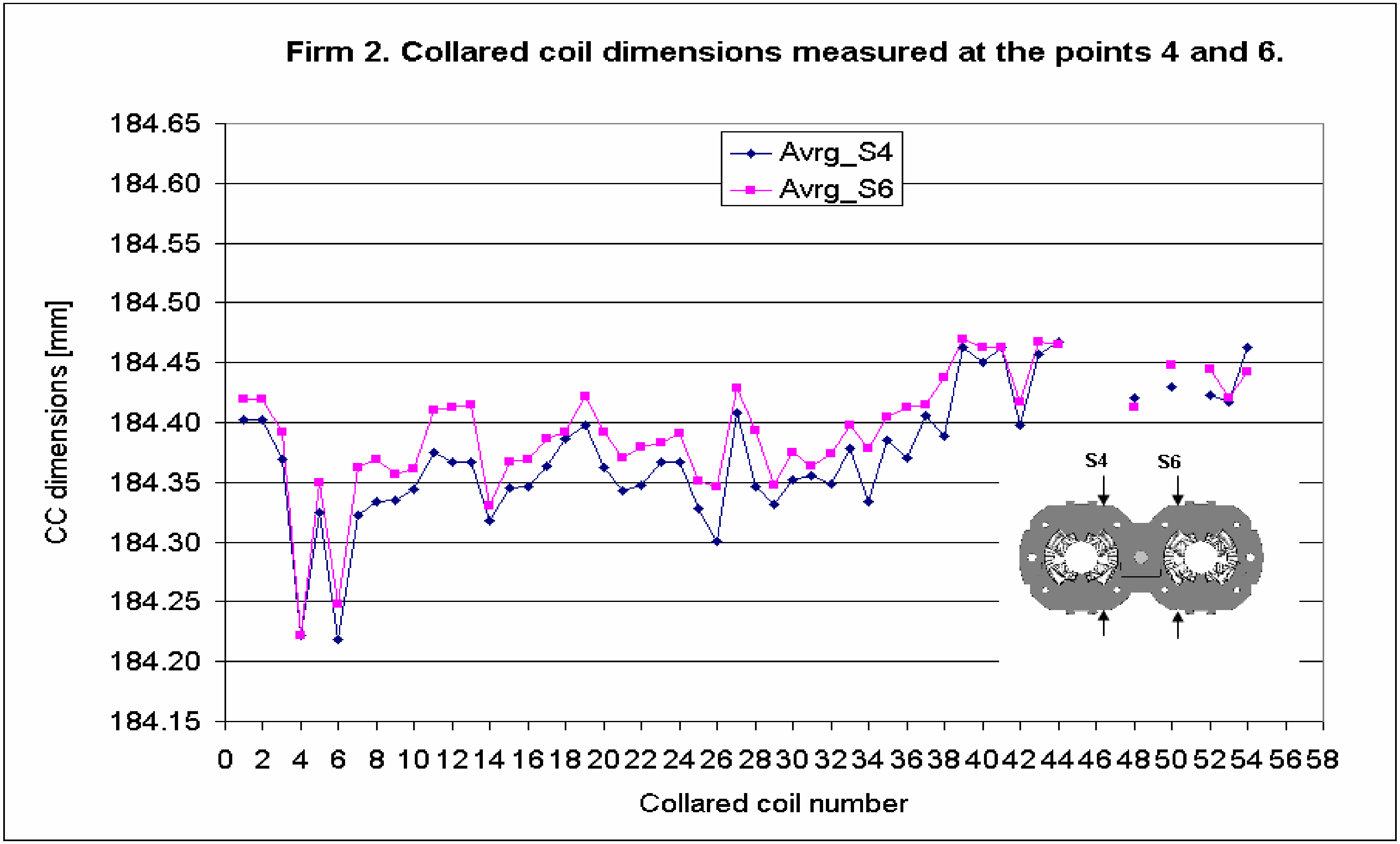

Fig. 24 Firm 2. Collared coil dimensions measured at the points S4 and S6.

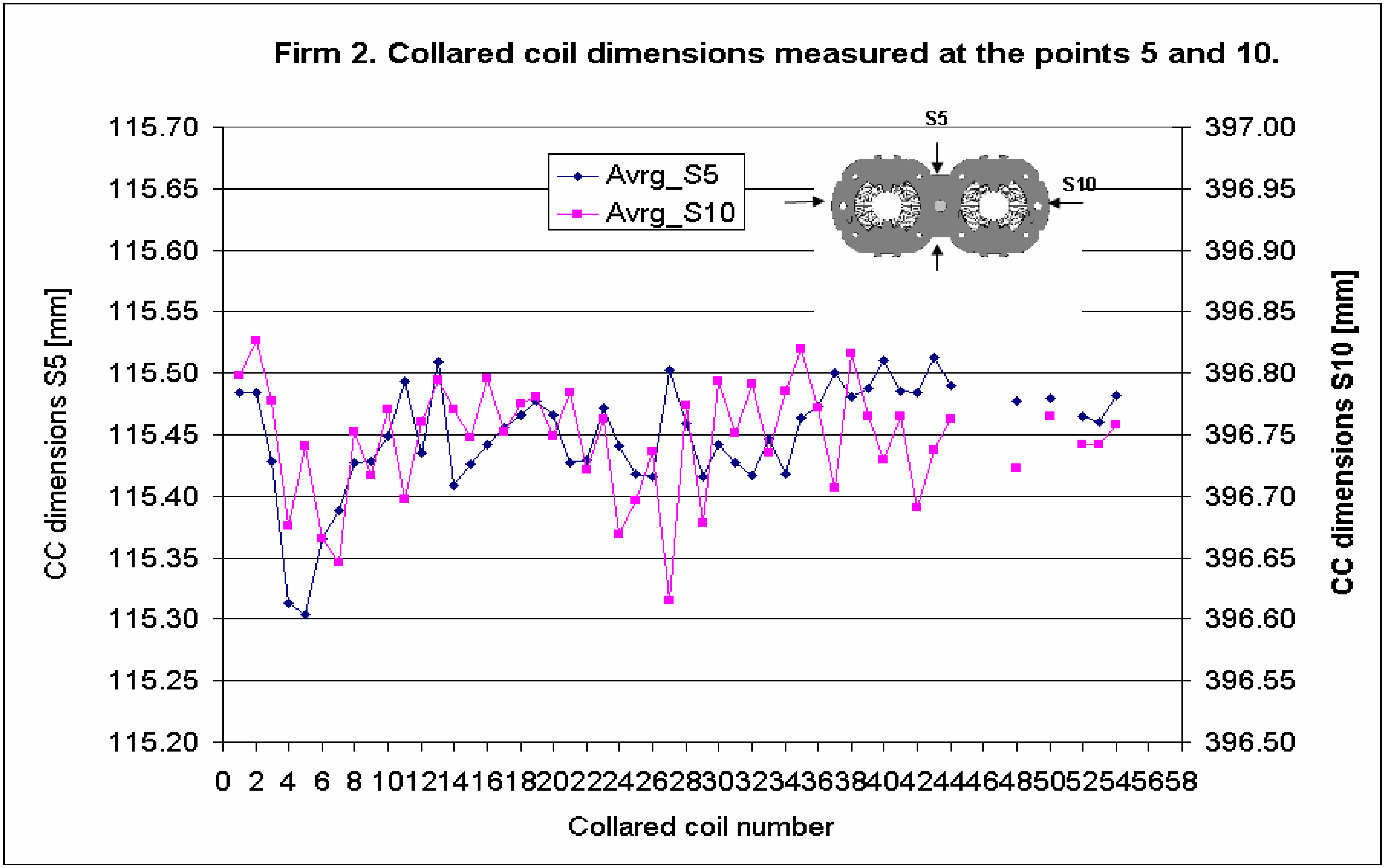

Fig. 25 Firm 2. Collared coil dimensions measured at the points S5 and S10.

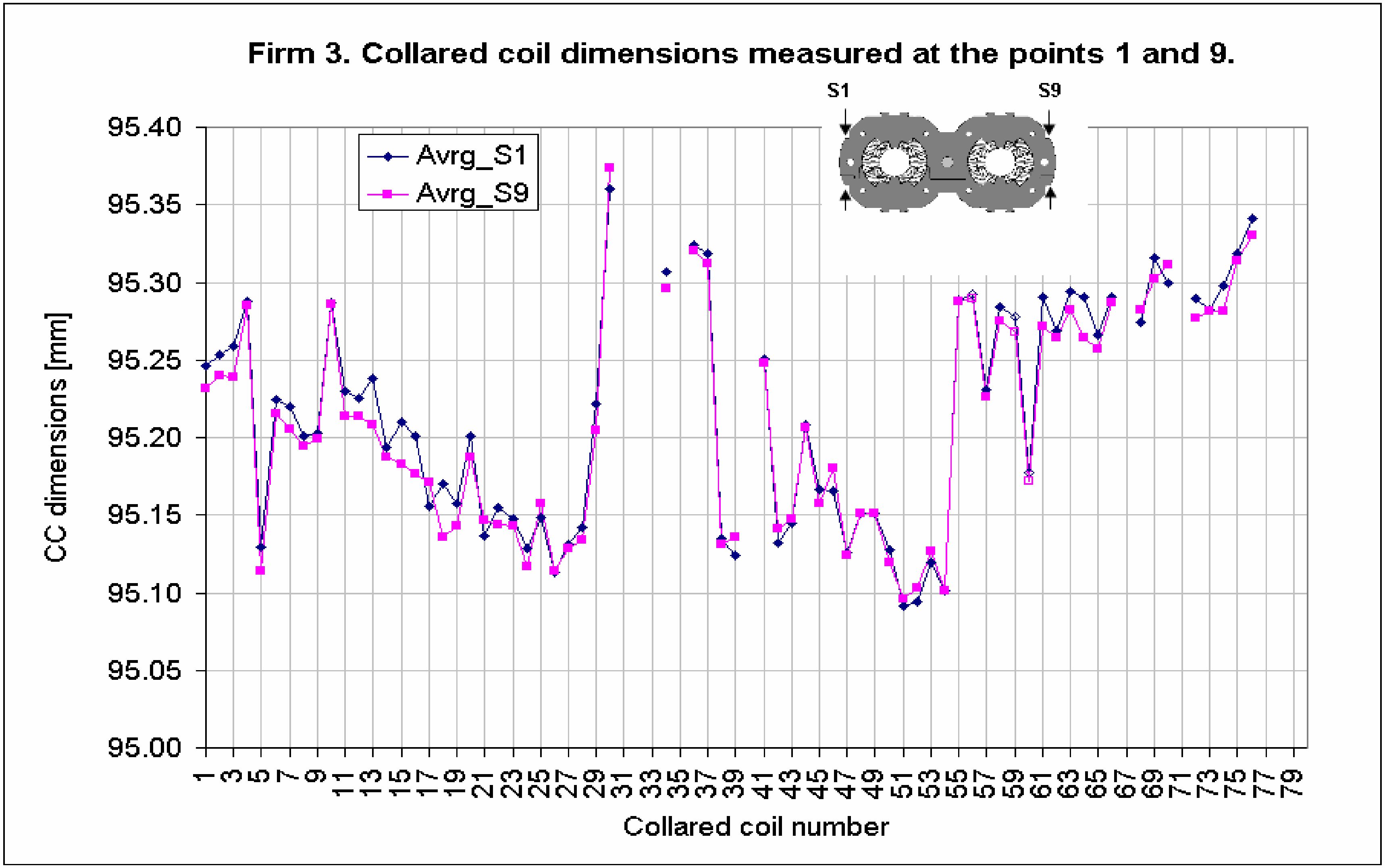

Fig. 26 Firm 3. Collared coil dimensions measured at the points S1 and S9.

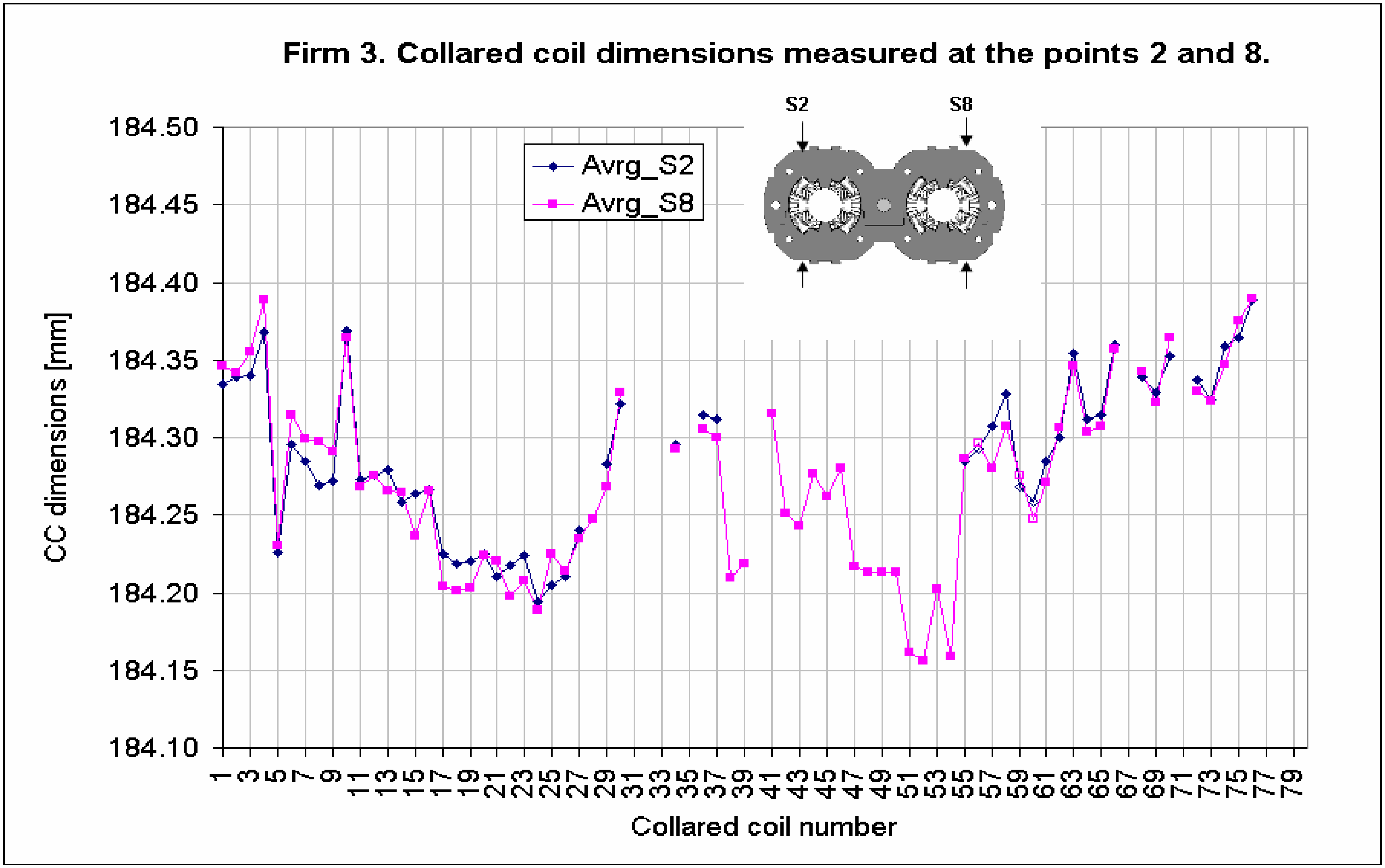

Fig. 27 Firm 3. Collared coil dimensions measured at the points S2 and S8.

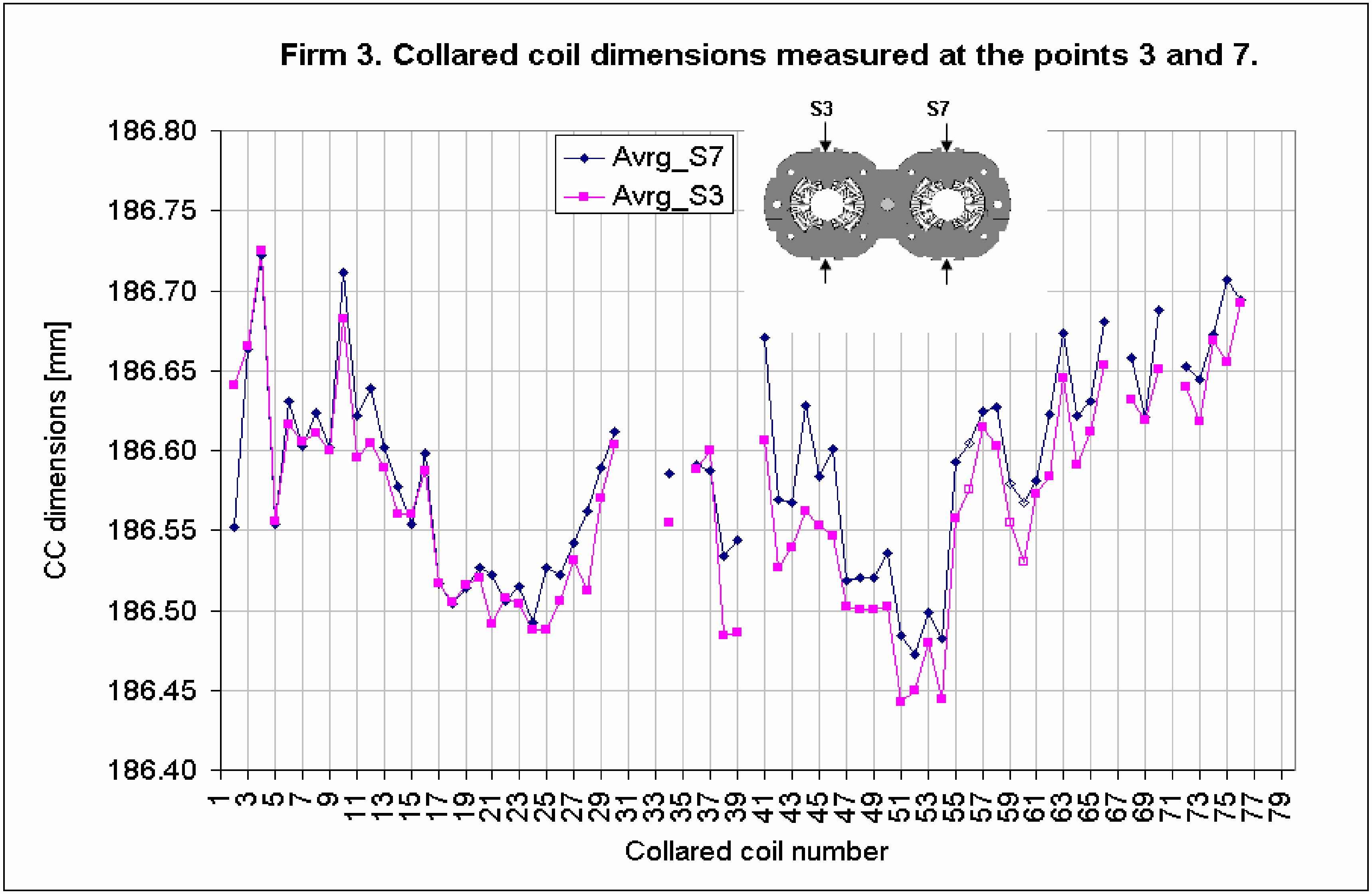

Fig. 28 Firm 3. Collared coil dimensions measured at the points S3 and S7.

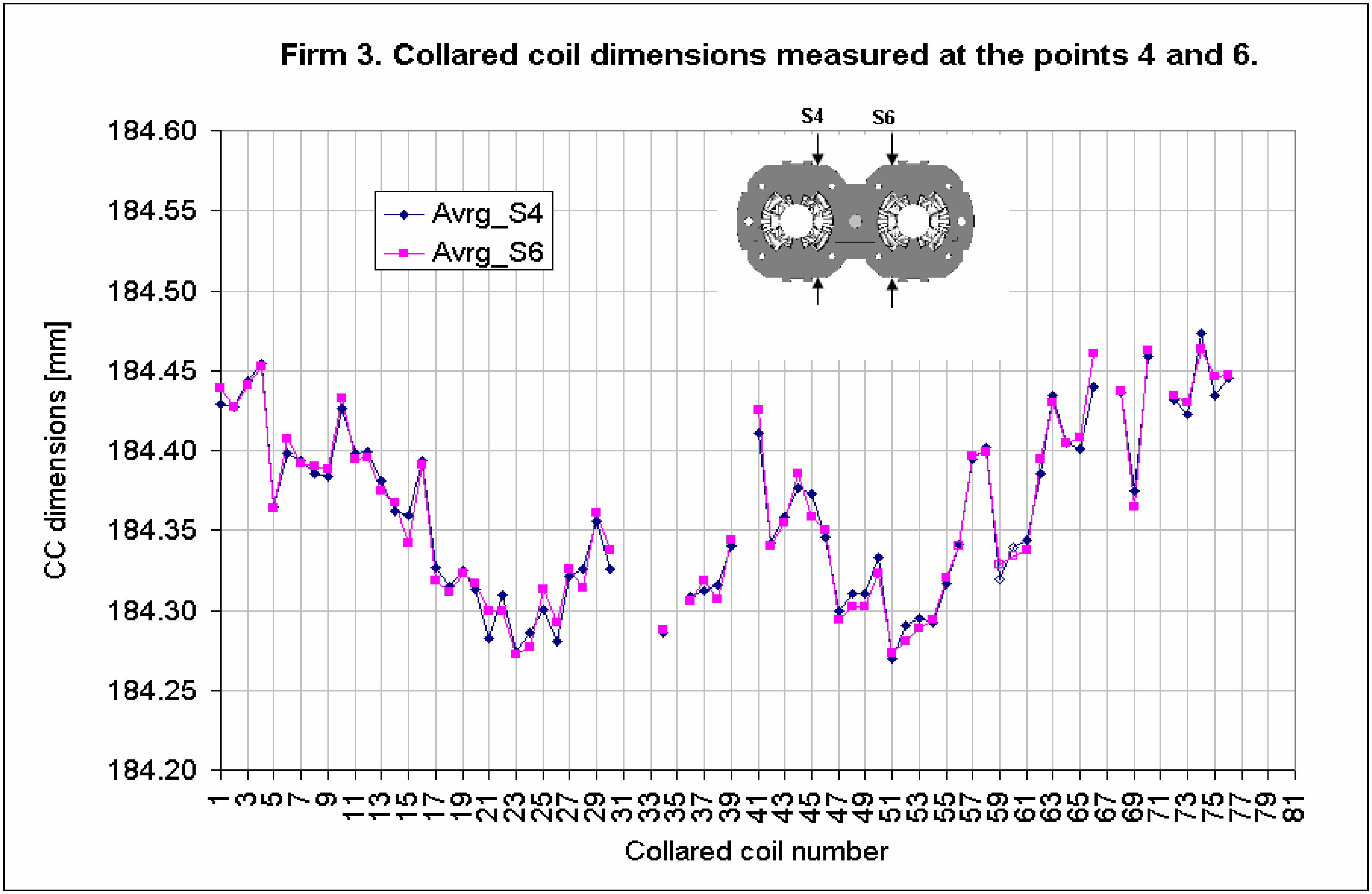

Fig. 29 Firm 3. Collared coil dimensions measured at the points S4 and S6.

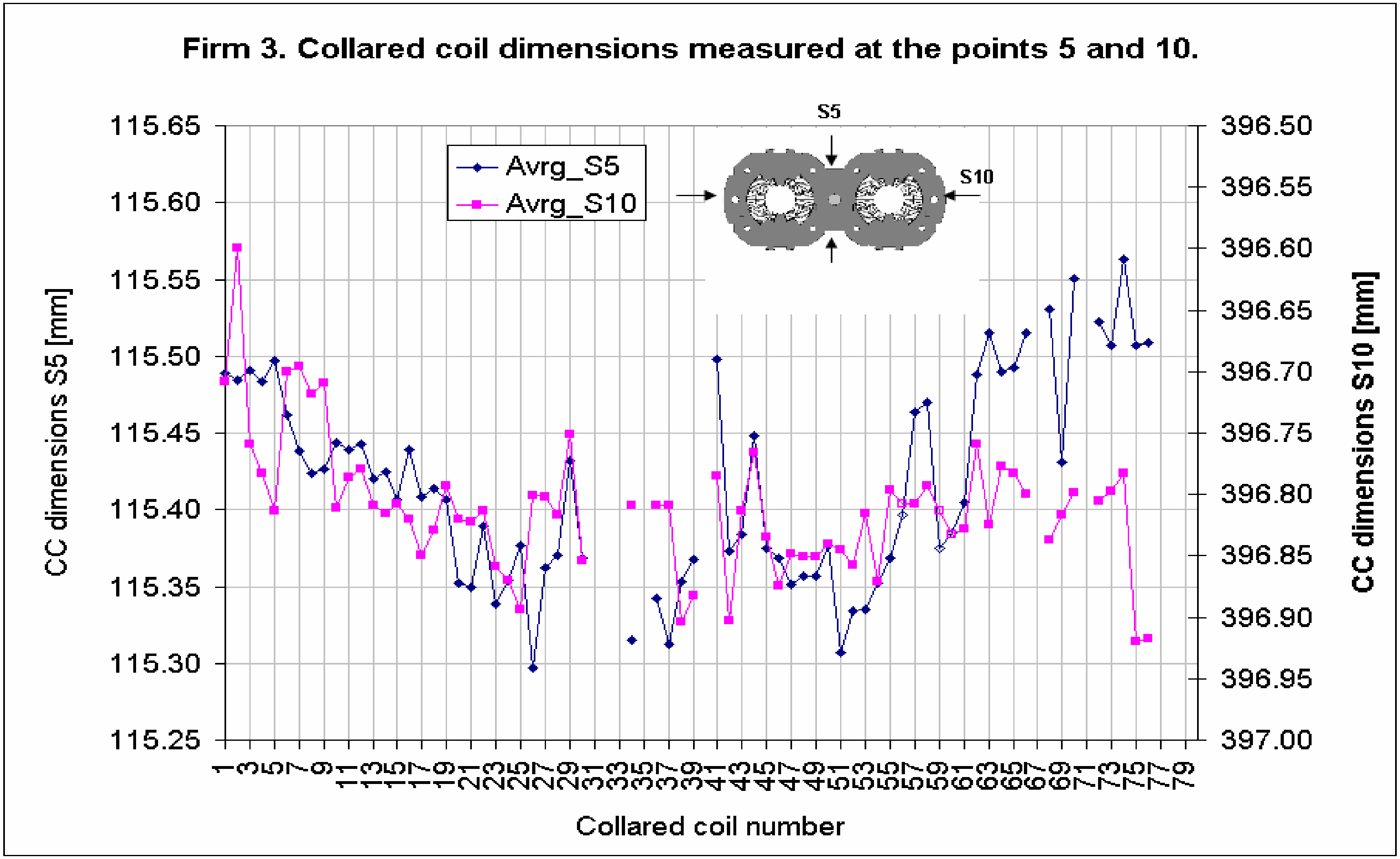

Fig. 30 Firm 3. Collared coil dimensions measured at the points S5 and S10 (notice that the scale for S10 axis is reversed).

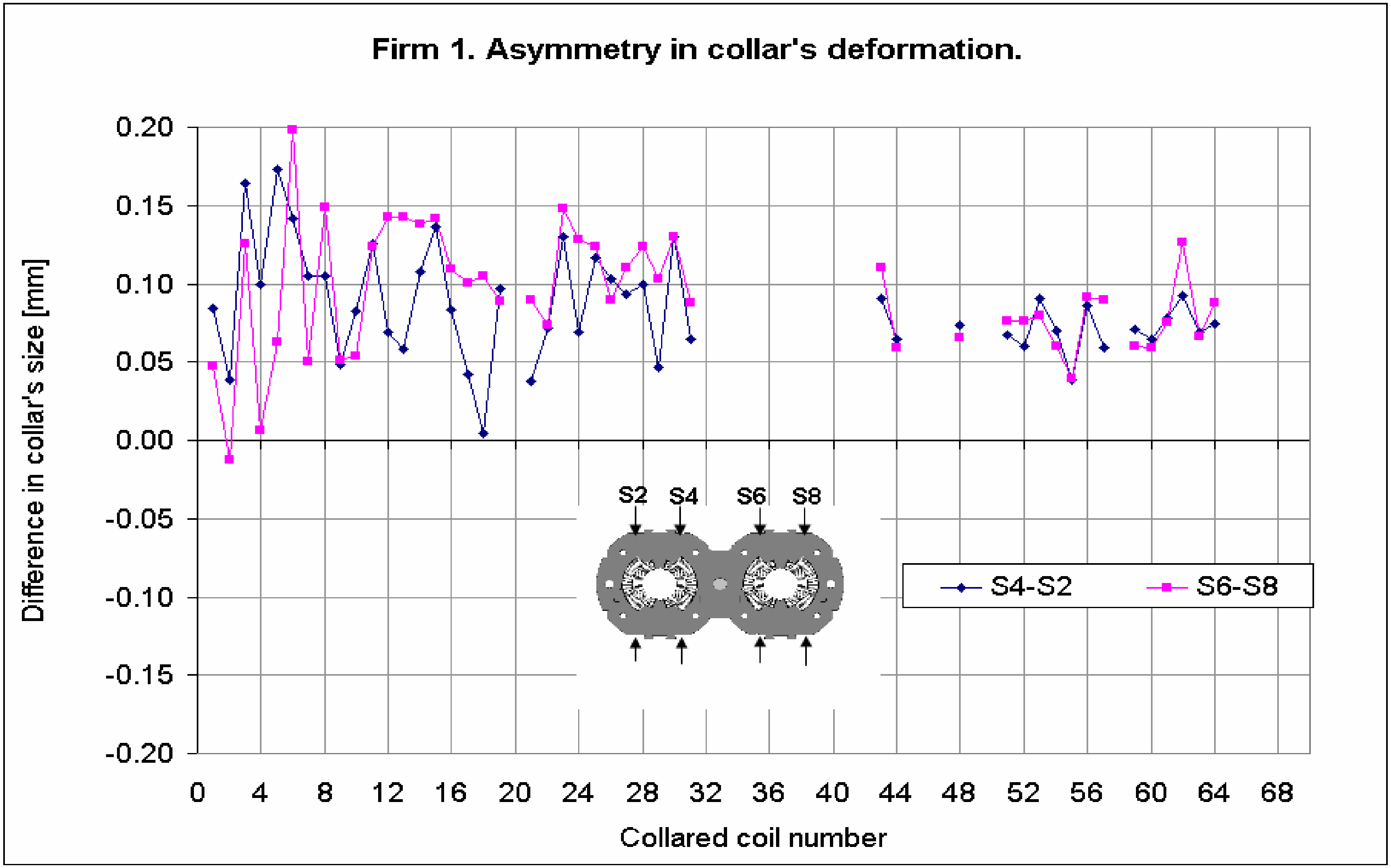

Fig. 31 Firm 1. Measured asymmetry in collared coil dimensions.

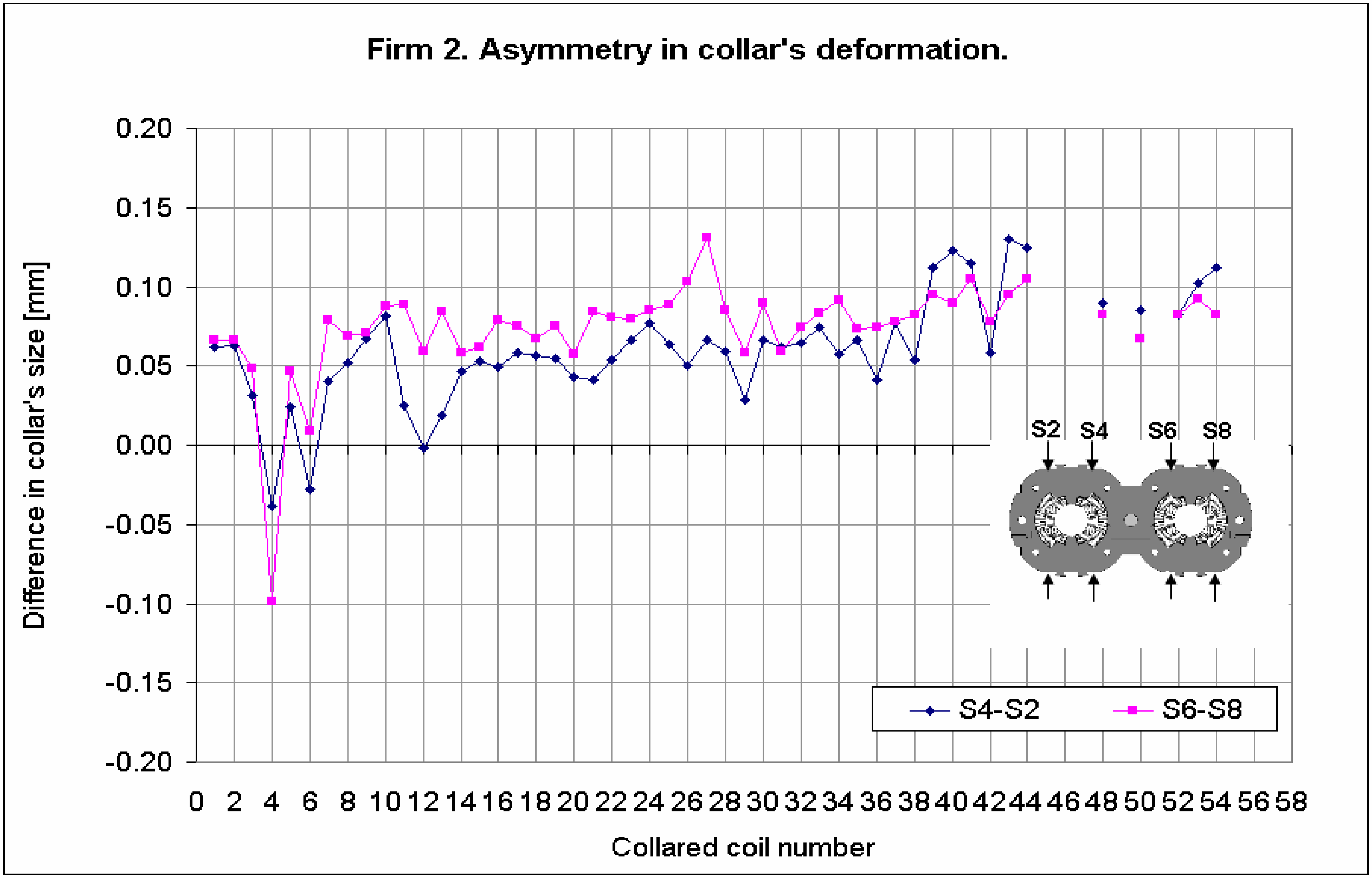

Fig. 32 Firm 2. Measured asymmetry in collared coil dimensions.

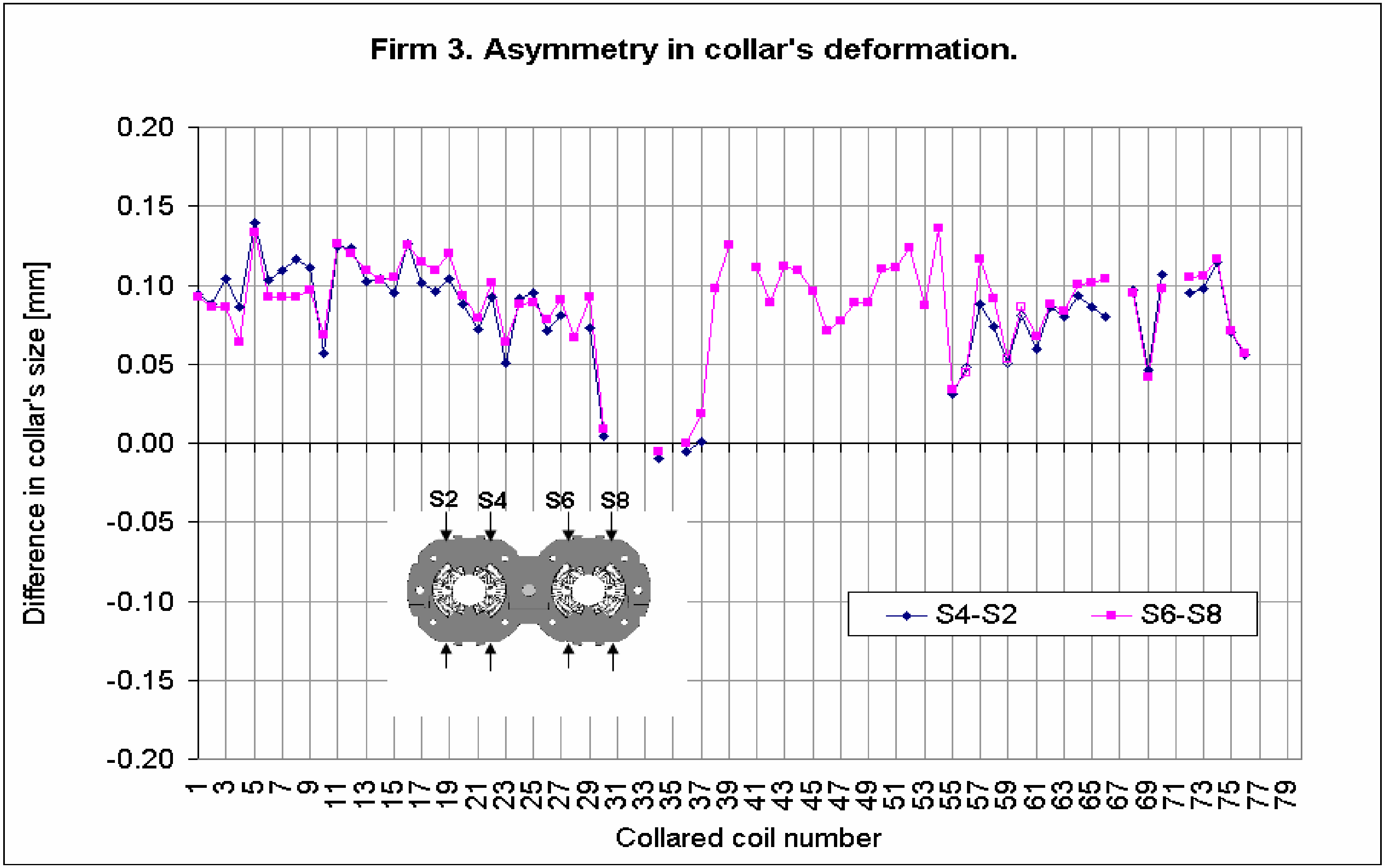

Fig. 33 Firm 3. Measured asymmetry in collared coil dimensions.