Report on mechanical measurements in the main LHC dipole collared coils: January-February 2004

I.Vanenkov, AT-MAS-MA

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, the data on coils size measurements for 460 poles is available, where 80 poles are measured in last 2 months. Last 8 poles were measured with reduced number of measuring sections along the coil (5 instead 15).
- **Firm 2 (ANSALDO)** –Up to date, more then 365 inner and outer layers have been produced (65 layers of each type in the last 2 months) and 105 inner and 117 outer have been measured (typically, one inner and one outer layer per magnet are measured).
- **Firm 3 (NOELL)** – The missing data on coil size measurements for ~80 magnets finally was send to CERN by firm. In order to reduce cost of these measurements, only the raw data was send and post-processing of this data was done at CERN. Following series production specification, the number of measuring coils and the number of measuring sections along the coil has been gradually reduced. Actually, two inner and two outer layers per magnet are measured. Up to date, the data on coil size measurements for 496 outer and inner layers (150 collared coils) is available at CERN.

What is new:

Collared coils dimensional data. A lower quench performance of some tested magnets has triggered investigation on coil ends shimming. The data on collared coil dimensional measurements taken over magnets ends was used for evaluating the difference in the coil pre-stress in coil ends between different magnets. More details can be found in the minutes of QWI meeting at http://lhc-div-mms.web.cern.ch/lhc-div-mms/Quench%20working%20unit/. Following the decision of this meeting, the monitoring on collared coil dimensions data for the measurements taken over coil ends is added to this report.

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 at several positions along the coil for tree firms. Unfortunately, due to significant reduction of the measuring points along the coils at firm 3, and firm 1 there is no more possibility to monitor this parameter.

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. Up to now, the coils at Firm 1 were measured in 15 longitudinal positions. In order to speed up the production starting from the poles set 114 the number of measuring sections has been reduced to 5 (also poles set 109 was measured with the new map). In figure 1 the average of all measuring points is used to show the coil size trends. A larger variation of coil size on the outer layer is related to the problem with the measuring machine, mentioned in a previous report. In order to reduce the error coming from the measuring machine, in fig. 1 we add the plot "Outer cleaned" where for computing the average coil size we used the data cleaned from the bad measuring points. Nevertheless, even after the "cleaning", the variation of coil size reminds rather important and for some coils exceeds a ± 0.1 mm range, typical for others two firms. The investigations carried out on the tolerances of coil components in MAS/MA section, has shown that the major part of this coils size variation is due to the tolerances on cable insulation tape [1].

The standard deviation (one sigma) of coil size variation along the coil is shown in figure 2. Due to reduced number of measuring section in the pole sets 109 and 114, the data on these pole sets is not shown in figure 2.

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 is related to the problem with the measuring machine, mentioned in a previous report. 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 65 inner and 65 outer layers have been produced over last two months, and 32 were measured for coil sizes (15 inner layers and 17 outer layers). In general, the variation in the coil size in the inner and outer layers coils of series production stays in the range of ±0.1 mm, but for the last measured coils it is approaching the lower limit (fig.6). 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.
At firm 2 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 difference in coil size between left and right sides of coils is shown in figure 8. Starting from the inner layer 253 we notice a shift down of the inner layer systematic by more then 0.1 mm. From the field quality point of view, this shift is in a good direction, as it should move the a3 multipole systematic closer to its nominal value.
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. The missing data on coil size measurements for ~80 magnets finally was send to CERN by the firm. In order to reduce cost of these measurements, only the raw data was send and post-processing of this data was done at CERN. For most of the coils, the variation in the coil size in the inner and outer layers coils of series production stays in the range of ±0.1 mm (fig.11). Following series production specification, the numbers of measuring coils per magnet and measuring sections along one coil has been gradually reduced. Actually, two inner and two outer layers per one magnet are measured at 5 longitudinal positions along the coil (14 positions in the past, see fig.11).
Due to reduced number of measuring sections, we removed the graph with standard deviation of coil size variation along the coil.
The difference in coil size between left and right sides of coils is shown in figure 12.
In figures 13 and 14, 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 15 ÷ 17 the collared coil dimensions (CCD) data for measuring points S2, S4-S6, S8 and S10 are shown (each plot gives the data on two symmetrical points). We remind, that a new machine to measure collared coil dimensions is in use at Firm 1 starting from the CC-51 (the collared coils 44 and 48 are also were measured with the new system). With new machine, the measuring points S1, S3, S7 and S9 are not measured; therefore we removed the corresponding figures.

Firm 2. In figures 18 ÷ 22 the CCD data 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 23 ÷ 27 the CCD data 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).

Trend graphs (coil ends)

For the magnets of pre-series, the CC dimensions were taken at 5 longitudinal positions over coil ends: at 0.02 m, 0.06 m, 0.1 m, 0.14 m and 0.18 m away from collared coil extremities. The magnets of series are measured at 3 longitudinal positions over each coil end: at 0.04 m, 0.110 m and 0.18 m away from collared coil extremities. The coil pre-stress is varies along the coil ends. The analysis, carried out in MA section have shown, that the average CCD data of all measuring sections over coil ends can be used to classify the magnets by the level of coil pre-stress in coil ends. From 10 measuring points S1-S10, the points S3 and S7 are the best to monitor the variation of coil pre-stress, as at these points the collars have maximum vertical deformation due to coil pre-stress. In figures 28÷31 we monitor the average value of CCD data for measurements taken over coil ends.

Firm 1. Due to difference in number of measuring points between old and new measuring machines at firm 1, we split the collared coils into two groups: the collared coils 1÷50, which were measured with use of old machine and collared coils 51÷110, which are measured with the new machine. In figures 28÷29 the CC dimensions for measurements taken over coil ends are shown together with the data on coil straight part.

Firm 2. In figures 30 the CC dimensions for measurements taken over coil ends are shown together with the data on coil straight part. Unfortunately, at firm 2 after switching to the measuring procedure of series, the measurements over non-connection coil end were taken not at correct longitudinal positions for CC from 36 to 63. Later, some of these collared coils were re-measured. In figure 30 only the data from correct measurements is shown.

Firm 3. In figures 31 the CC dimensions for measurements taken over coil ends are shown together with the data on coil straight part. The CC up to 3020 were measured at 5 longitudinal positions over each coil end (measuring procedure of pre-series), then all CC have been measured according to the measuring procedure of series (3 longitudinal positions over each coil end).

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 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 M. Bajko, M. Cornelis, P. Fessia, A. Musso, M. Modena, G. De Rijk, F. Savary, and W. Scandale for comments, discussions and valuable help.

Reference:

[1] I.Vanenkov, "The impact of the cable insulation thickness tolerances on LHC dipole coil size", LHC Project Report 680.

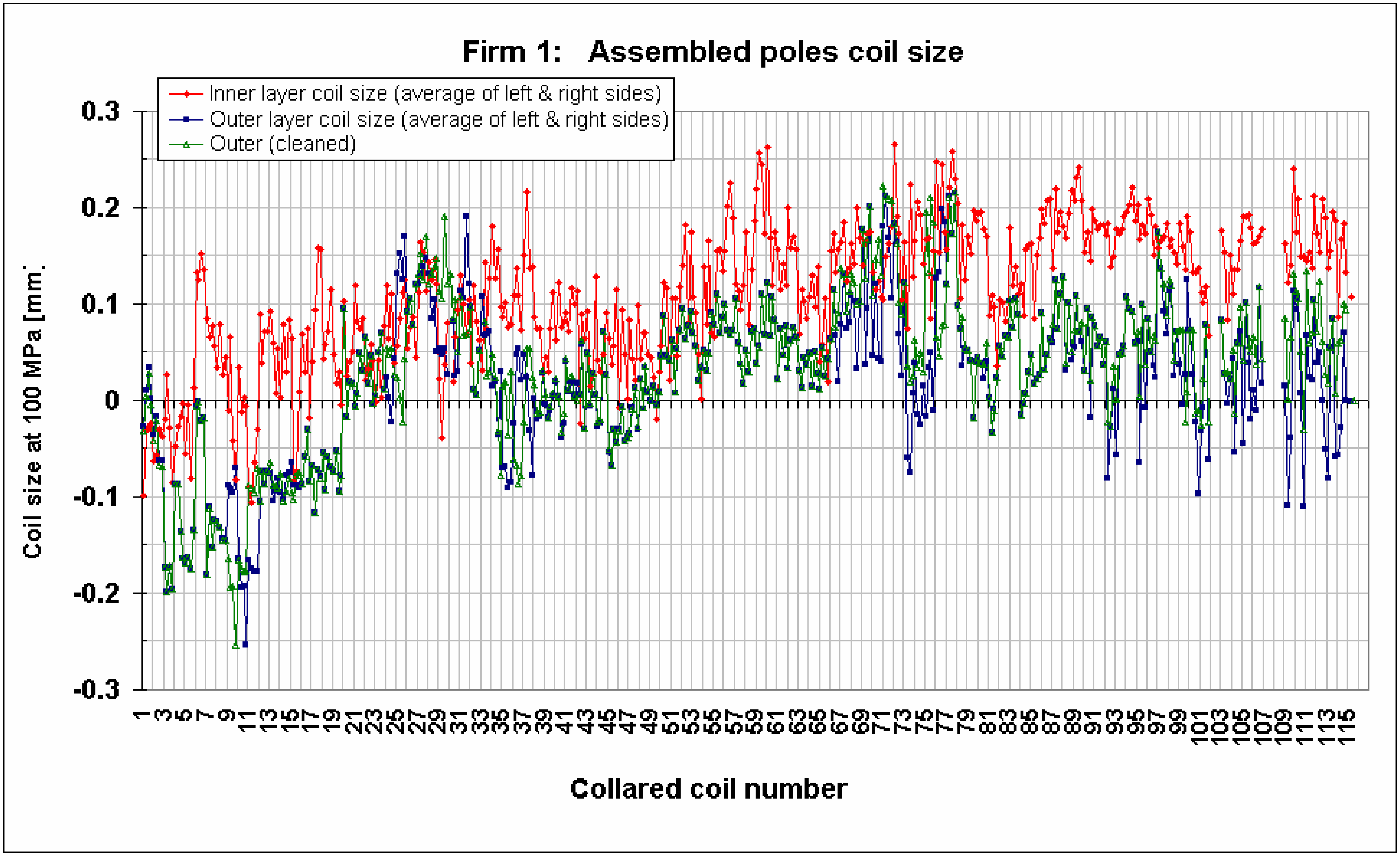

Fig. 1 Firm 1. Average coil size in the straight part of the assembled poles (380 poles).

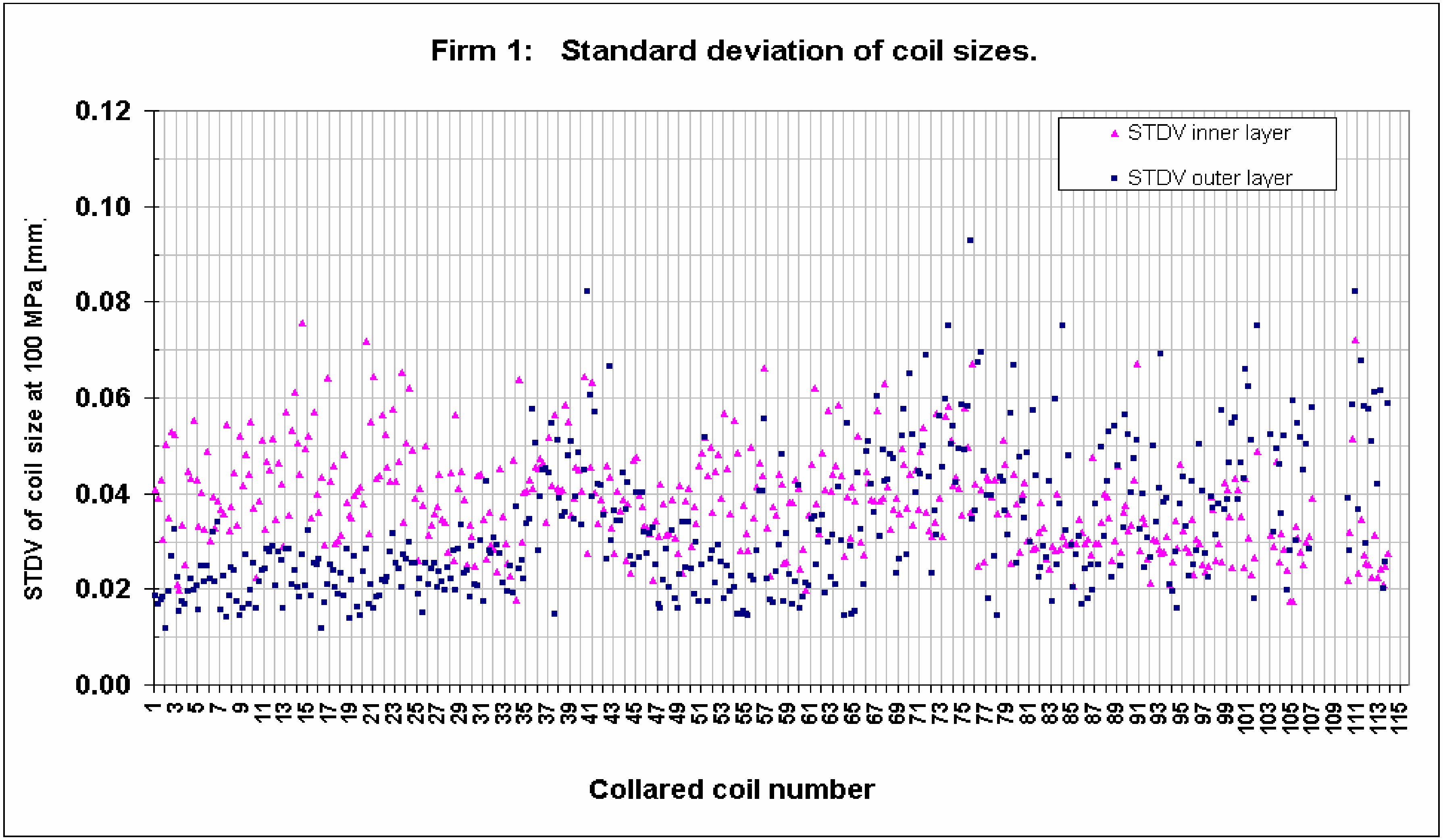

Fig. 2 Firm 1. Standard deviation of coil sizes measured in 15 positions along the coil (left and right coil sides in average).

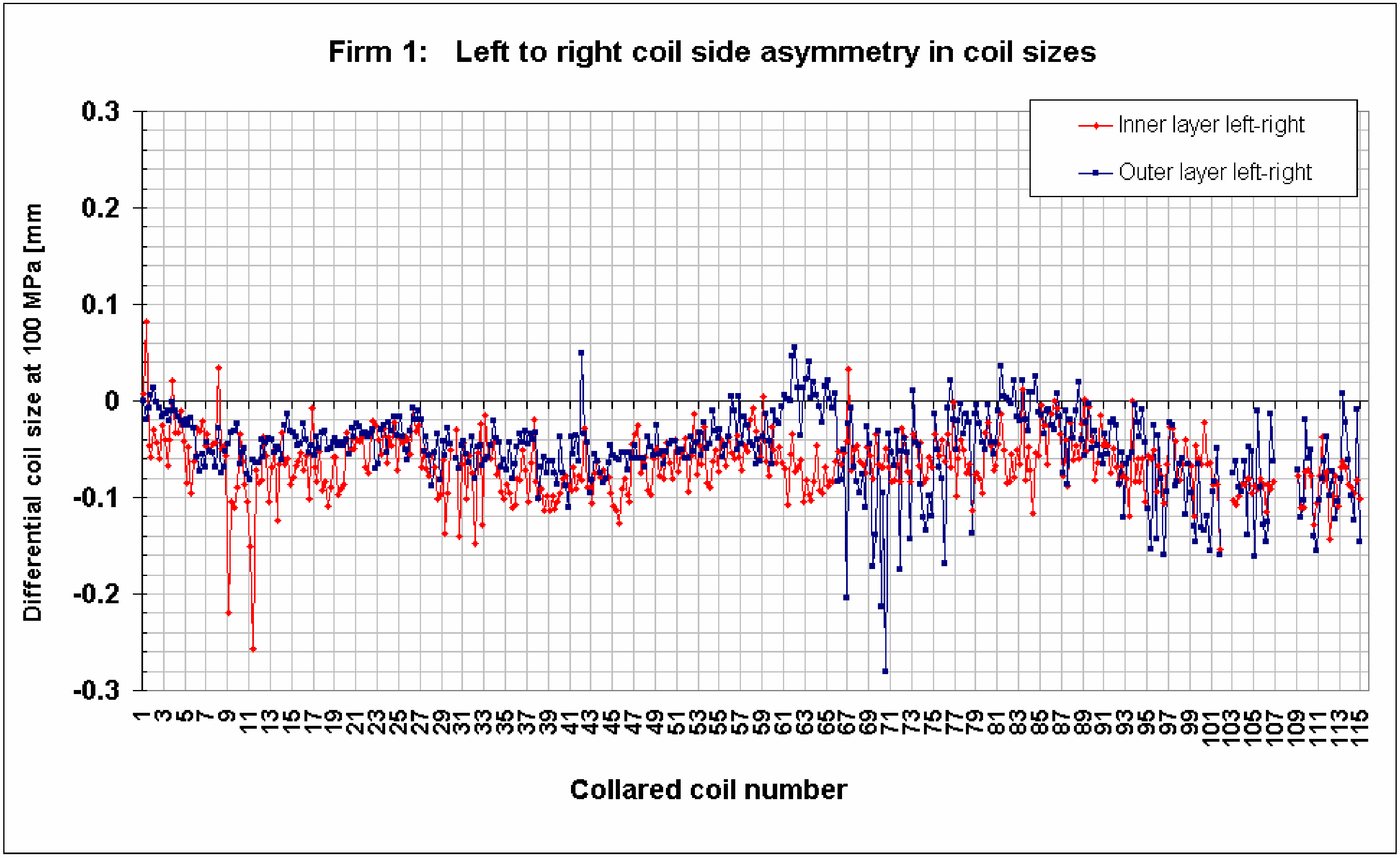

Fig. 3 Firm 1. Difference in the coil size between left and right sides of the coil on both layers.

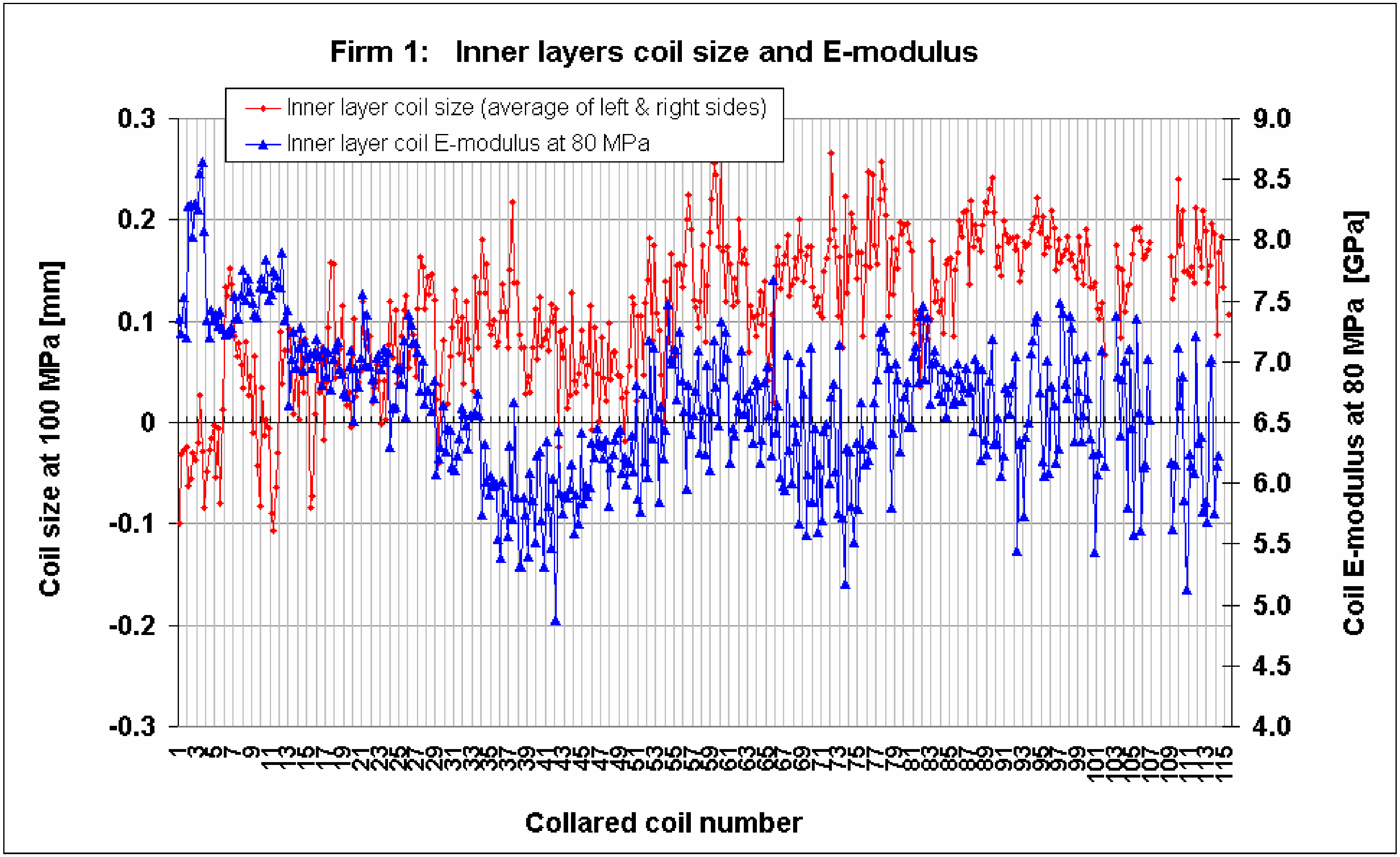

Fig. 4 Firm 1. Inner layer coil size (average) and E-modulus computed at 80 MPa.
(Data extracted from pole size measurements).

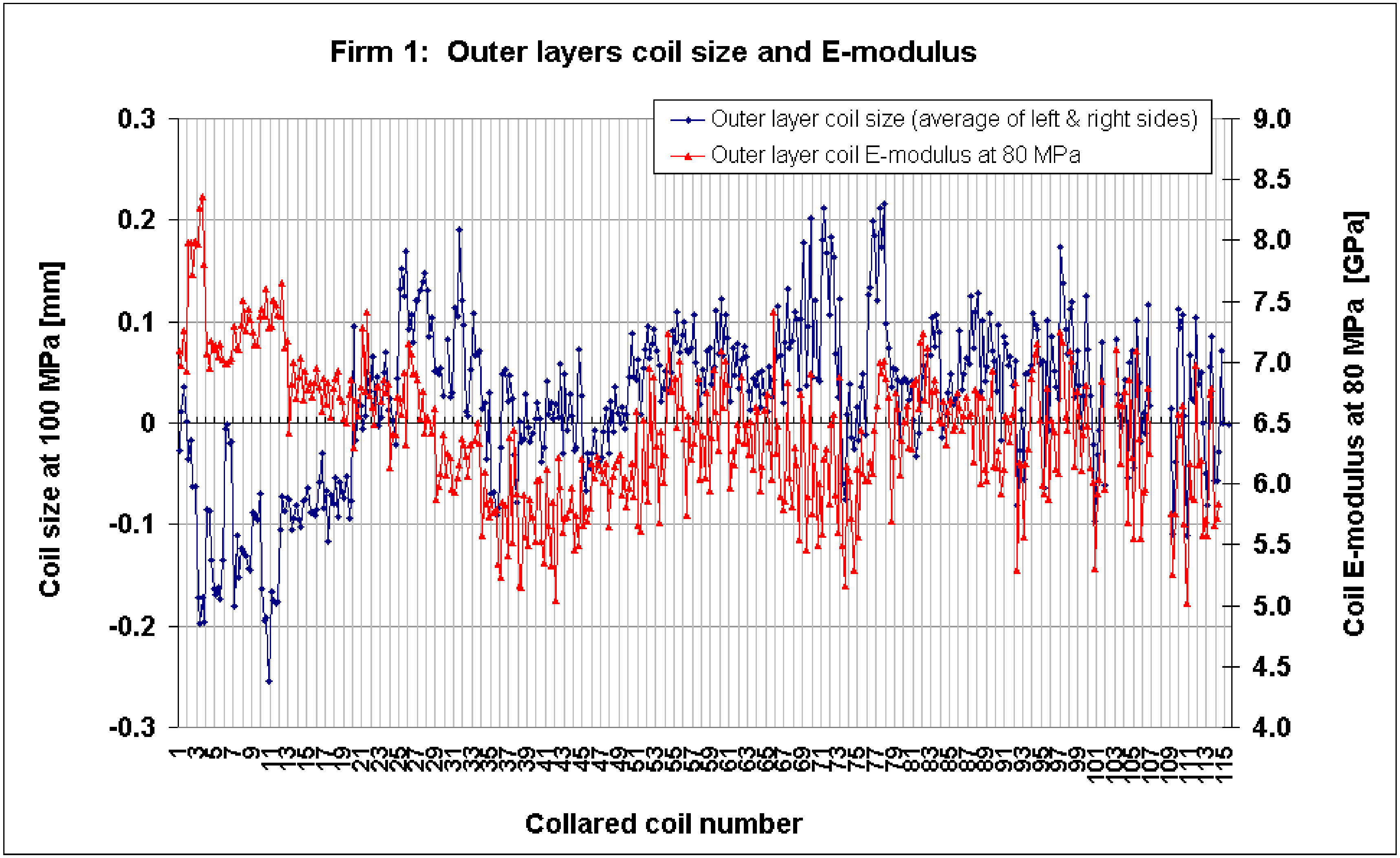

Fig. 5 Firm 1. Outer layer coil size (average) and E-modulus computed at 80 MPa. (Data extracted from pole size measurements).

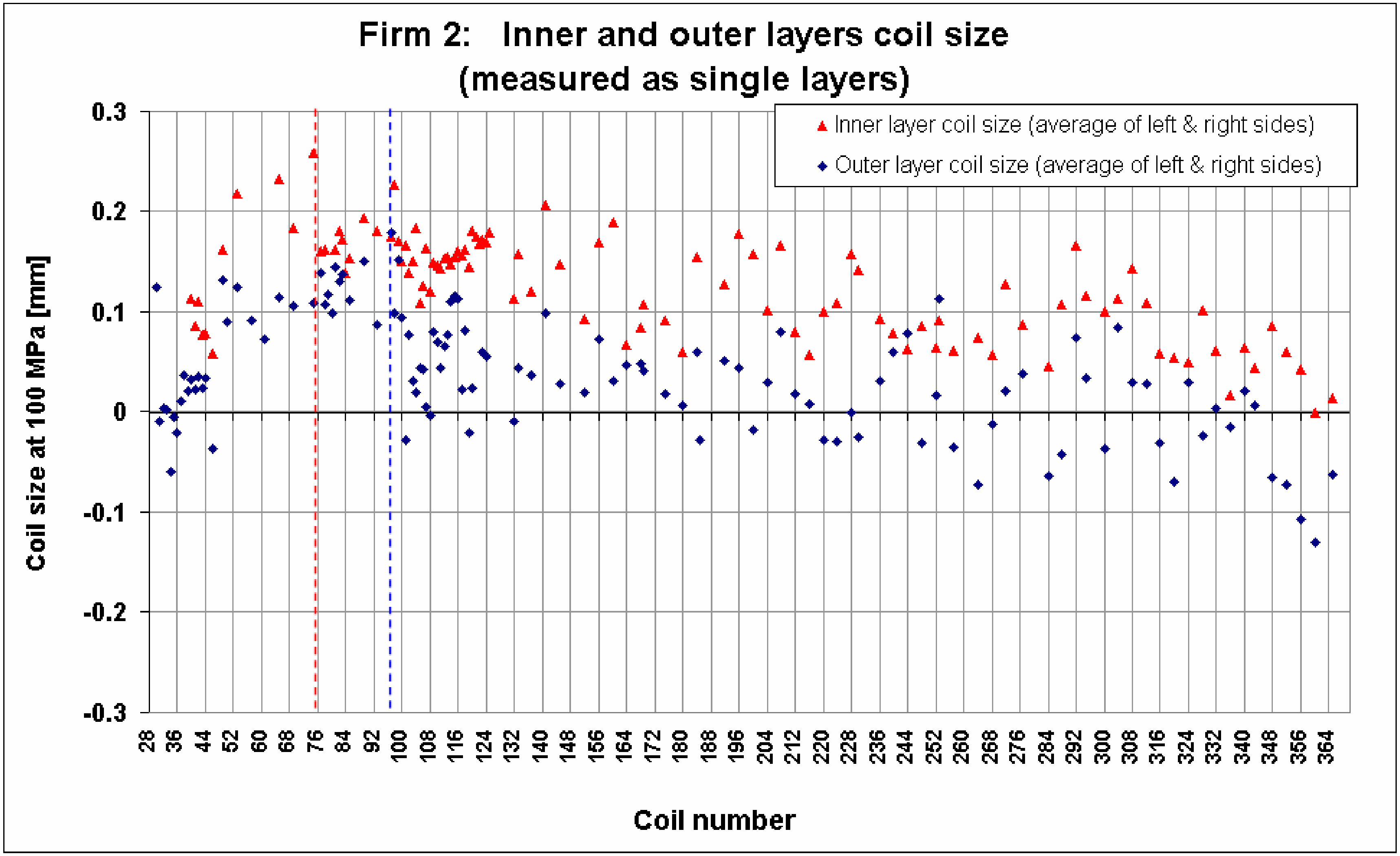

Fig. 6 Firm 2. Average coil size in the straight part of the inner and outer layers.

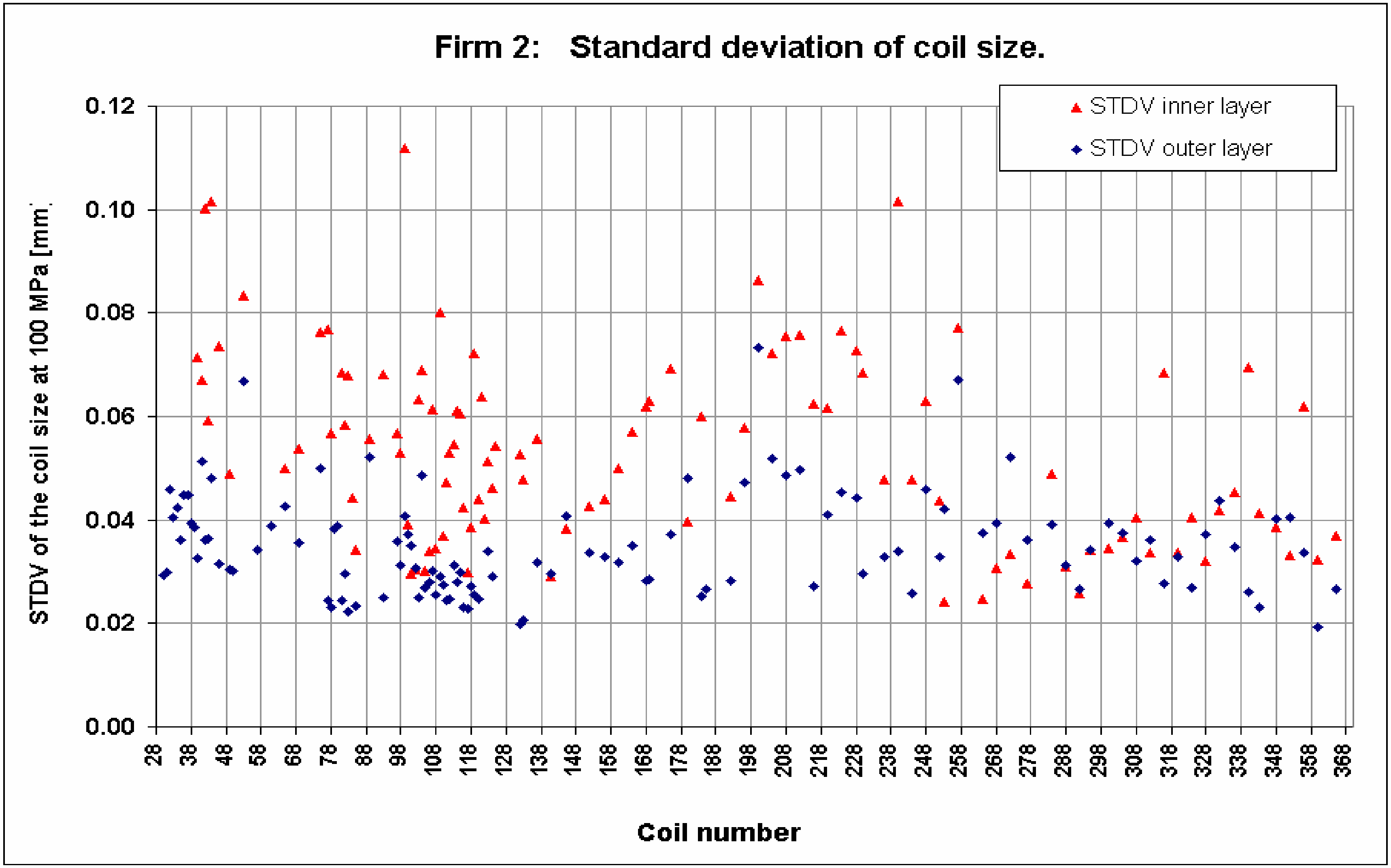

Fig. 7 Firm 2. Standard deviation of coil sizes measured in 15 positions along the coil (left and right coil sides in average).

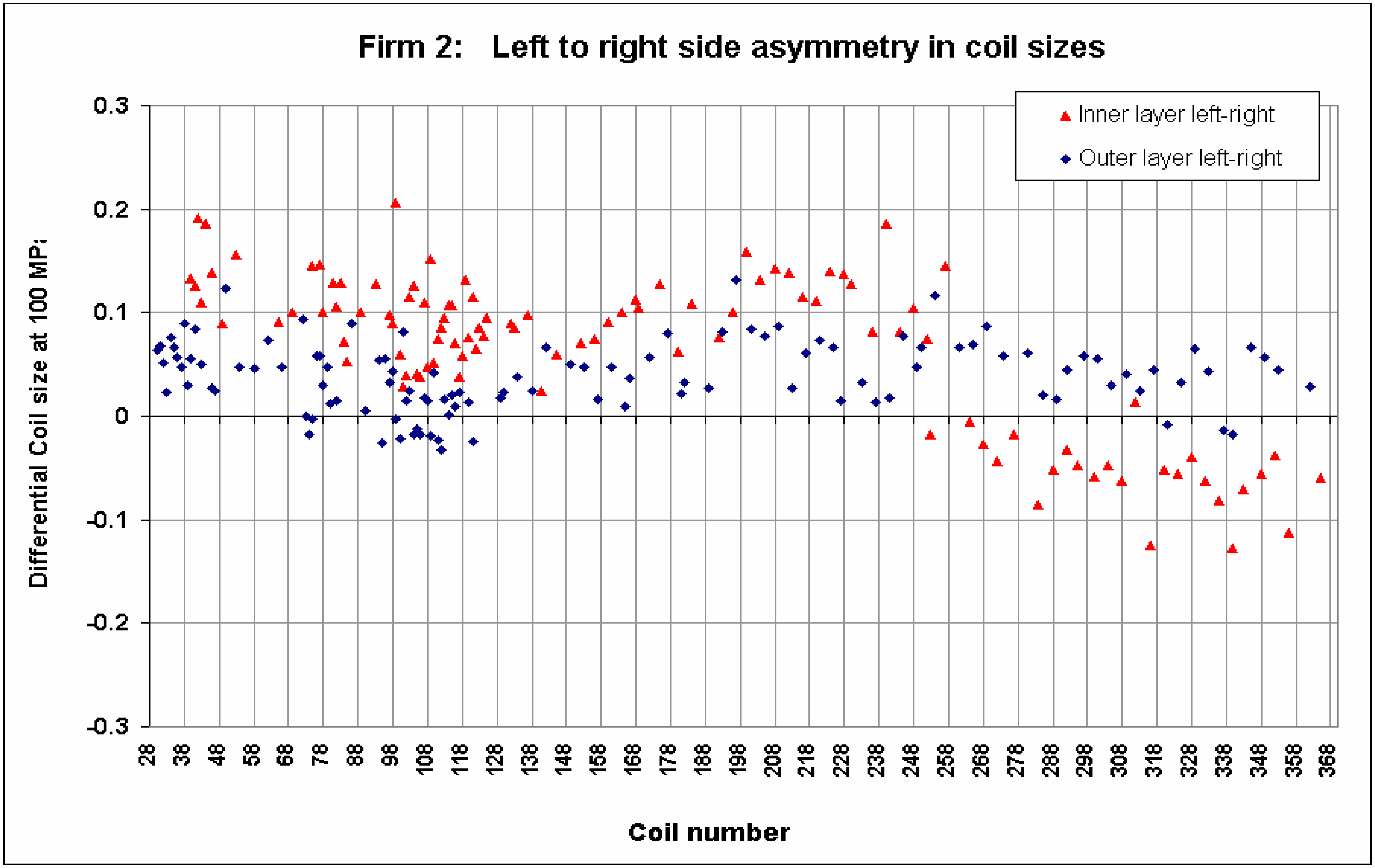

Fig. 8 Firm 2. Difference in the coil size between left and right sides of the coil on both layers.

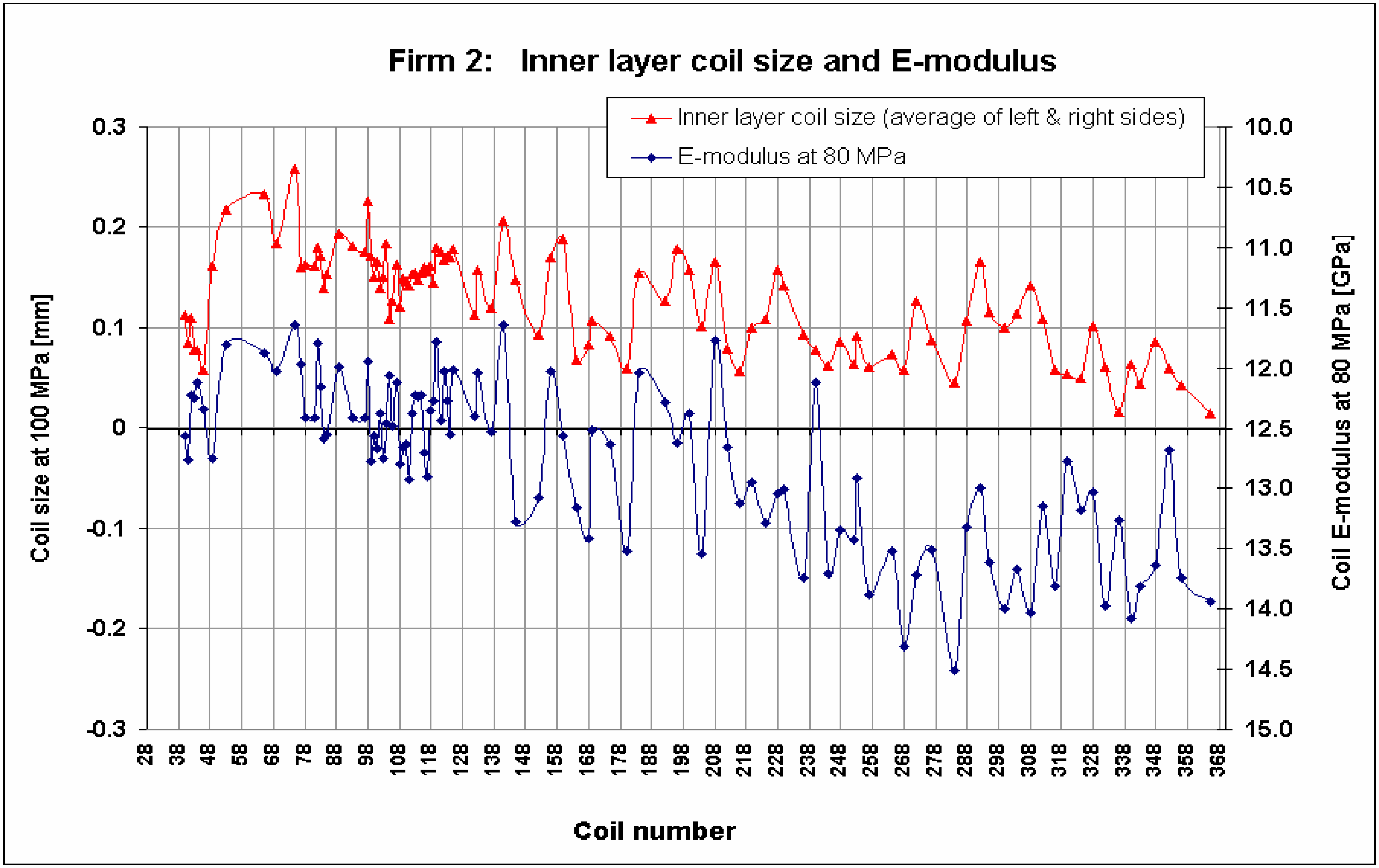

Fig. 9 Firm 2. Inner layer coil size (average) and E-modulus computed at 80 MPa.

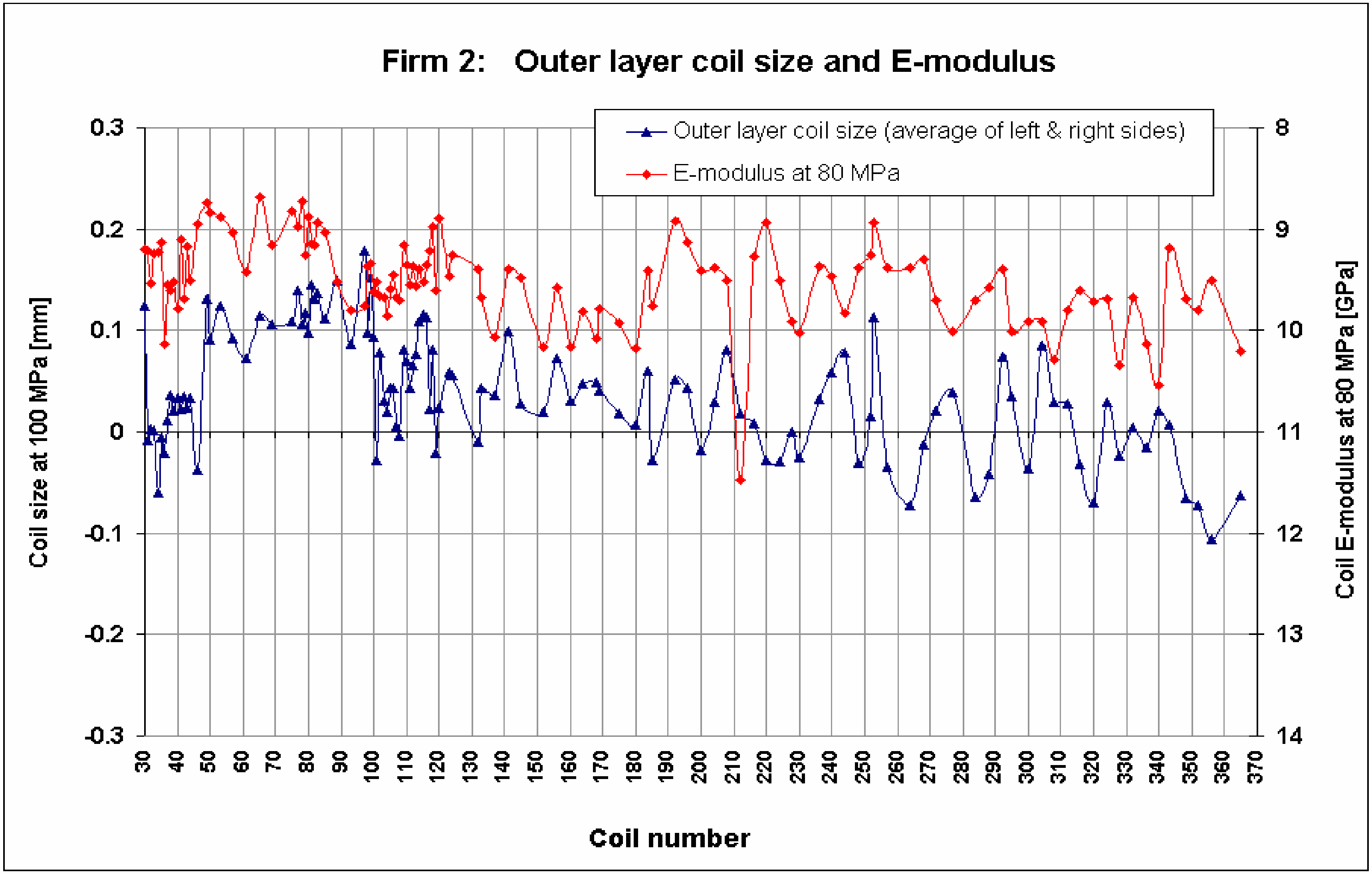

Fig. 10 Firm 2. Outer layer coil size (average) and E-modulus computed at 80 MPa.

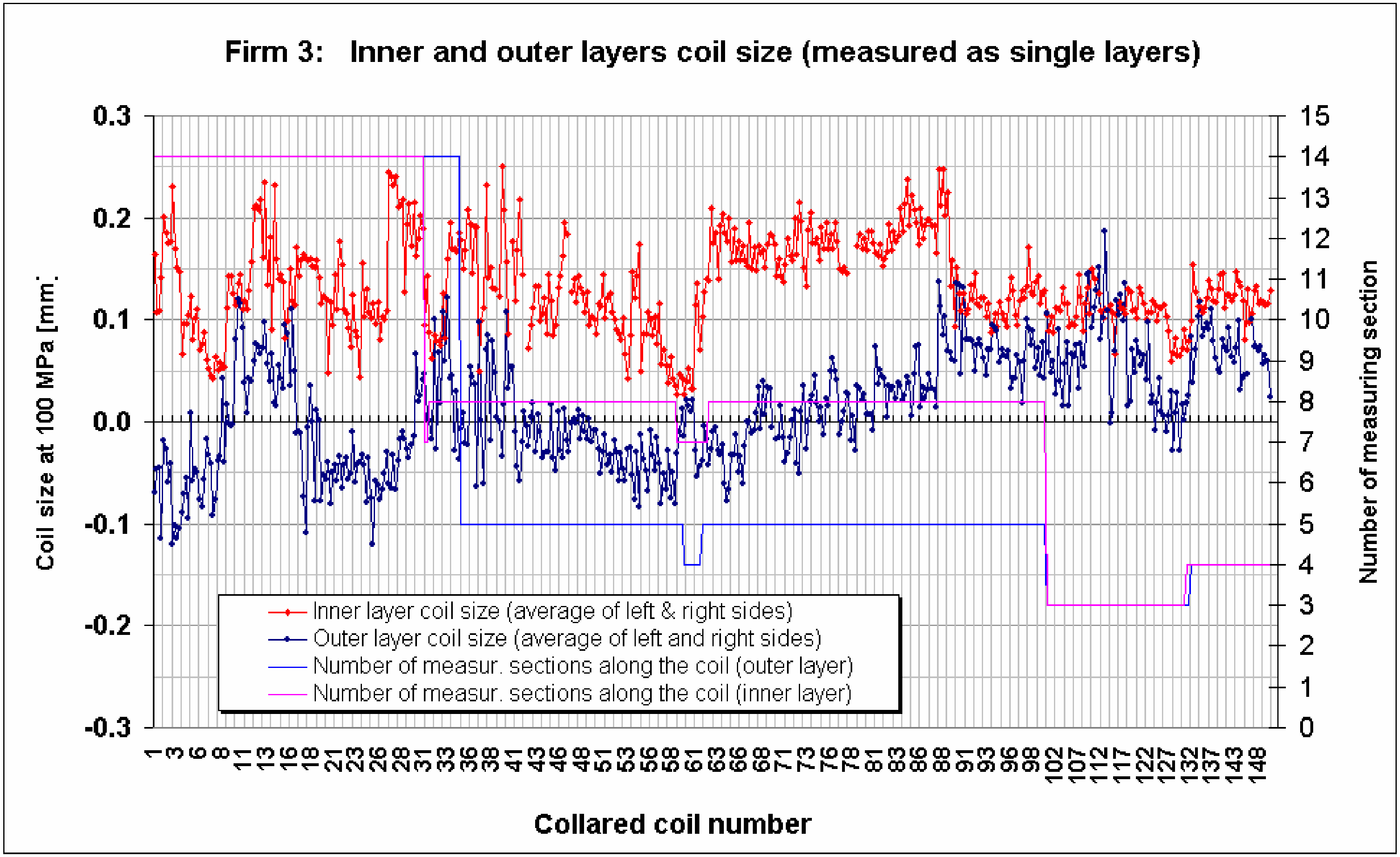

Fig. 11 Firm 3. Average coil size in the straight part of inner and outer layers.

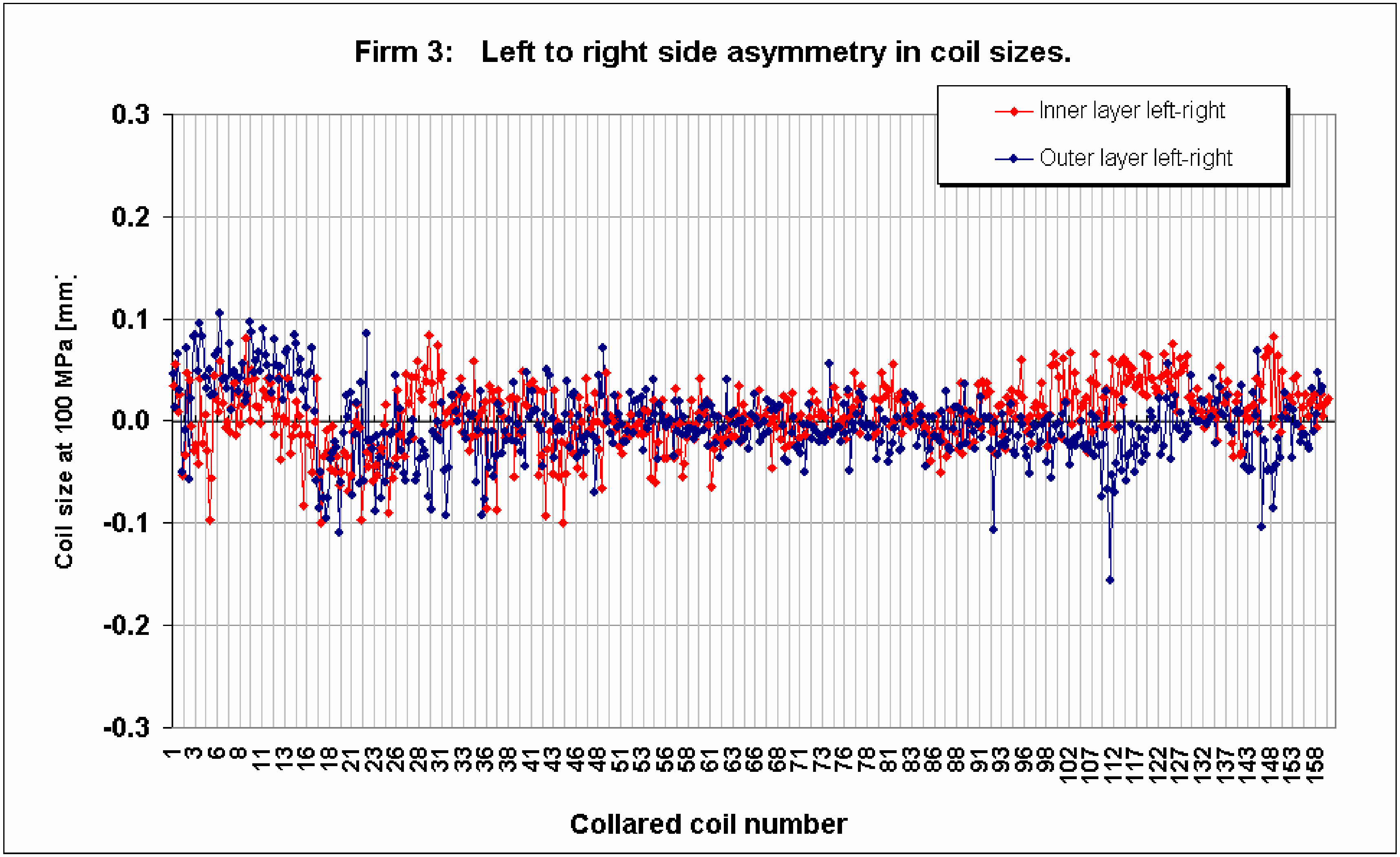

Fig.12 Firm 3. Difference in the coil size between left and right side of the coil on both layers.

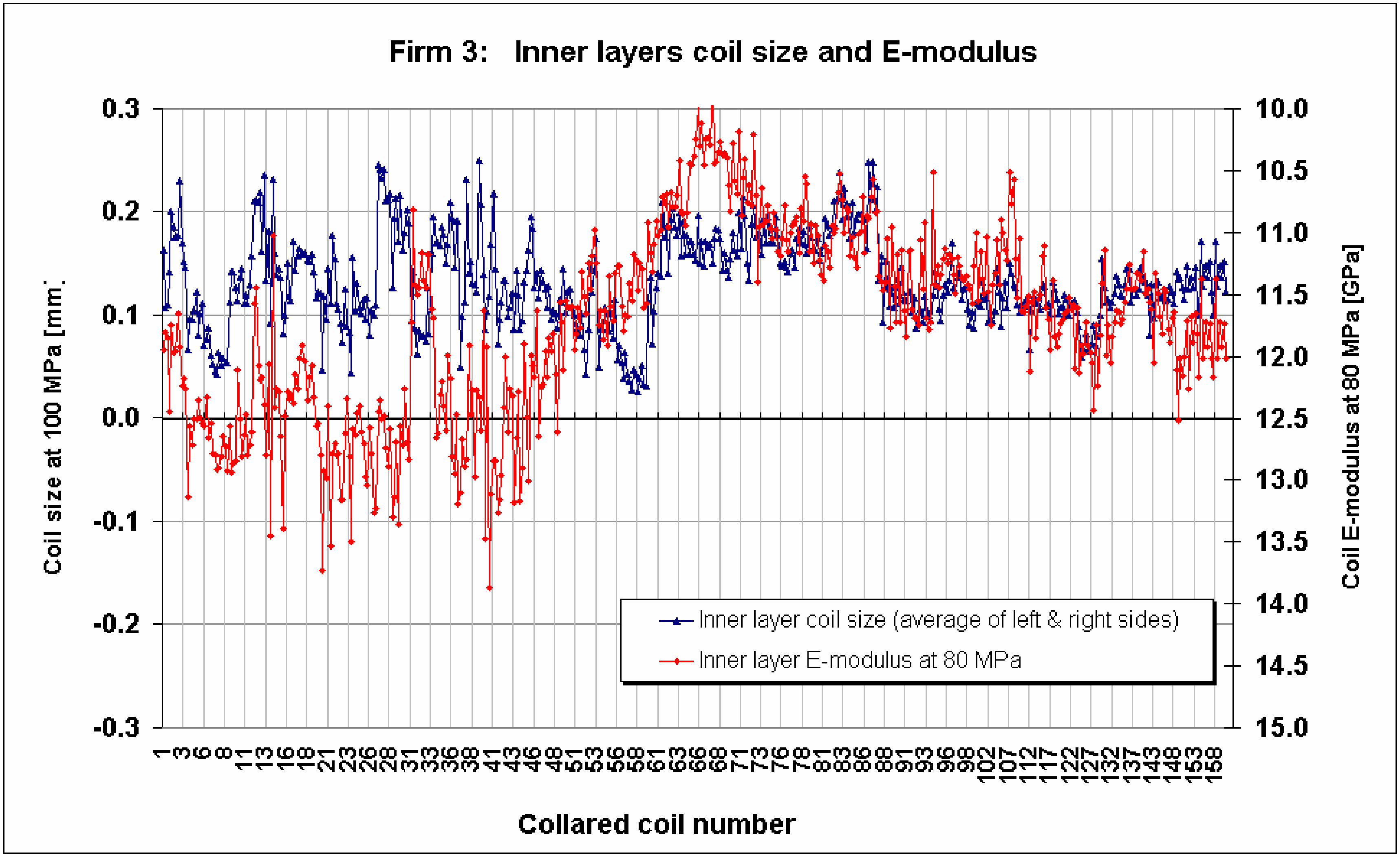

Fig. 13 Firm 3. Inner layer coil size (average) and E-modulus computed at 80 MPa.

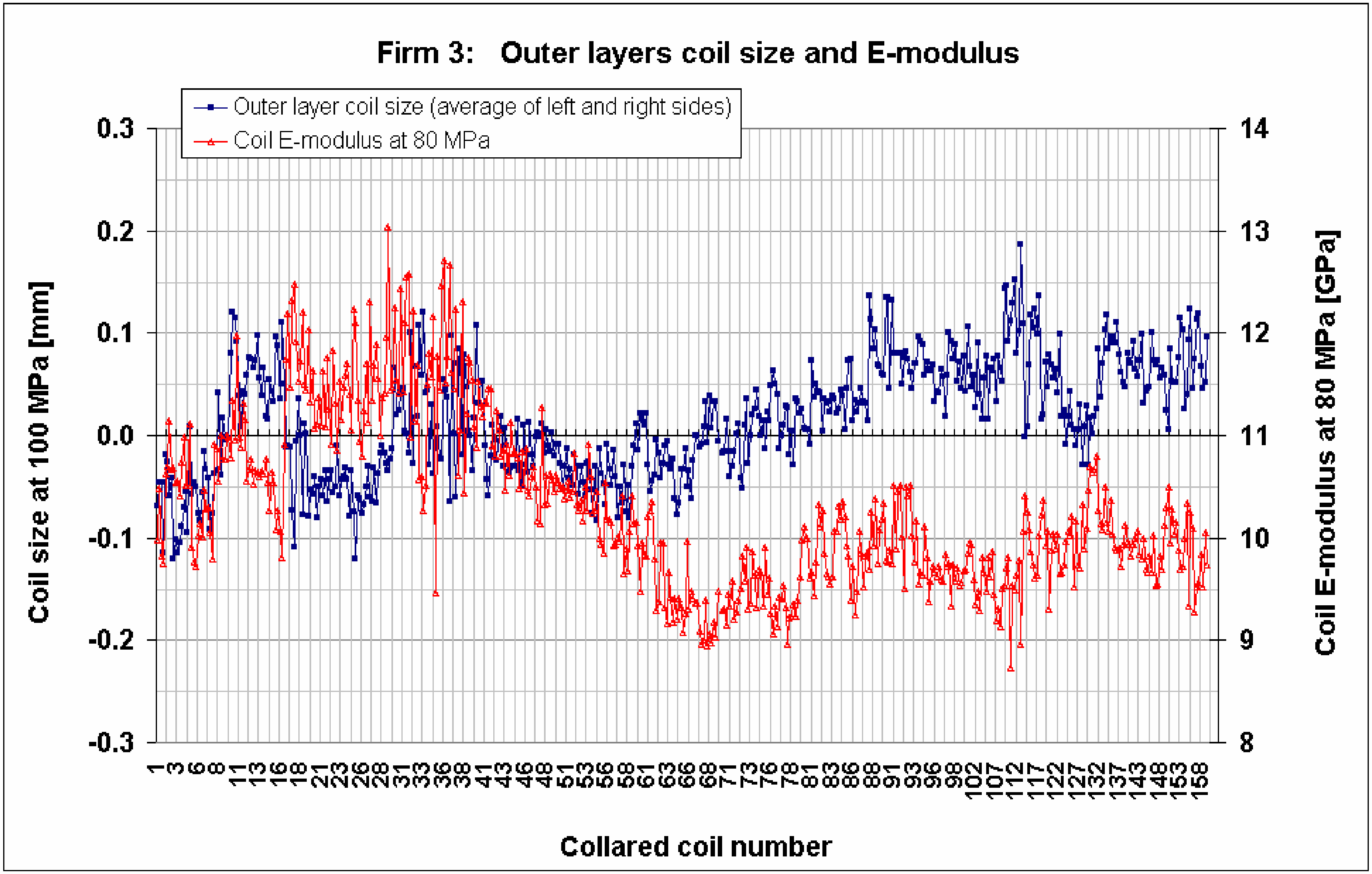

Fig. 14 Firm 3. Outer layer coil size (average) and E-modulus computed at 80 MPa.

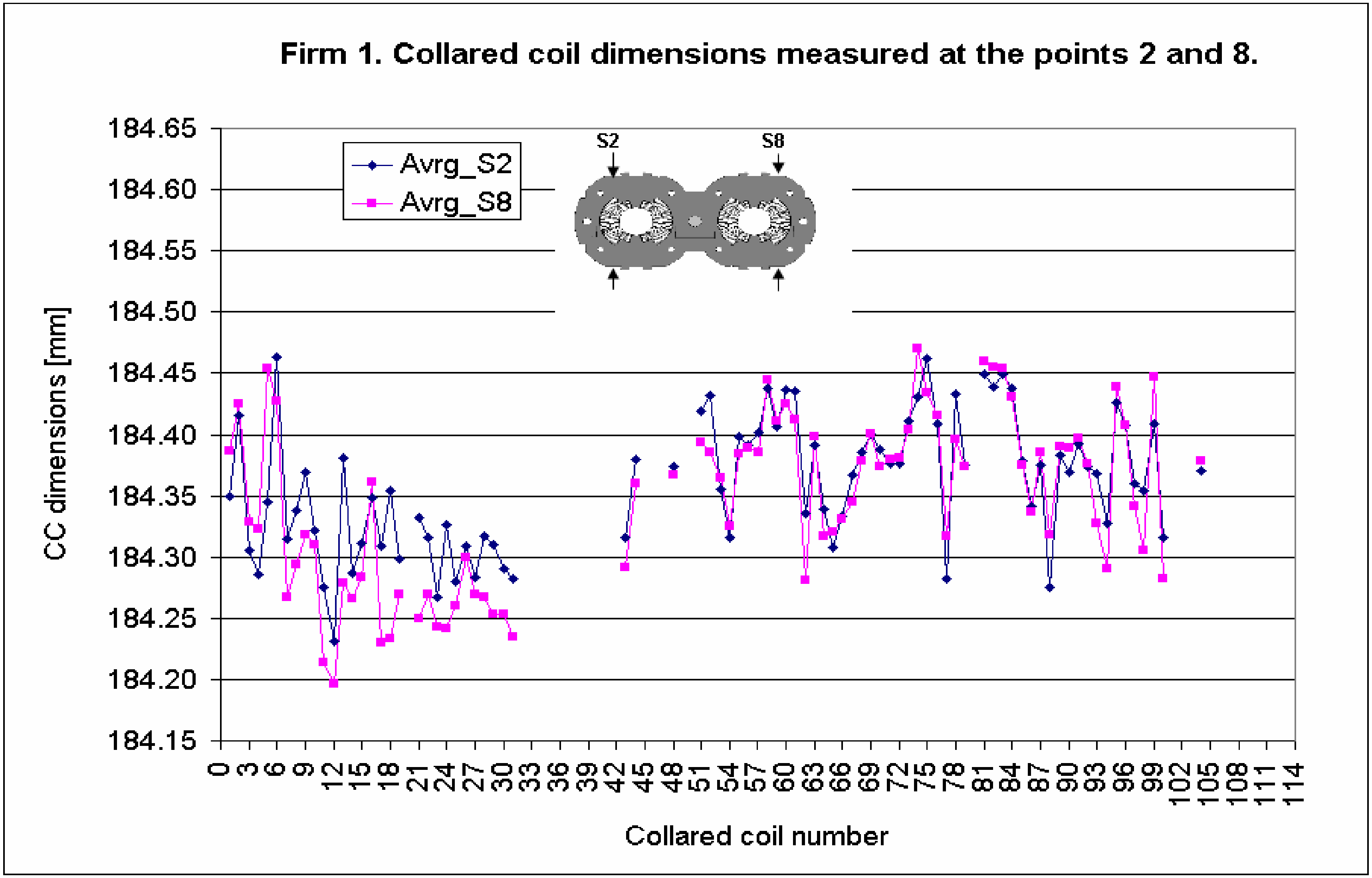

Fig. 15 Firm 1. Collared coil dimensions measured at the points S2 and S8.

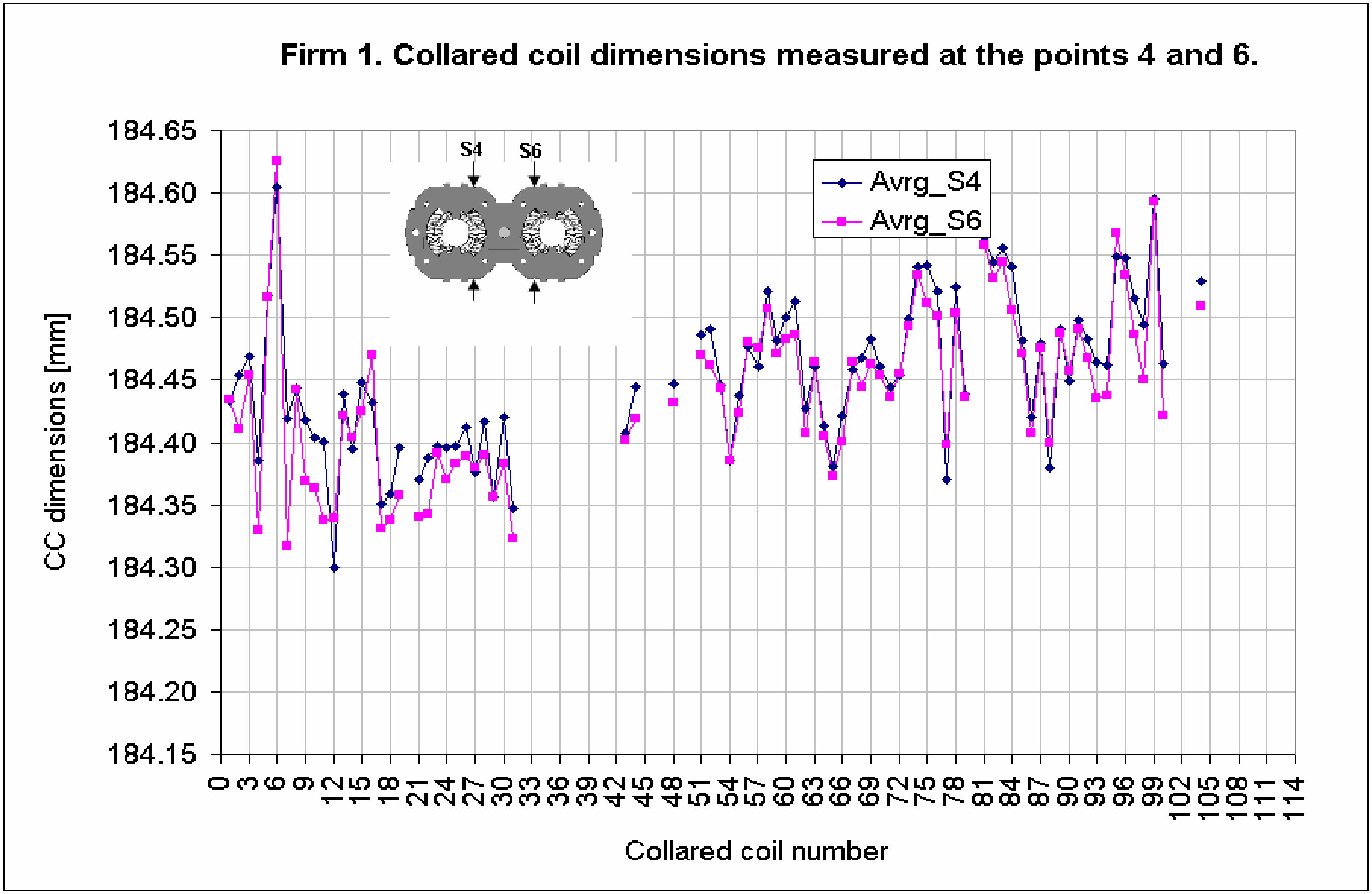

Fig. 16 Firm 1. Collared coil dimensions measured at the points S4 and S6.

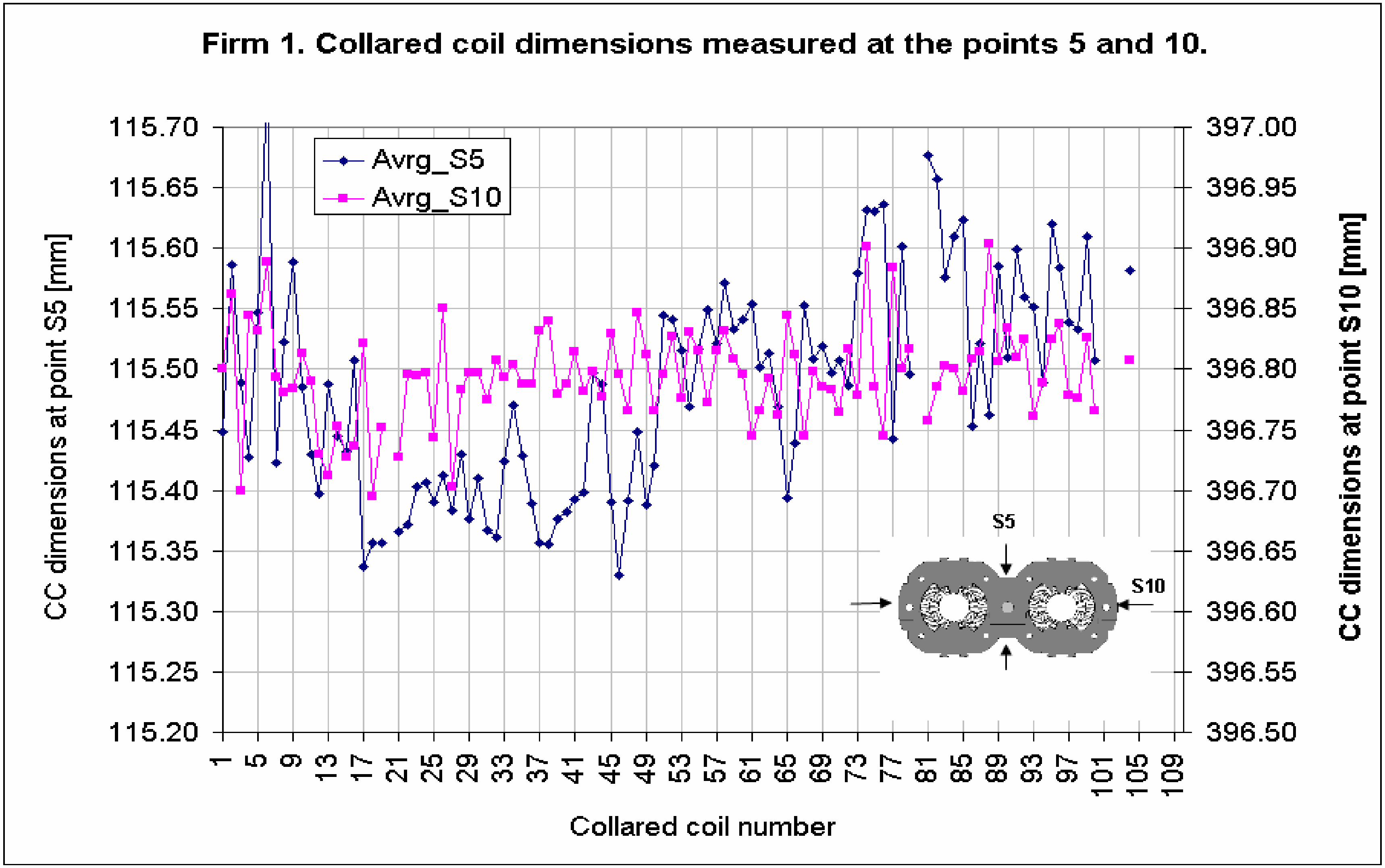

Fig. 17 Firm 1. Collared coil dimensions measured at the points S5 and S10.

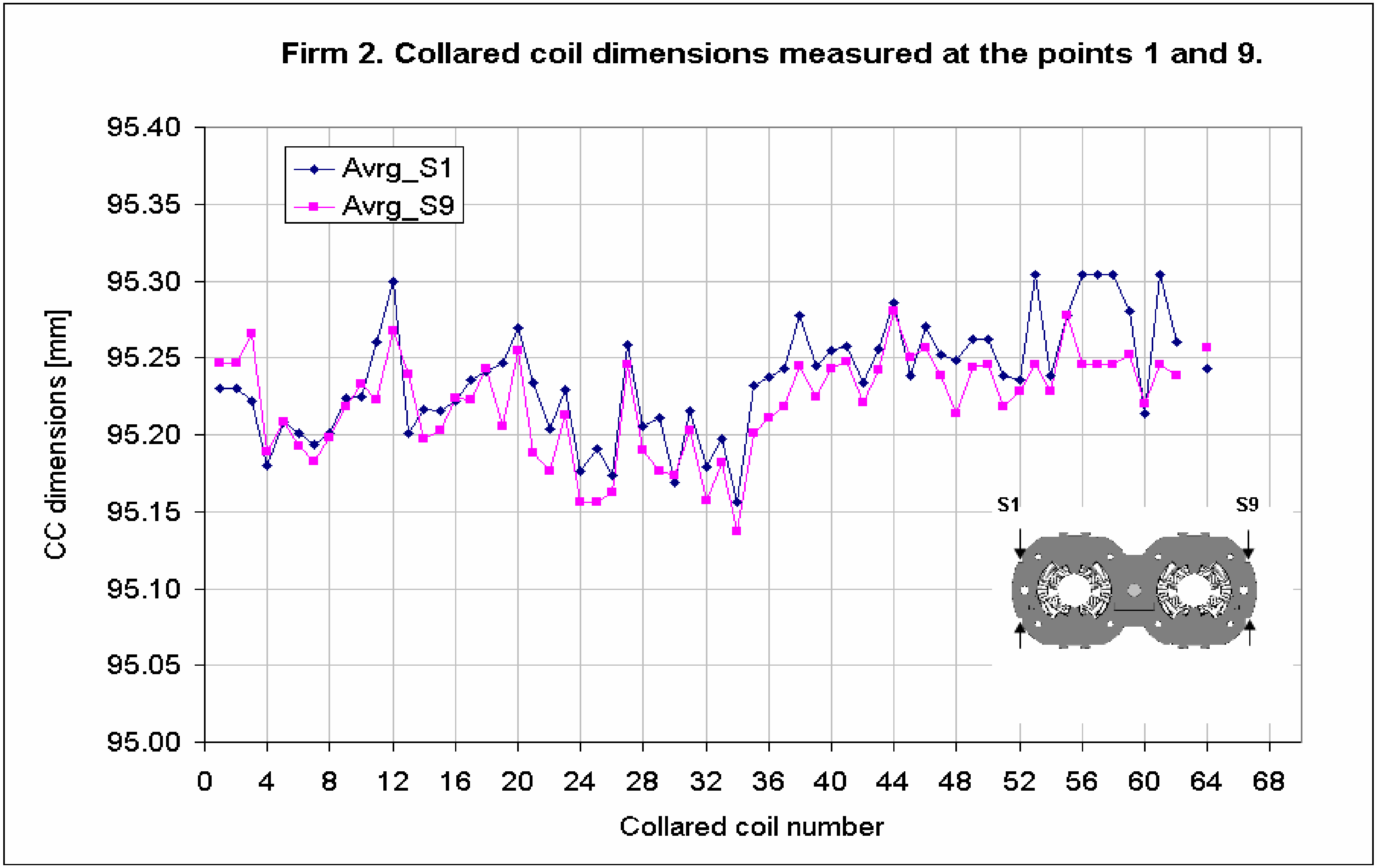

Fig. 18 Firm 2. Collared coil dimensions measured at the points S1 and S9.

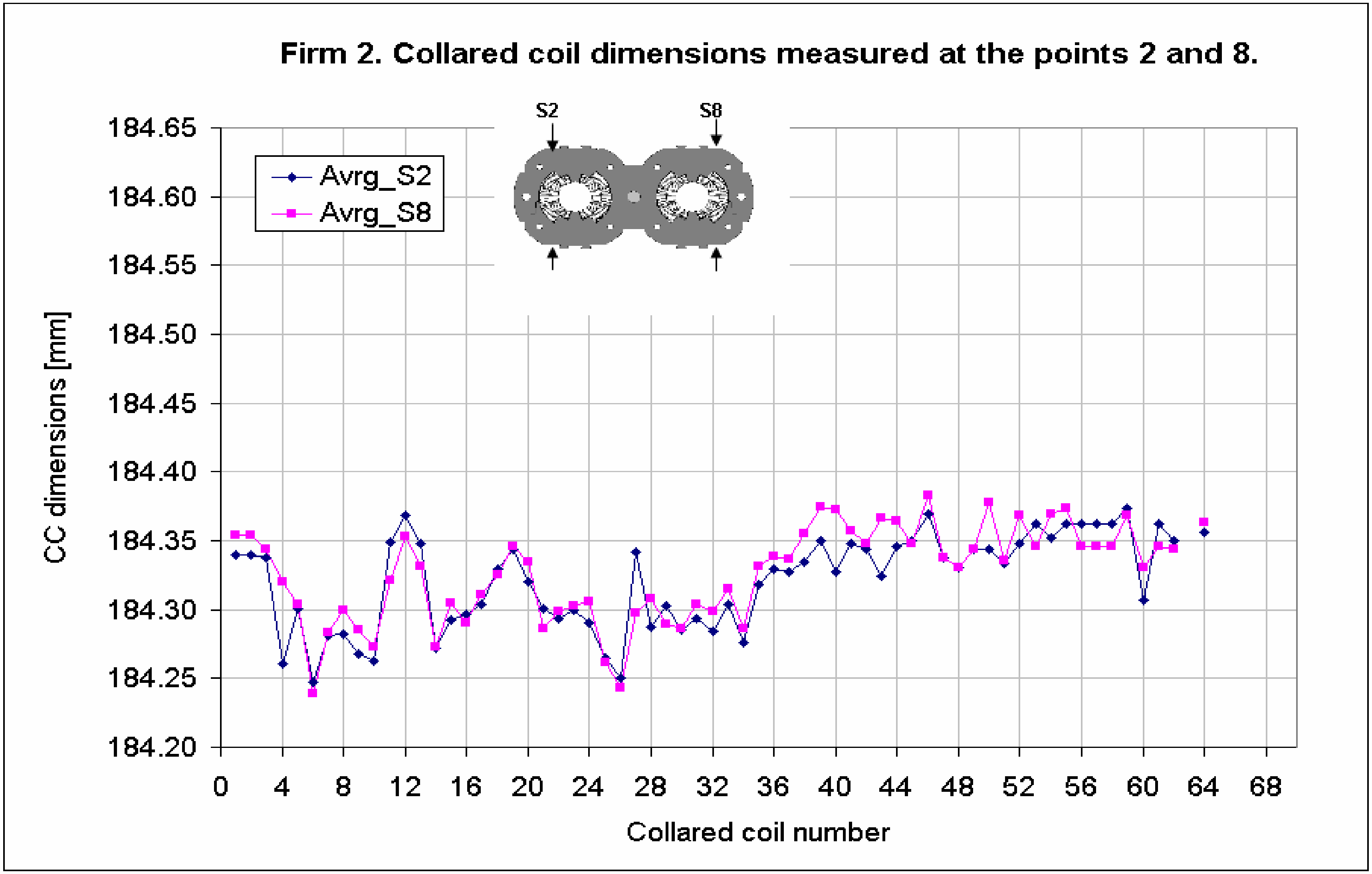

Fig. 19 Firm 2. Collared coil dimensions measured at the points S2 and S8.

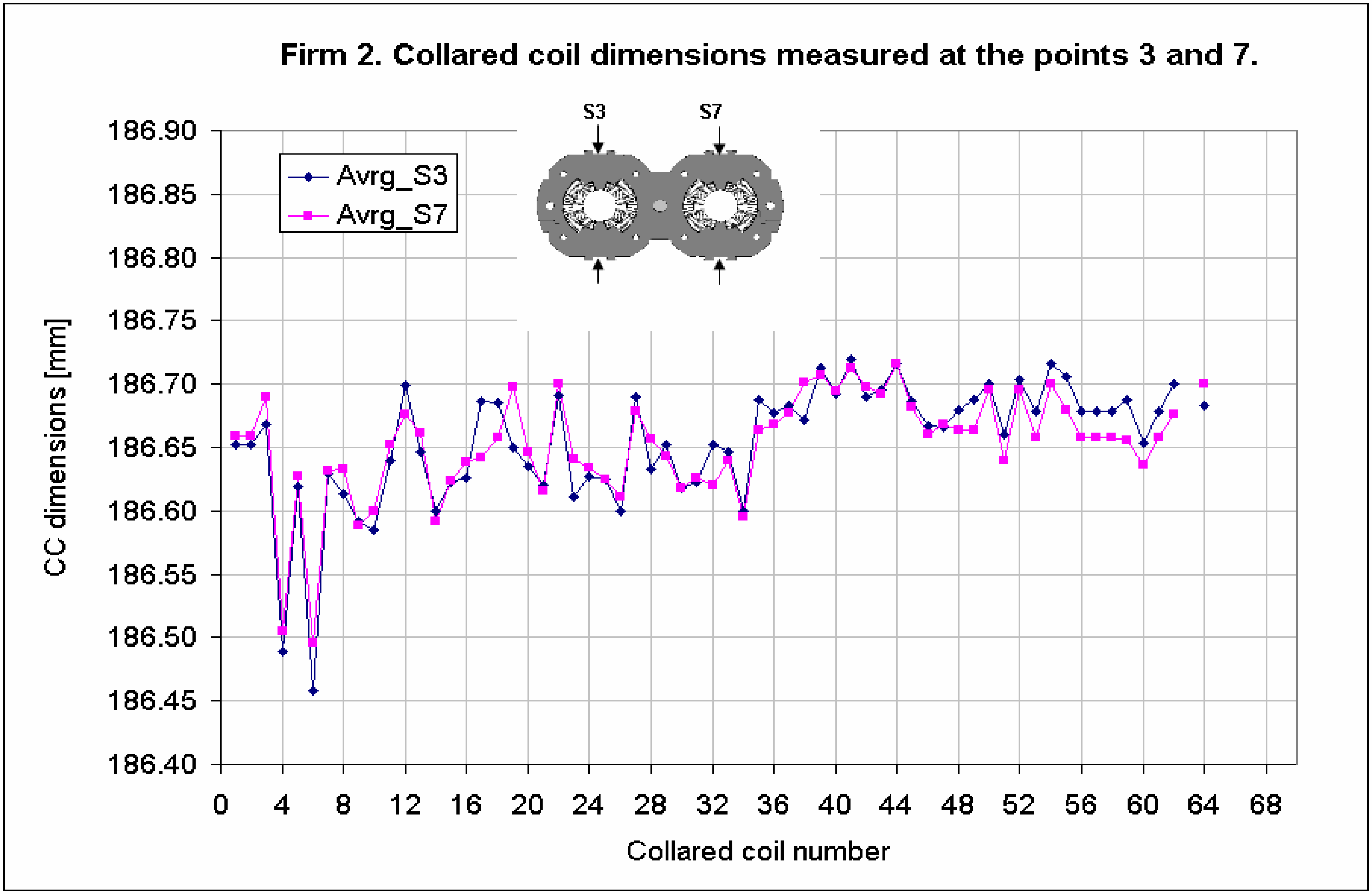

Fig. 20 Firm 2. Collared coil dimensions measured at the points S3 and S7.

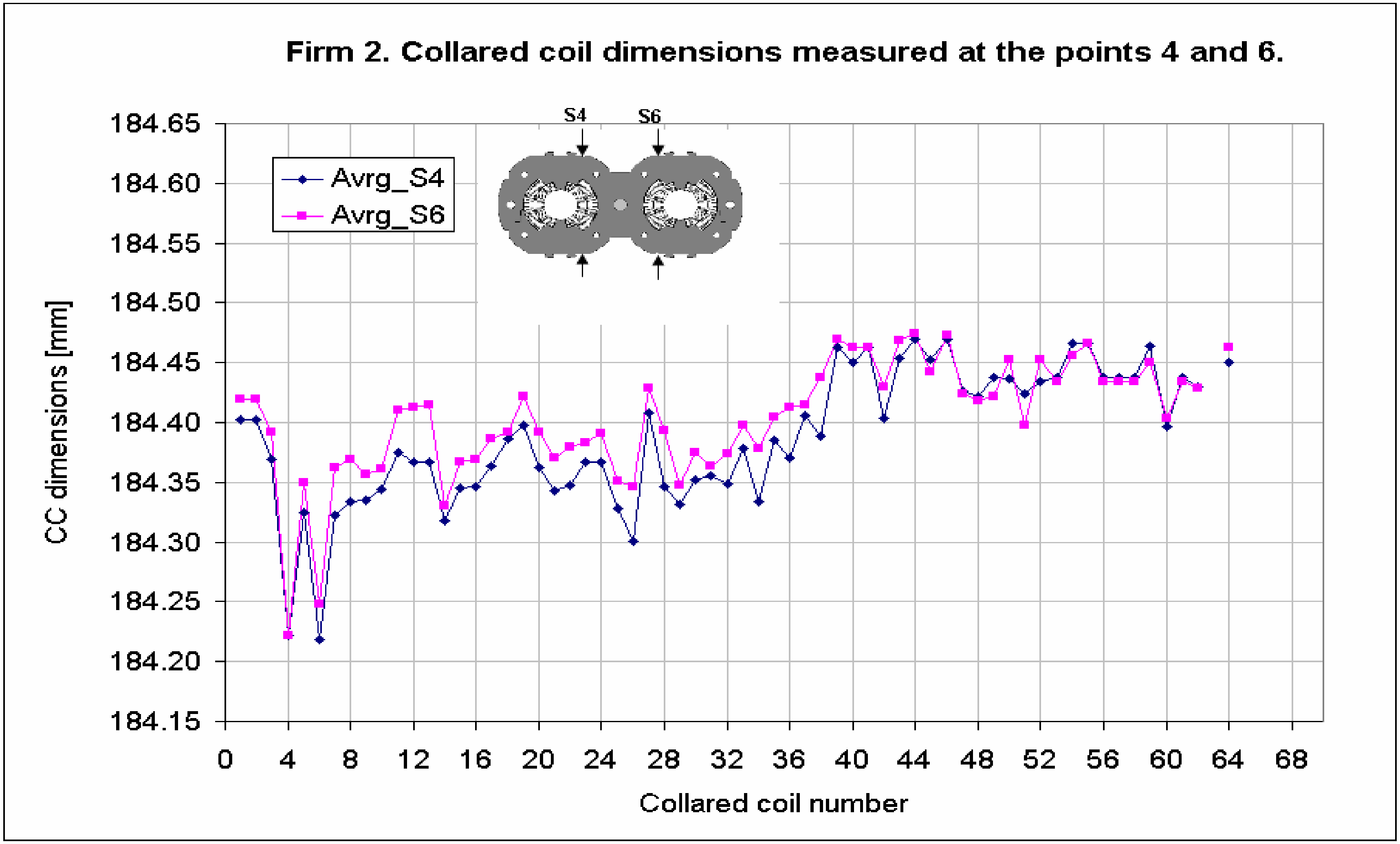

Fig. 21 Firm 2. Collared coil dimensions measured at the points S4 and S6.

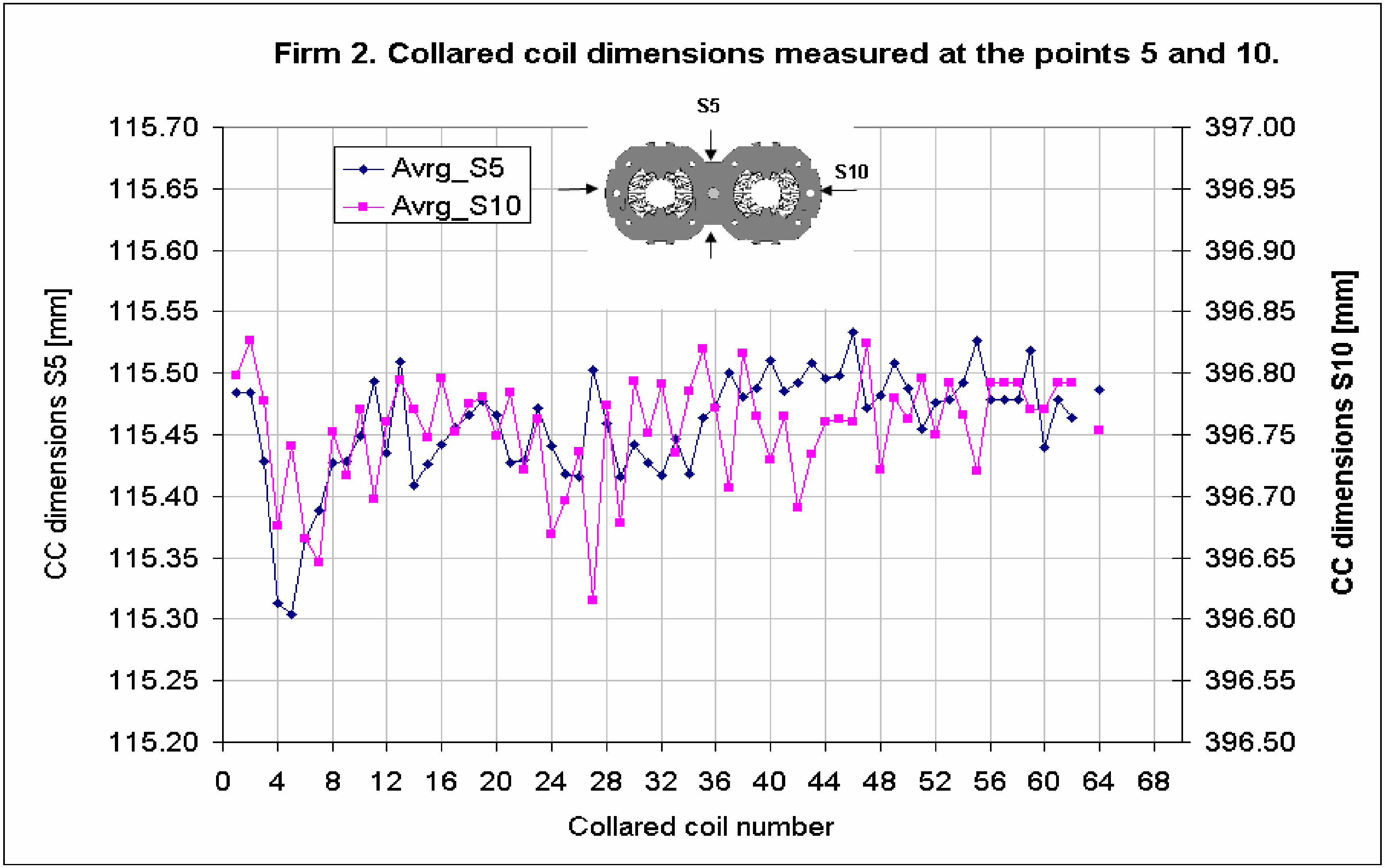

Fig. 22 Firm 2. Collared coil dimensions measured at the points S5 and S10.

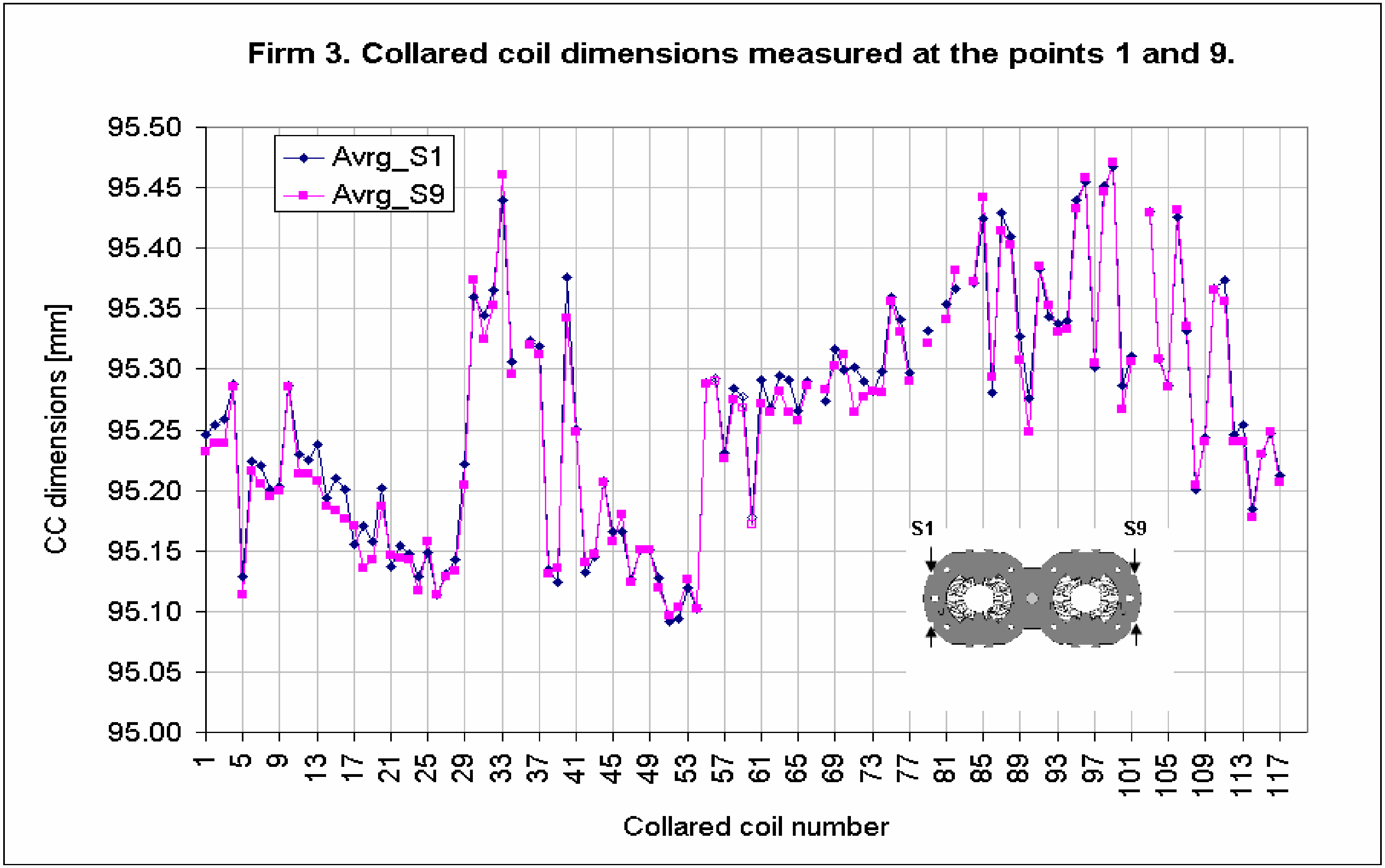

Fig. 23 Firm 3. Collared coil dimensions measured at the points S1 and S9.

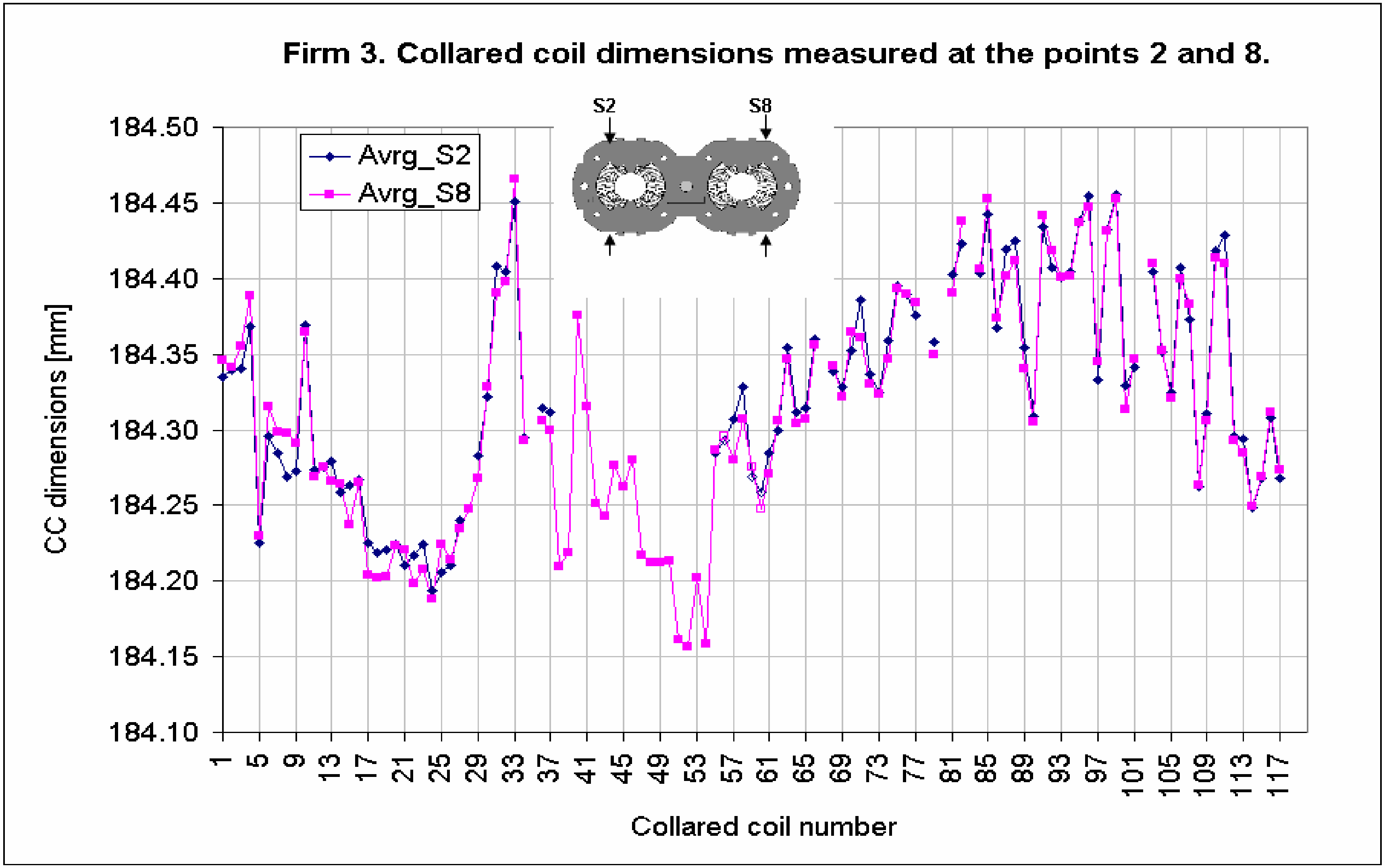

Fig. 24 Firm 3. Collared coil dimensions measured at the points S2 and S8.

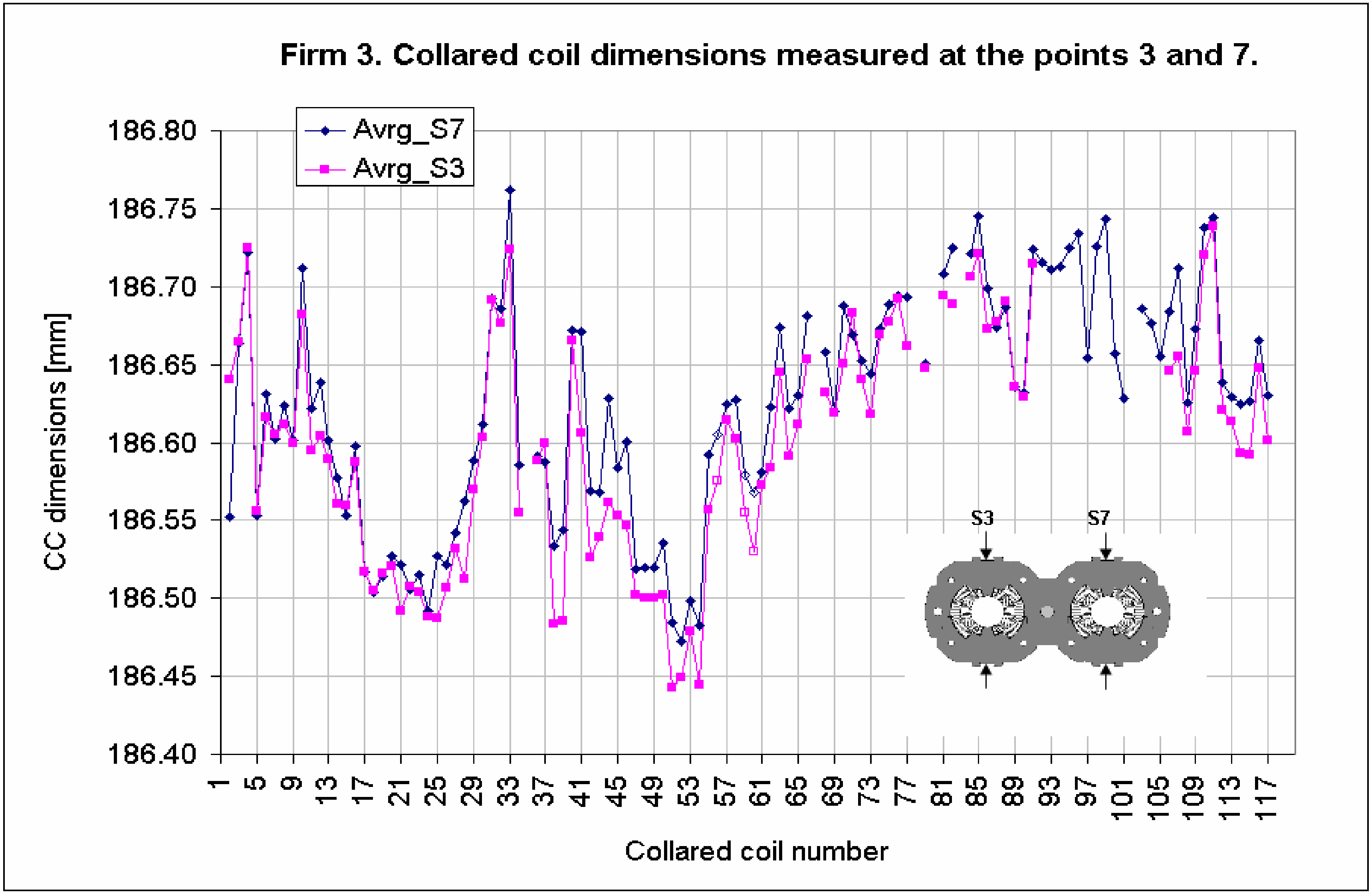

Fig. 25 Firm 3. Collared coil dimensions measured at the points S3 and S7.

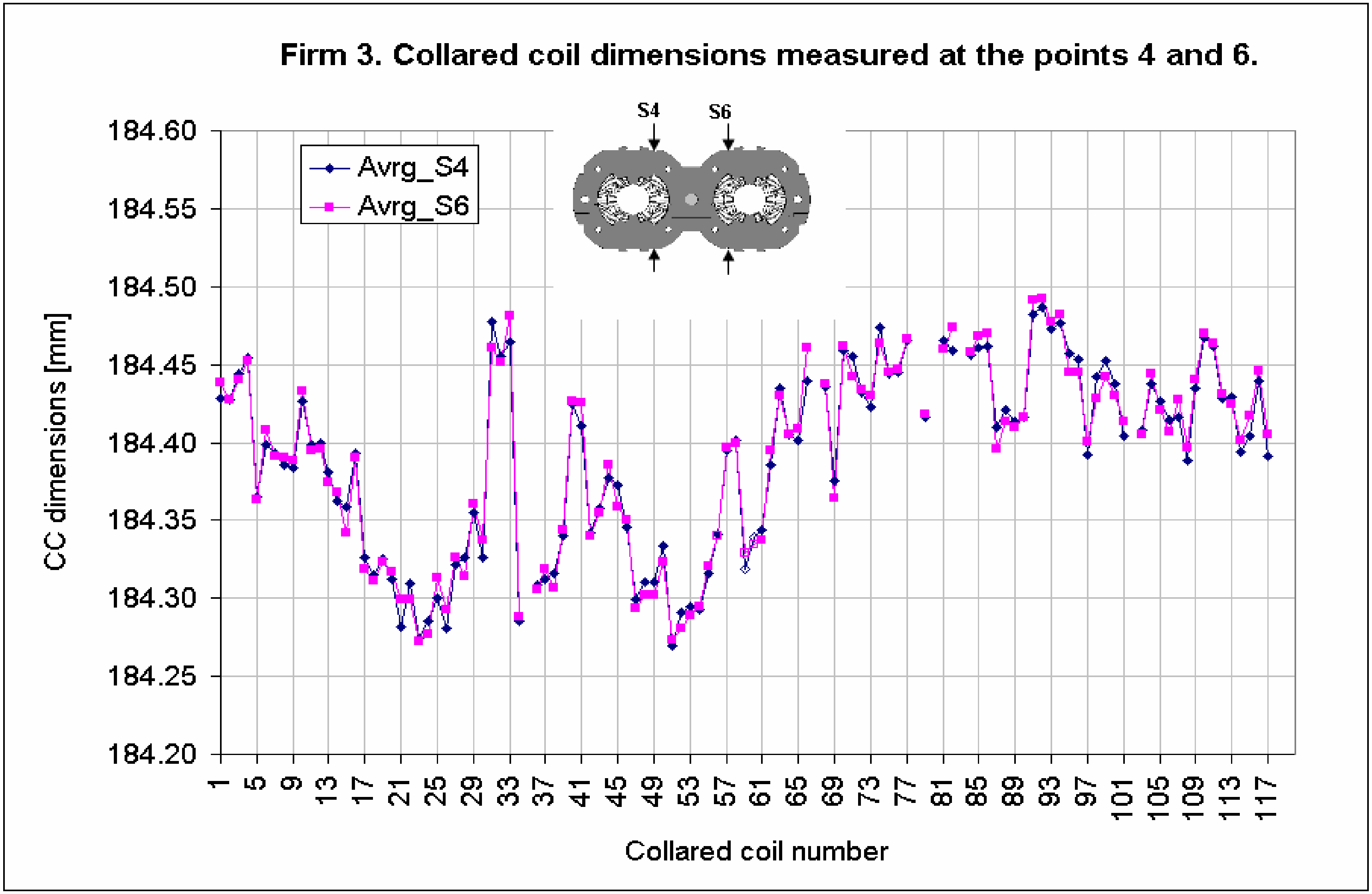

Fig. 26 Firm 3. Collared coil dimensions measured at the points S4 and S6.

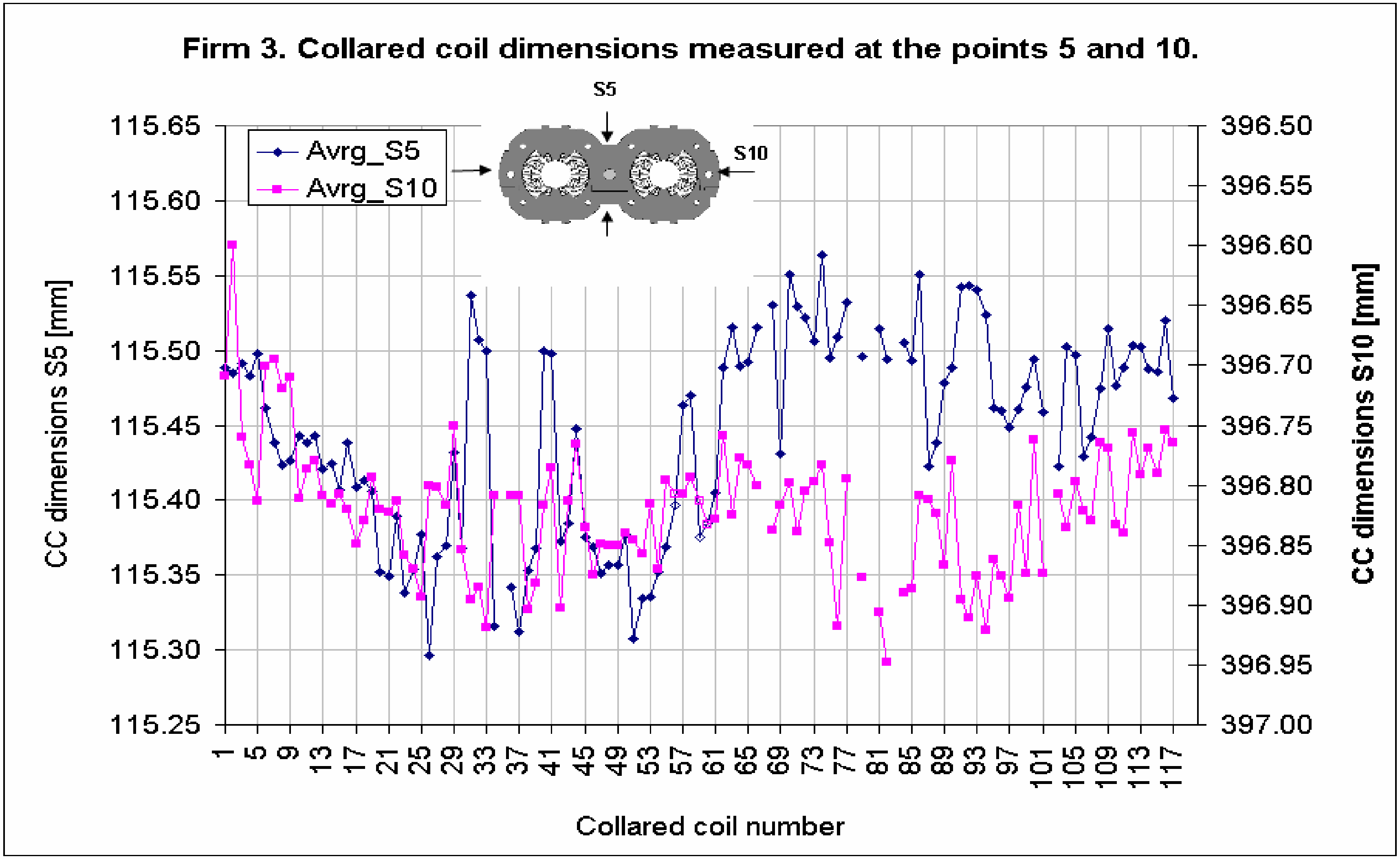

Fig. 27 Firm 3. Collared coil dimensions measured at the points S5 and S10 (notice that the scale for S10 axis is reversed).

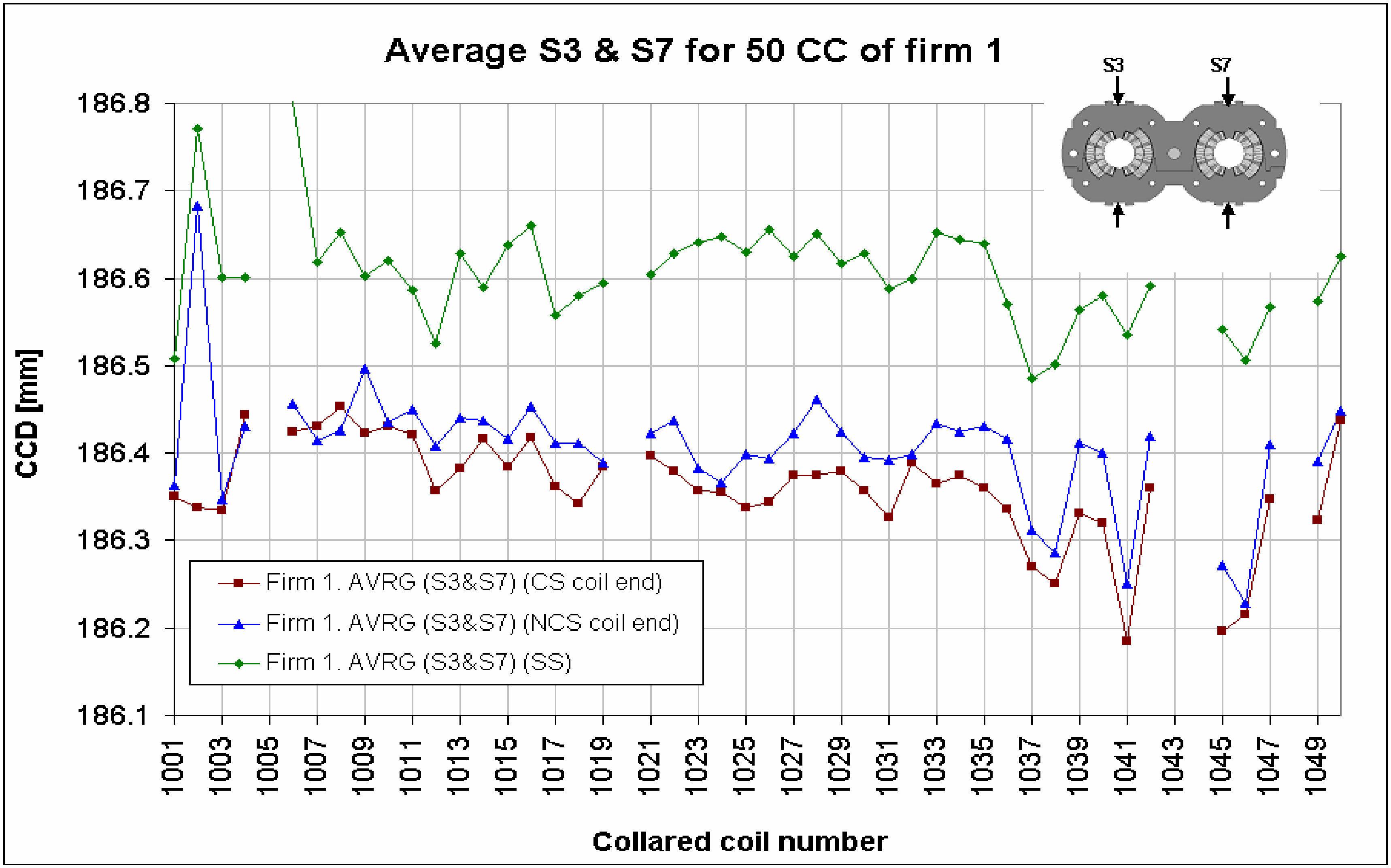

Fig. 28 Firm 1. Average of collared coil dimensions measured over coil ends and coil straight part at the points S3 and S7 (old measuring machine)

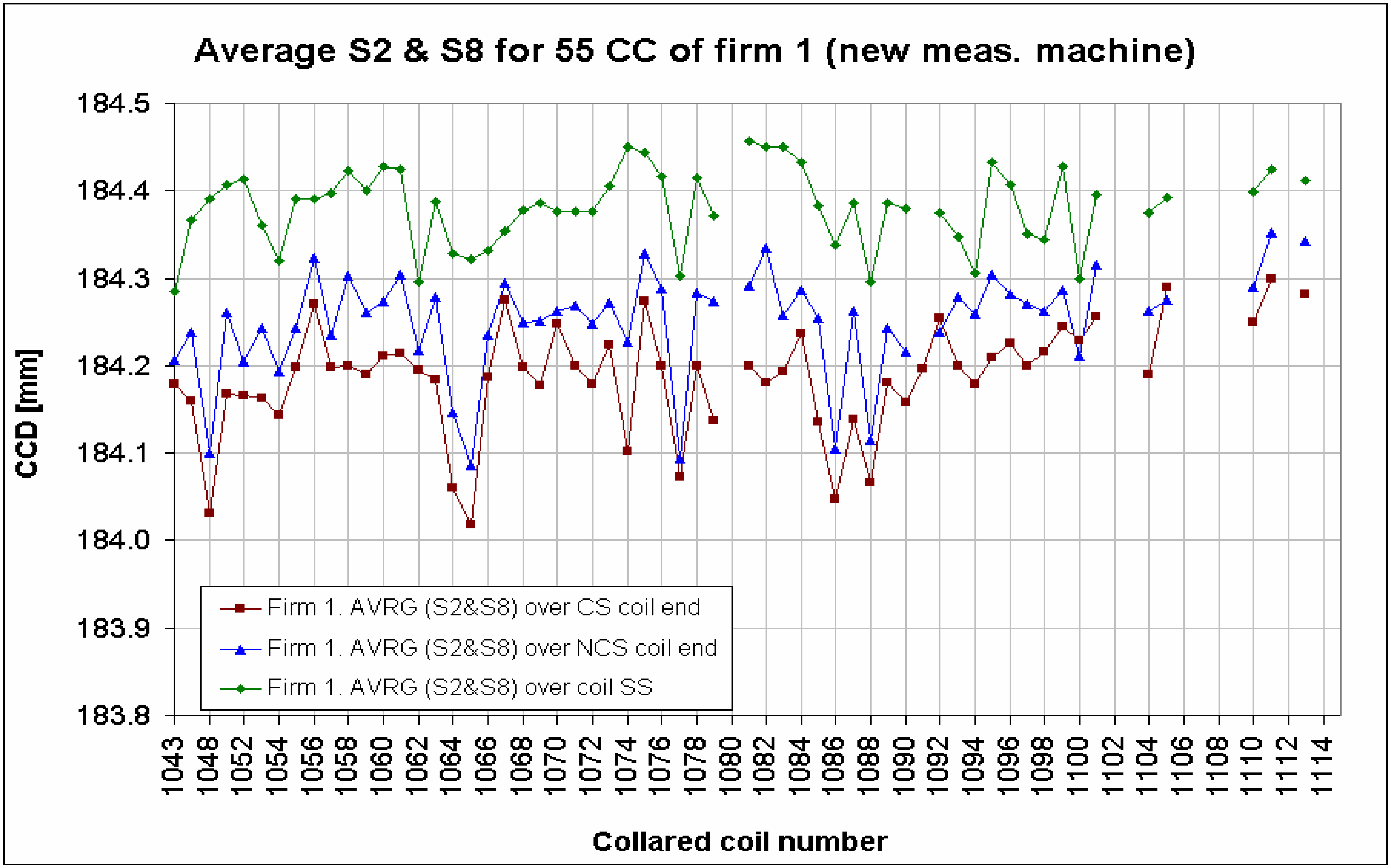

Fig. 29 Firm 1. Average of collared coil dimensions measured over coil ends and coil straight part at the points S2 and S8 (new measuring machine)

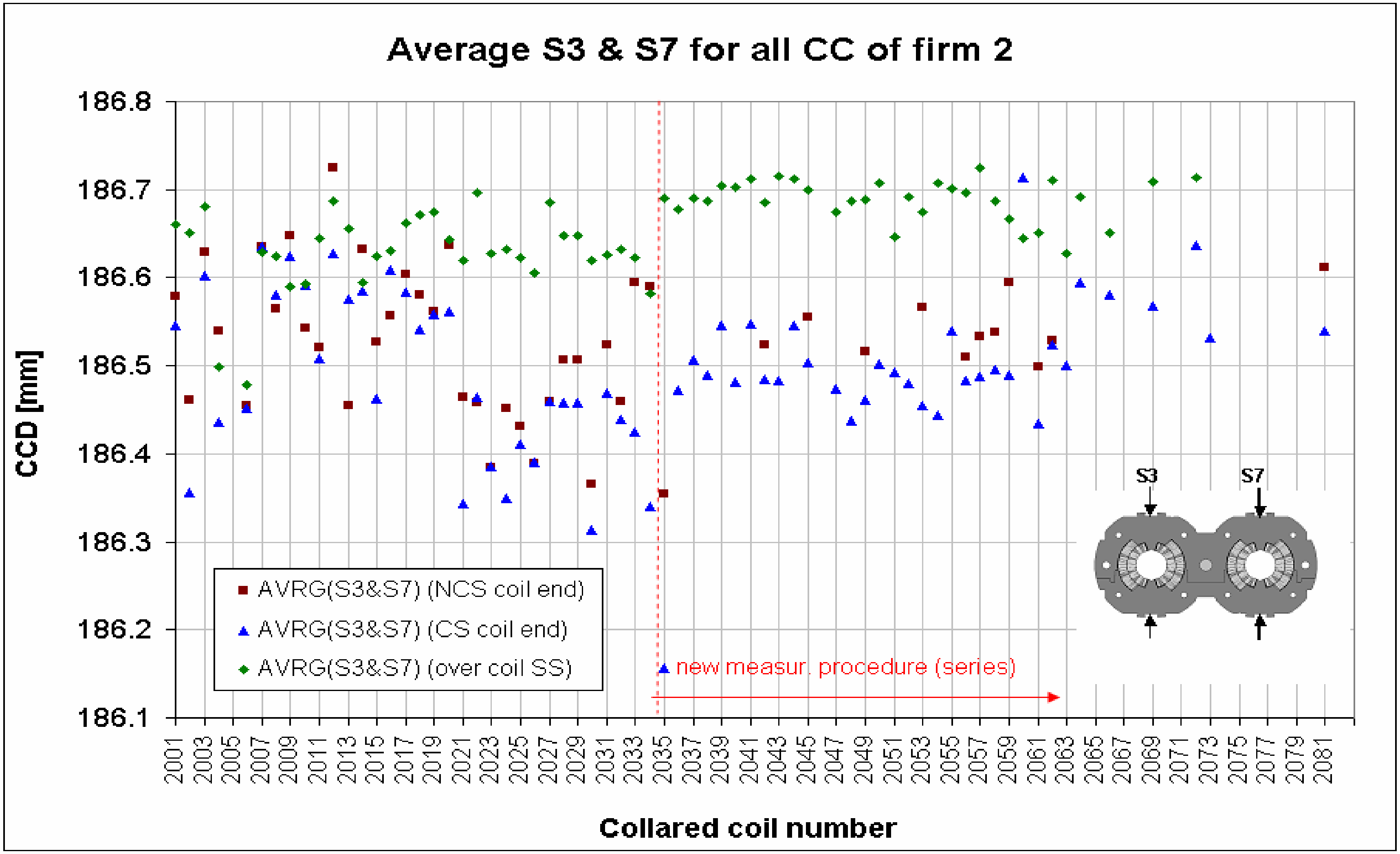

Fig. 30 Firm 2. Average of collared coil dimensions measured over coil ends and coil straight part at the points S2 and S8 (new measuring machine)

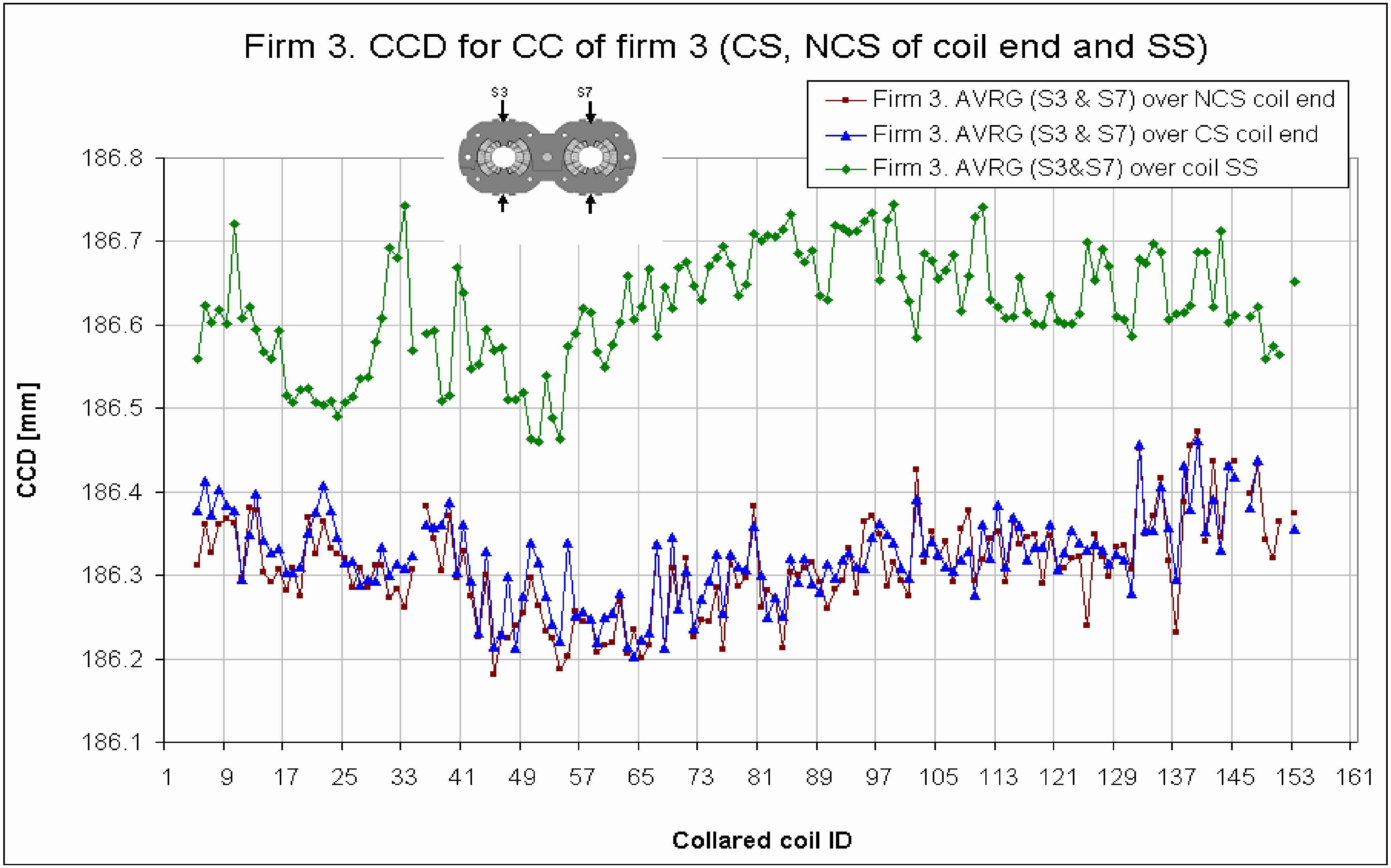

Fig. 31 Firm 3. Average of collared coil dimensions measured over coil ends and coil straight part at the points S3 and S7.

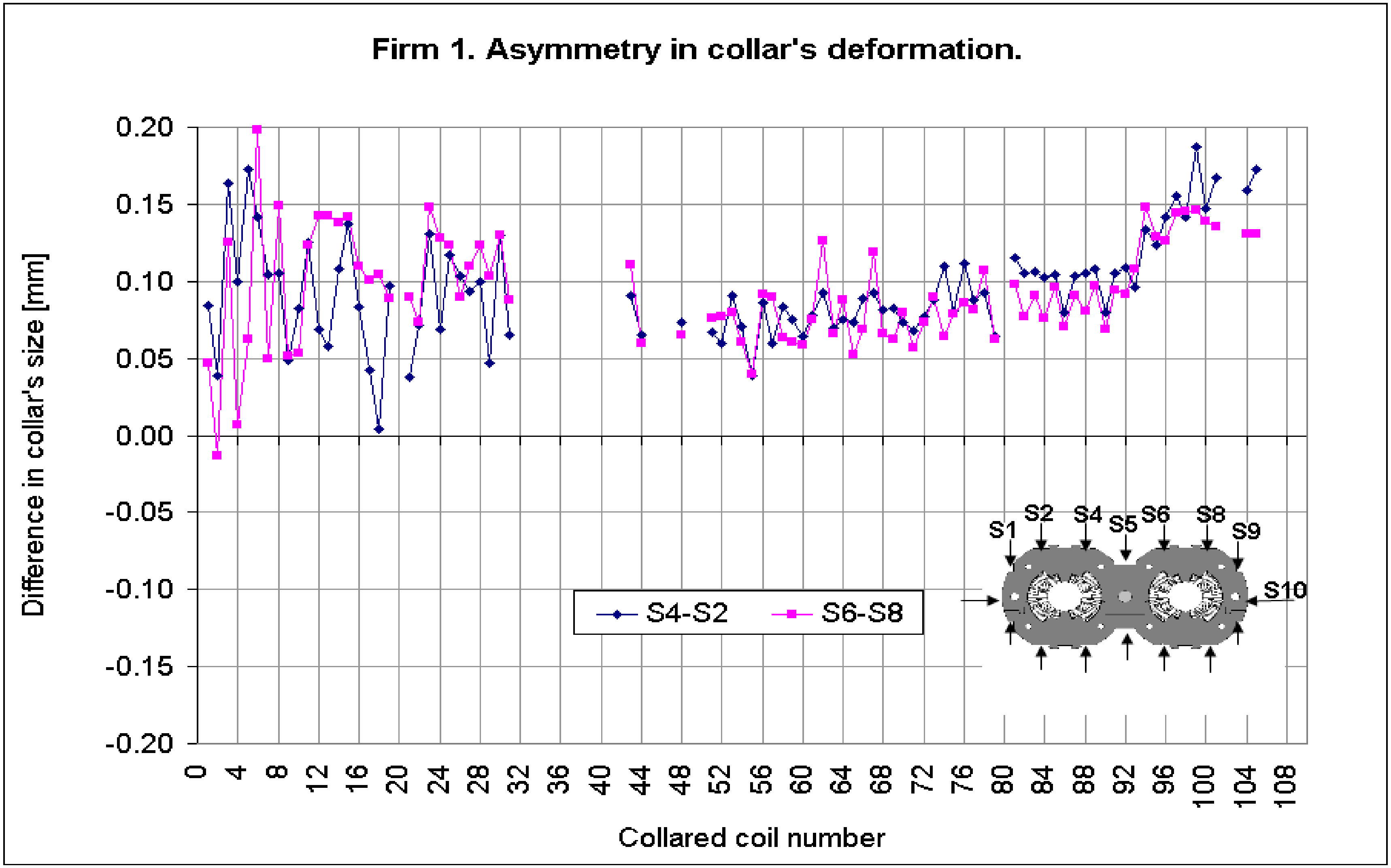

Fig. 32 Firm 1. Measured asymmetry in collared coil dimensions.

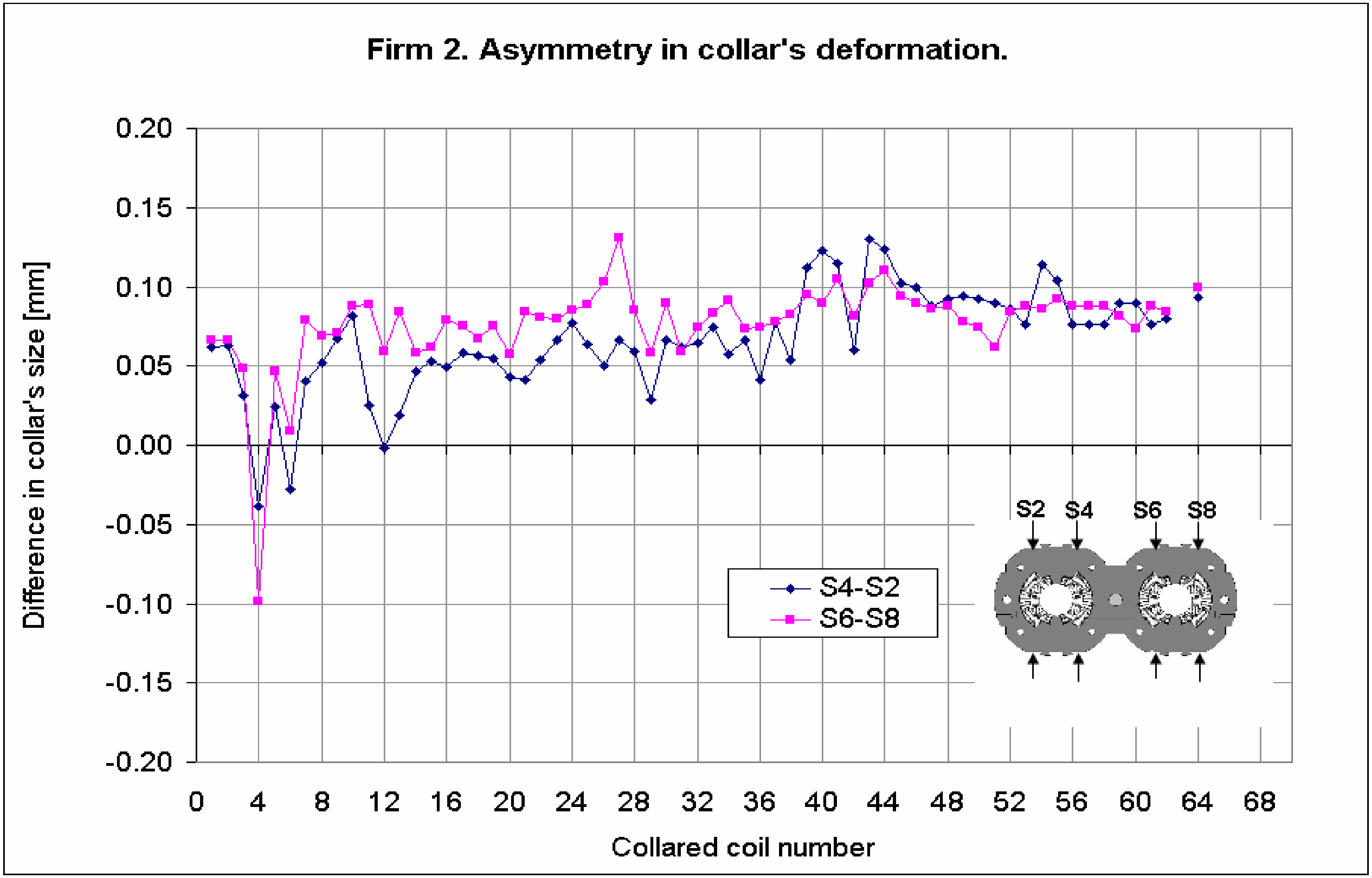

Fig. 33 Firm 2. Measured asymmetry in collared coil dimensions.

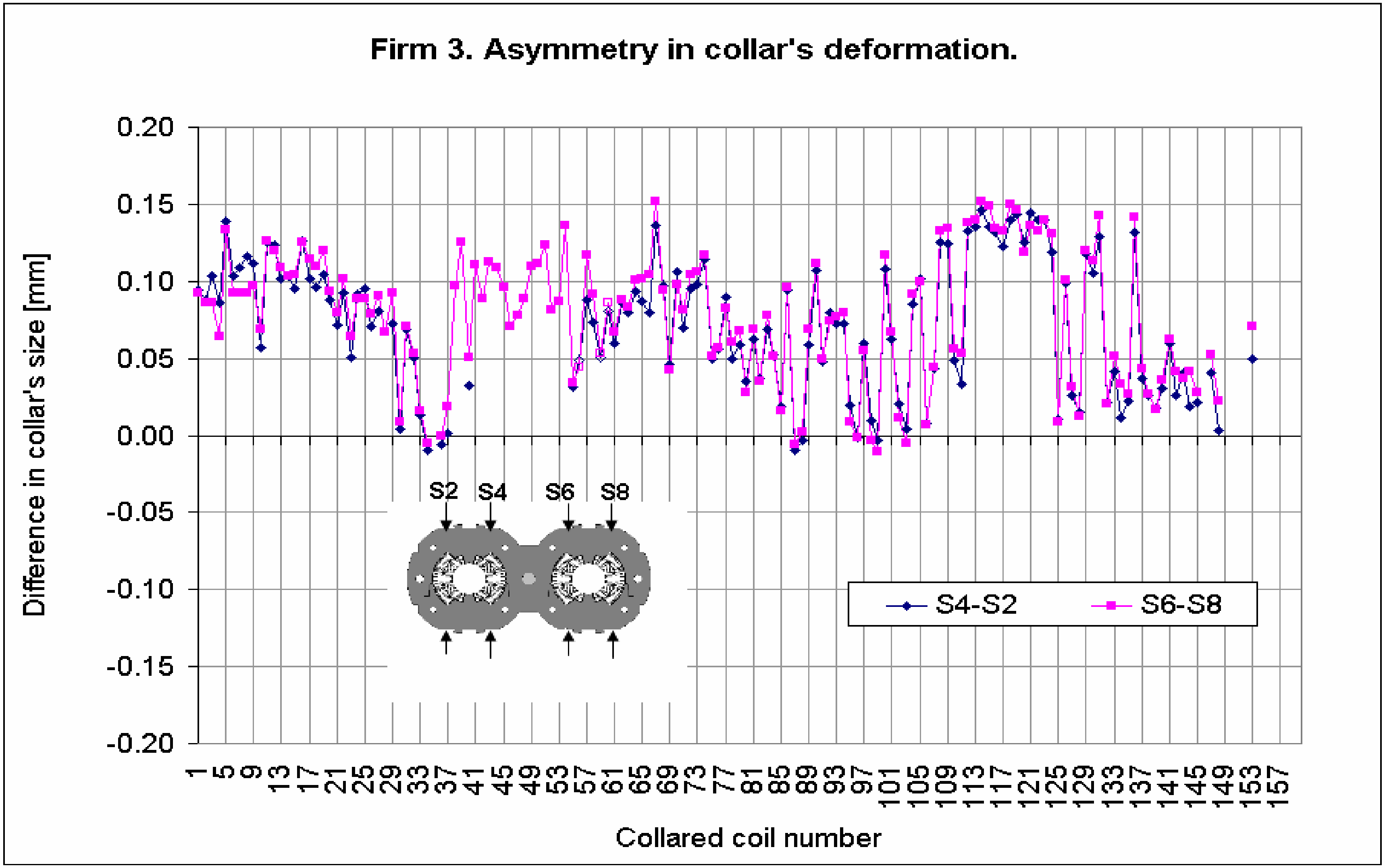

Fig. 34 Firm 3. Measured asymmetry in collared coil dimensions.