Report on mechanical measurements in the main LHC dipole collared coils: July-August 2004

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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

The available data on coils size by the end of June:

- **Firm 1 (ALSTOM-JEUMONT)** – Up to the end of June, in total 653 poles have been produced and 569 have been measured for coil size. During July-August period 52 poles were fabricated at Jeumont and 1/4 of them measured for coil size (one pole per pole set, where one pole set is needed to make one magnet). Compared to the May-June period, the average speed of coil production has dropped by ~25%. In last two months the average production rate was ~ 6 sets of poles per month (8 sets of poles in previous period). Now all poles are measured with reduced number of measuring sections along the coil (5 instead 15). For coil size measurements Jeumont is still using their old E-modulus machine, the new one is being commissioned.
- **Firm 2 (ANSALDO)** – Up to the end of August, in total, about 484 inner and outer layers have been produced, where 40 layers of each type in the last 2 months. Compared to the May-June period, the average coil production speed is almost the same: ~ 5 sets of poles per month. The highest production rate was achieved during January – February period: 8 sets of poles per month. At Ansaldo one inner and one outer layer per magnet are measured.
- **Firm 3 (BNN)** – CERN receives the raw data on mechanical measurements from BNN by batches with 3÷4 weeks interval. All data is post-processed at CERN. Up to date, the data on 720 inner and outer layers for 260 magnets is available at CERN. During July-August period 140 inner and outer layers have been produced (this corresponds to 40 magnets) and half of them were measured for coil sizes. Actually, two inner and two outer layers per magnet are measured, each at 4 longitudinal positions. Despite the summer holidays period, during last two months the company has increased the speed of coil production up to 20 sets of poles per month (in previous period it was 15 sets of poles per month). BNN has been working during summer with reduced personnel without closing.

What is new:

Trends in coil sizes. Periodic trends (with positive and negative slopes) are still present in the coils size data for firm 1, while at firm 2 and particularly at firm 3, the amplitude of these trends has been significantly reduced. At firm 1, despite the curing shims modification, described in our previous report, the coils size variation remains rather large on both inner and outer layers, but inside of the allowed range (± 0.1 mm).
Coil waviness. We present the graph on this parameter only for firm 2, as it is the only one who keeps measure the coil size in all longitudinal positions along the coil.
Collared coils dimensional data. The data on collared coil dimensional measurements taken over magnets ends shows a significant difference in the CC dimensions between different magnets and between different firms. The investigations are going on in MA section concerning the collars tolerances and their impact on magnet field quality. The preliminary results show that the difference in CC dimensions between magnets of the same firms is not only due to the variation of coil pre-stress, but also related to the collar's tolerances.

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. We recall that in order to speed up the production, starting from the poles set 114 the number of measuring sections in coil straight part has been reduced to 5 (from 15). 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 dashed line in figure 1) the coils are cured with additional curing shim, made of polyimide tape, 0.125 mm thick. Moreover, the coils of pole sets 108 and 127 were cured with 2x0.125 mm shims. Despite this action, we can see that there is no visible reduction in the amplitude of coil size variations on both coil layers. However, following the decision which was taken during coil size crisis meeting, the use of non-nominal polar shims at firm 1 now is minimized (see E. Todesco report on field quality in collared coils).

The difference in coil size between the left and right sides of coils is shown in figure 2. In figures 3 and 4, the inner and outer layers coil sizes are plotted together with their E-modulus.

Firm 2. About 40 inner and outer layers have been produced over last two months, and a quarter of them have been measured for coil sizes. 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 (fig. 5). Moreover, for the last 100 produced layers, both inner and outer, we notice a small reduction in coil size variation: in the coils manufactured during two last months the coil size variation is not exceed ± 0.05 mm and even better for inner layer coils.
At firm 2 the coil size measurements are still taken in 15 longitudinal positions along the coil. By measuring the coils at all positions the firm keeps control on the coil production tooling shape. The standard deviation (one sigma) of coil size variation along the coil is shown in figure 6. As we can see from this figure there is significant reduction of coil waviness in the last 100 coils (25 magnets).
The difference in coil size between left and right sides of coils is shown in figure 7.
In figures 8 and 9, the inner and outer layers coil sizes are plotted together with their E-modulus (notice that the scale for E-modulus axis is reversed). We notice significant trends in the coil E-modulus, particularly in the inner layer coils. Since the beginning of series (the coil number 121 in figure 8) the value of coil E-modulus has been drifted up by more then 20%. This is in line with the trend on the inner layer average coil size, which has been drifted down by almost 0.1 of mm. Most probably this is related to the tolerances on coil components.

Firm 3. . Up to date, the data on 720 inner and outer layers for 260 magnets is available at CERN (last delivery beginning of September). Following series production specification, the number of measuring coils and the number of measuring sections along the coil has been gradually reduced (see the pink and blue lines in figure 10). Starting from the magnet 100, only half of coils are measured for coil sizes (two inner and two outer coil layers per magnet).
Starting from the magnet 89 (after the last modification of the curing shim), the coil size variation at firm 3 is smallest among three firms. The coil size is varied in the range of ±0.05 mm, which is twice smaller compared to the coils of firm 1 (see figure 10).
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 11.
In figures 12 and 13, the inner and outer layers coil sizes are plotted together with their E-modulus (notice that the scale for E-modulus axis is reversed). Again, similar to firm 2, we observe significant trend in the coil E-modulus data on both coil layers. Usually the trends on coil size are following the trends on coil E-modulus, while this is not a

case for the coils of firm 3. Since the last modification of curing shim (the coil number 89 in figure 10) the value of coil E-modulus has been drifted up by almost 20%, while the coil size did not move. Moreover, for the coils of both layers, around magnet number 214 we observe a sudden change of coil E-modulus (a drop almost by 20%), without important changes in coil sizes (see figures 12 and 13). We should stress the point that the field quality of the magnet rely on the final coil geometry which it takes after the collaring. The coil geometry in collared coils depends not only on the azimuthal coil size, which is measured at fixed pressure target, but also on coil elasticity, i.e. coil E-modulus, and coil radial dimensions. In fact, as we will see later from the collared coil dimensions measurements data, the magnets of firm 3, despite rather homogenous coil size shows significant trends in coil pre-stress, seen as collars deformation.

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 14 ÷ 16 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 17 ÷ 21 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 22 ÷ 26 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. 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 and there is no impact of the collaring press on the collar surface during collaring. In figures 27÷30 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÷150, which are measured with the new machine. In this report the data belonged to the first group, already published in the previous reports, has been dropped. In figure 27 the CC dimensions for measurements taken over coil ends are shown together with the data on coil straight part. We should notice that firm 1 is receiving the collars from two suppliers. As can be seen in figure 27, the magnets, collared with collars from FSG, systematically shows smaller CC dimensions over coil ends. The investigations on the source of this anomaly are still going on in MAS-MA and MAS-CC sections, no conclusion on coil pre-stress is yet possible.

Firm 2. In figure 28 the CC dimensions for measurements taken over coil ends are shown together with the data on coil straight part. For an easy cross-check with firm 1, in figure 29 the CCD data on the measuring points S2 and S8 is also shown.
For some of the magnets the measurements at NCS were done not correctly, therefore the data is not shown. Some of these magnets were re-measured and their IDs have an extension "R".

Firm 3. In figures 30 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). In figure 31 the CC dimensions for measurements taken at points S2 and S8 are shown. Apart of few first magnets, firm 3 is using the FSG collars.
There is a systematic difference in the CCD data for two collars producers. This difference is in the order of 0.1÷0.2 mm (see figures 27 and 31).

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.

In these figures the data not for all magnets is shown due to following reasons:

Firm 1. 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 L. Rossi for comments, discussions and valuable help.

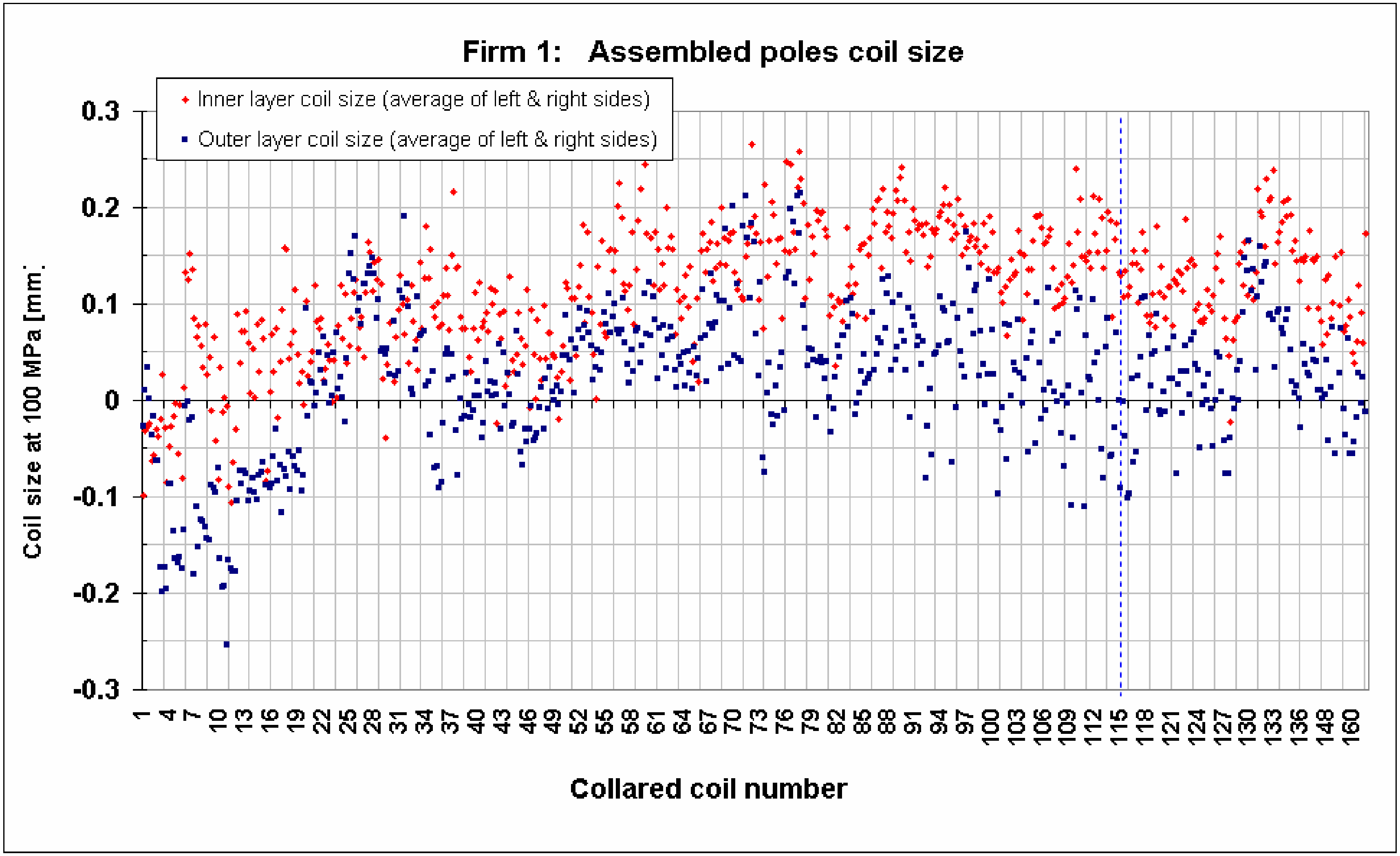

Fig. 1 Firm 1. Average coil size in the straight part of the assembled poles (642 poles).

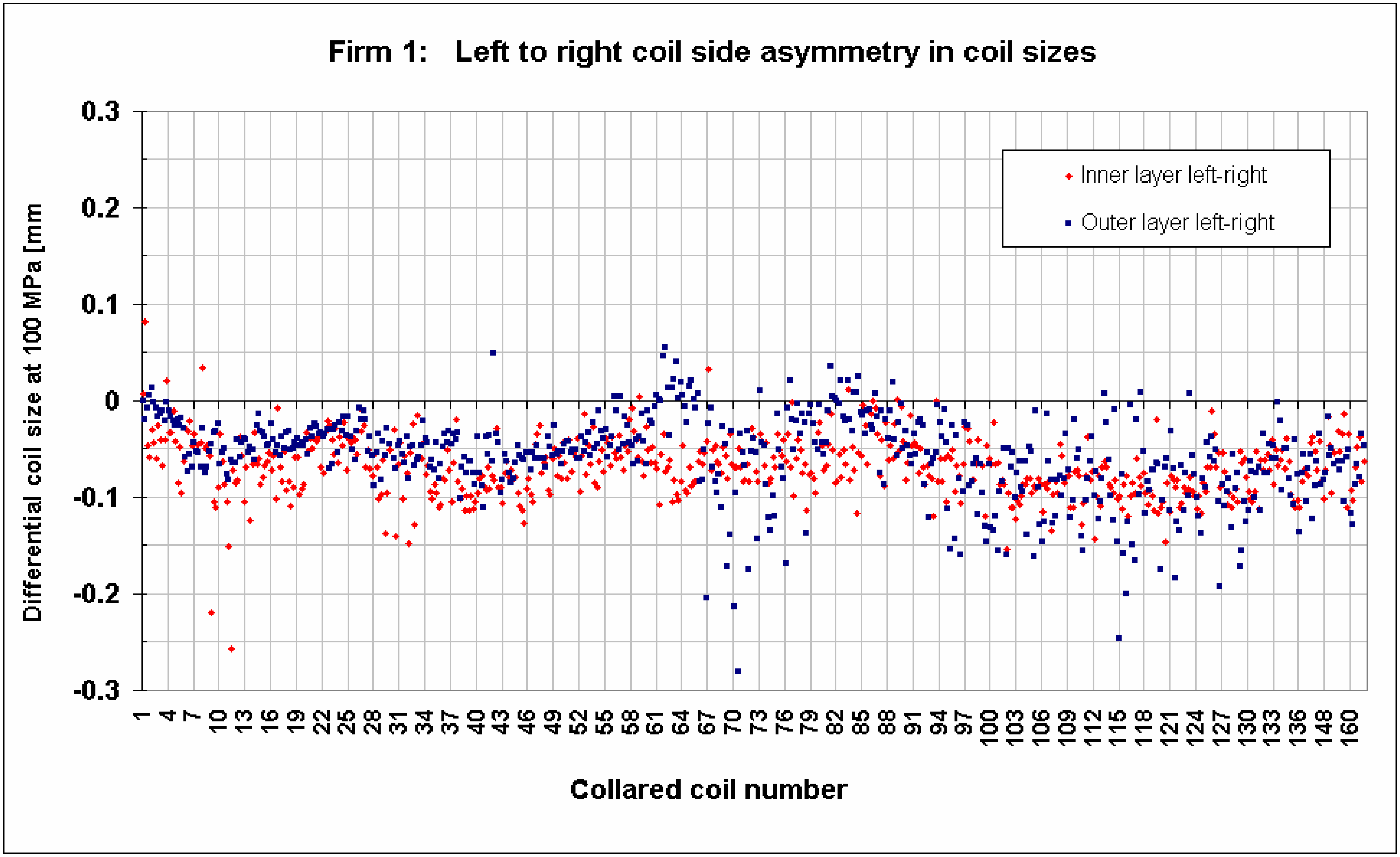

Fig. 2 Firm 1. Difference in the coil size between left and right sides of the coil on both layers.

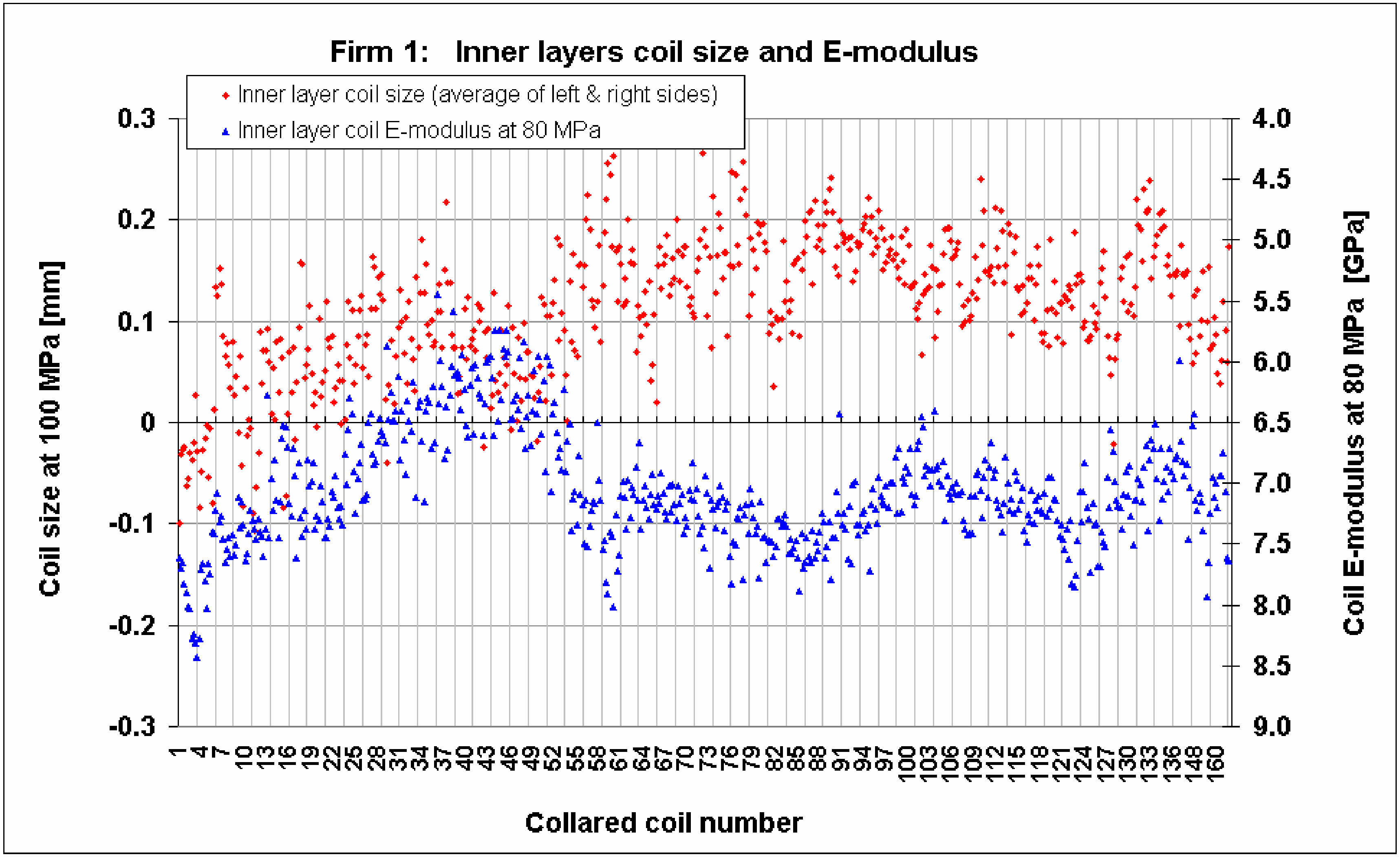

Fig. 3 Firm 1. Inner layer coil size (average) and E-modulus computed at 80 MPa. (Data extracted from pole size measurements).

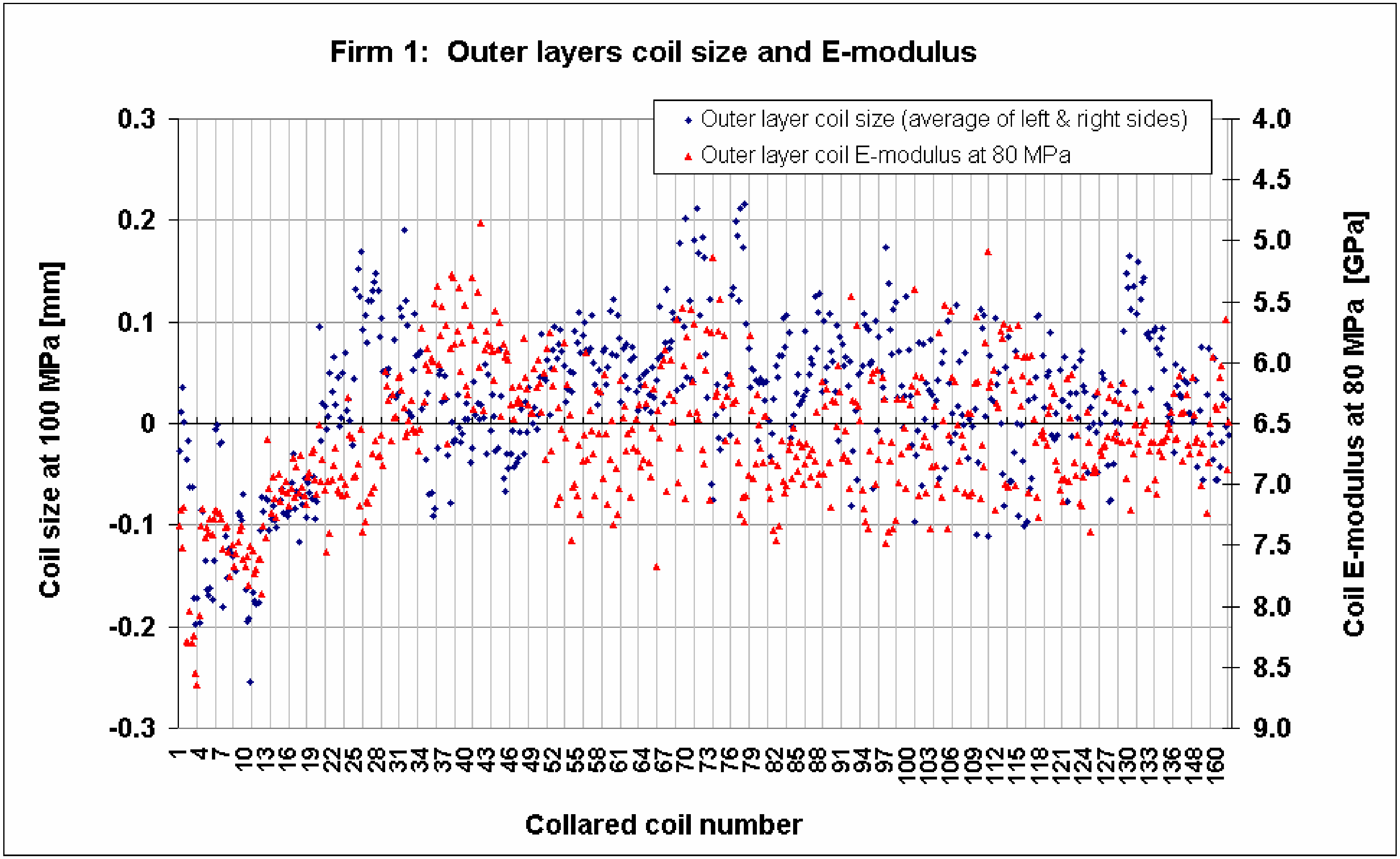

Fig. 4 Firm 1. Outer layer coil size (average) and E-modulus computed at 80 MPa. (Data extracted from pole size measurements).

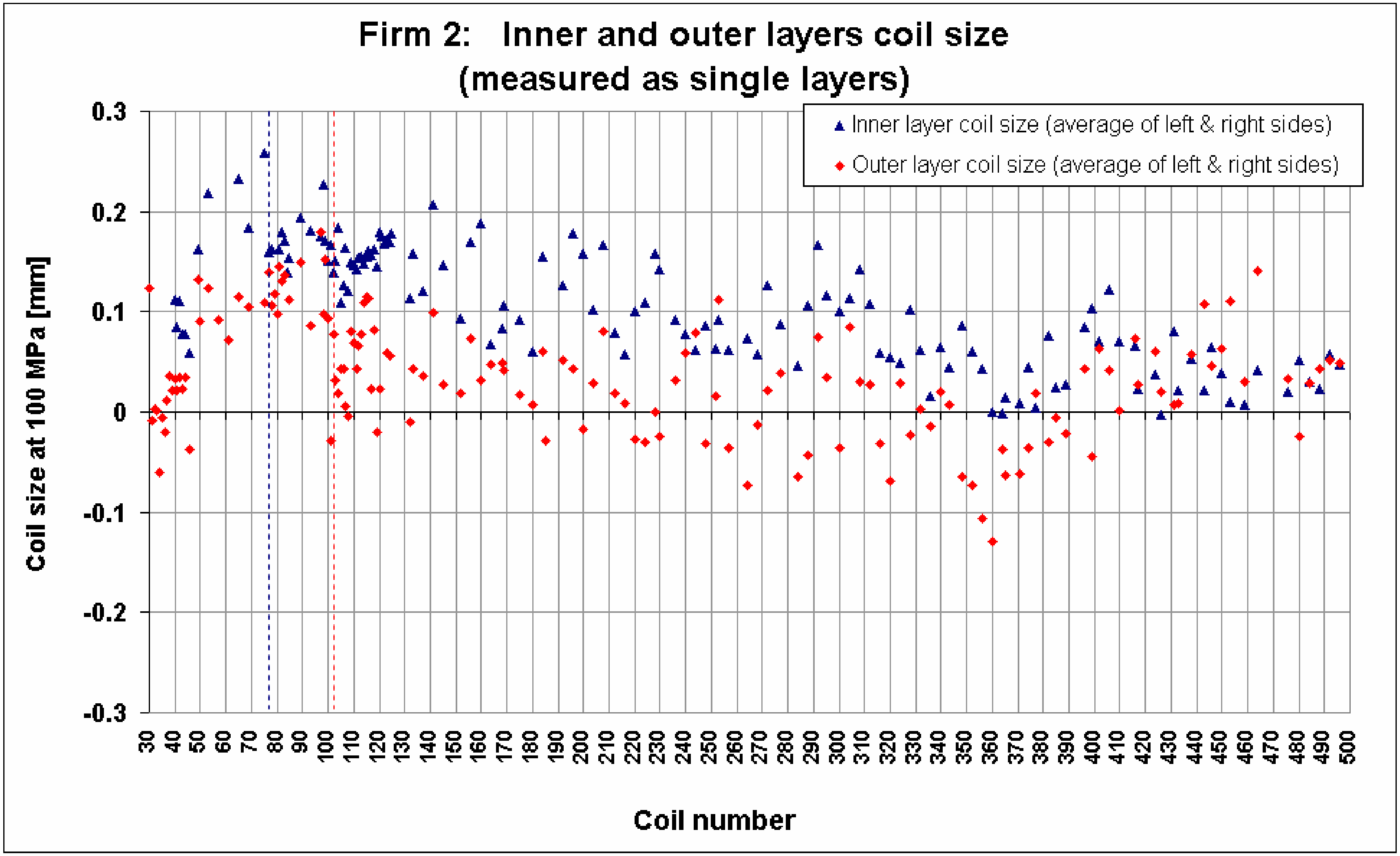

Fig. 5 Firm 2. Average coil size in the straight part of the inner and outer layers.

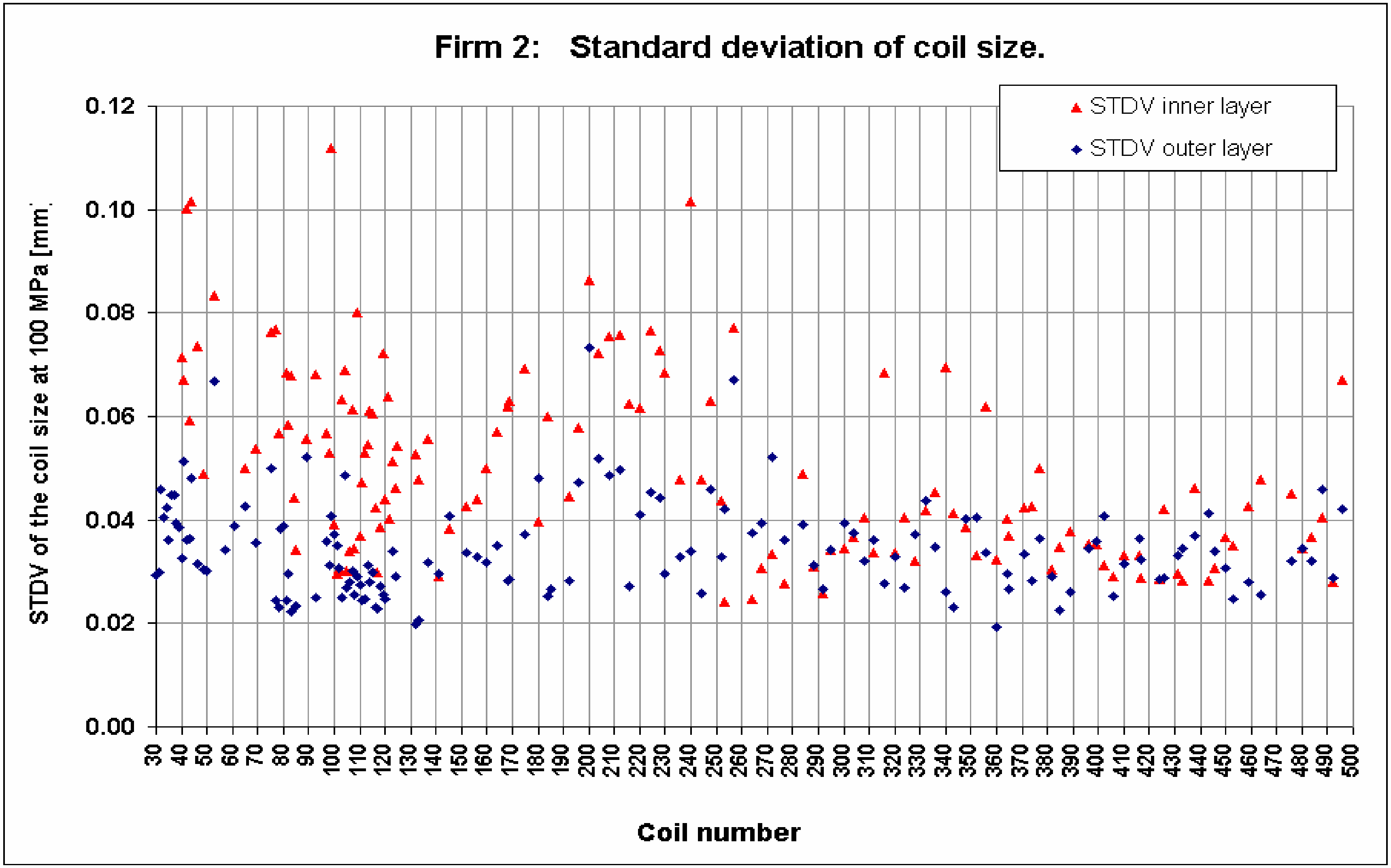

Fig. 6 Firm 2. Standard deviation of coil sizes measured in 15 positions along the coil (left and right coil sides in average).

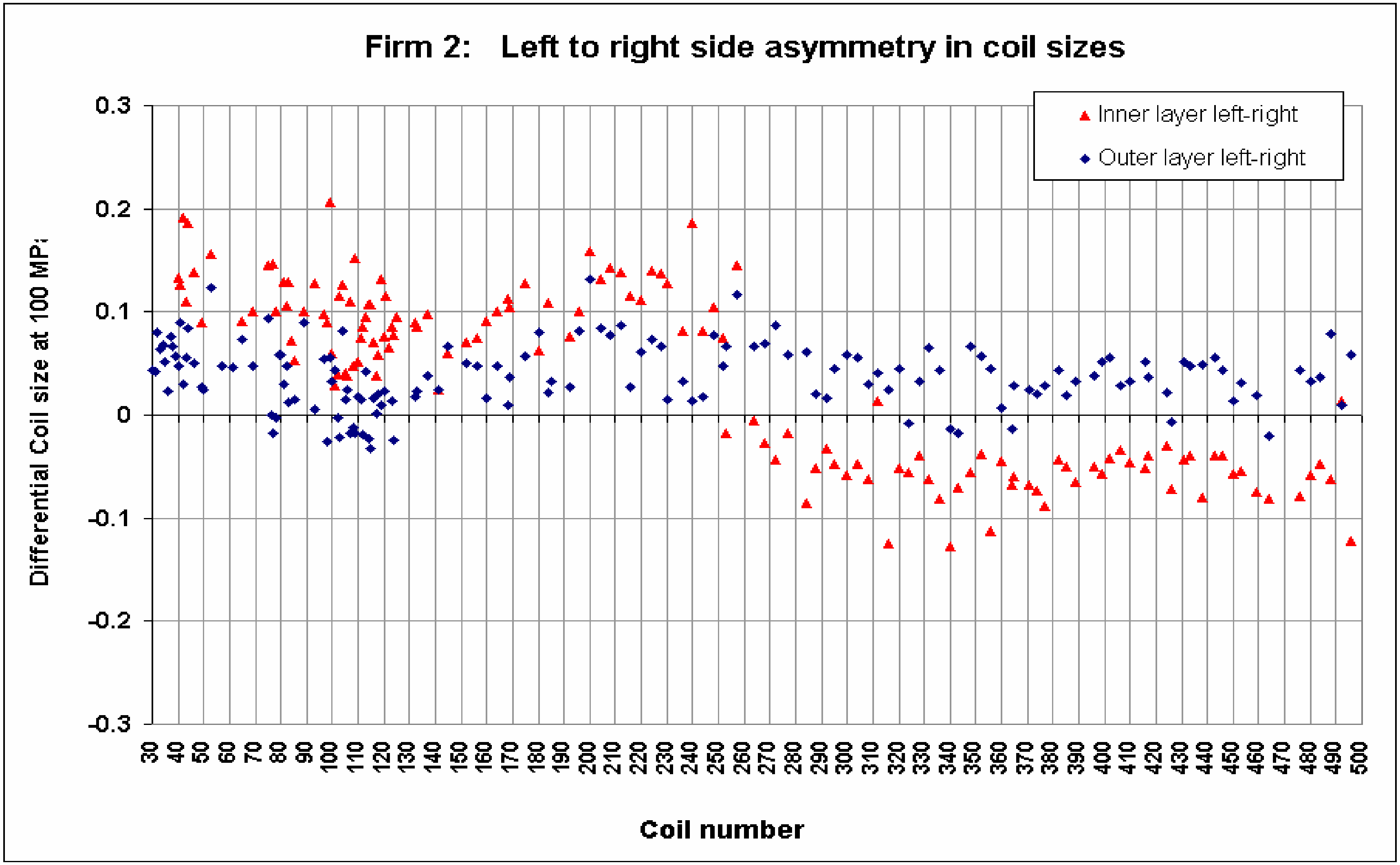

Fig. 7 Firm 2. Difference in the coil size between left and right sides of the coil on both layers.

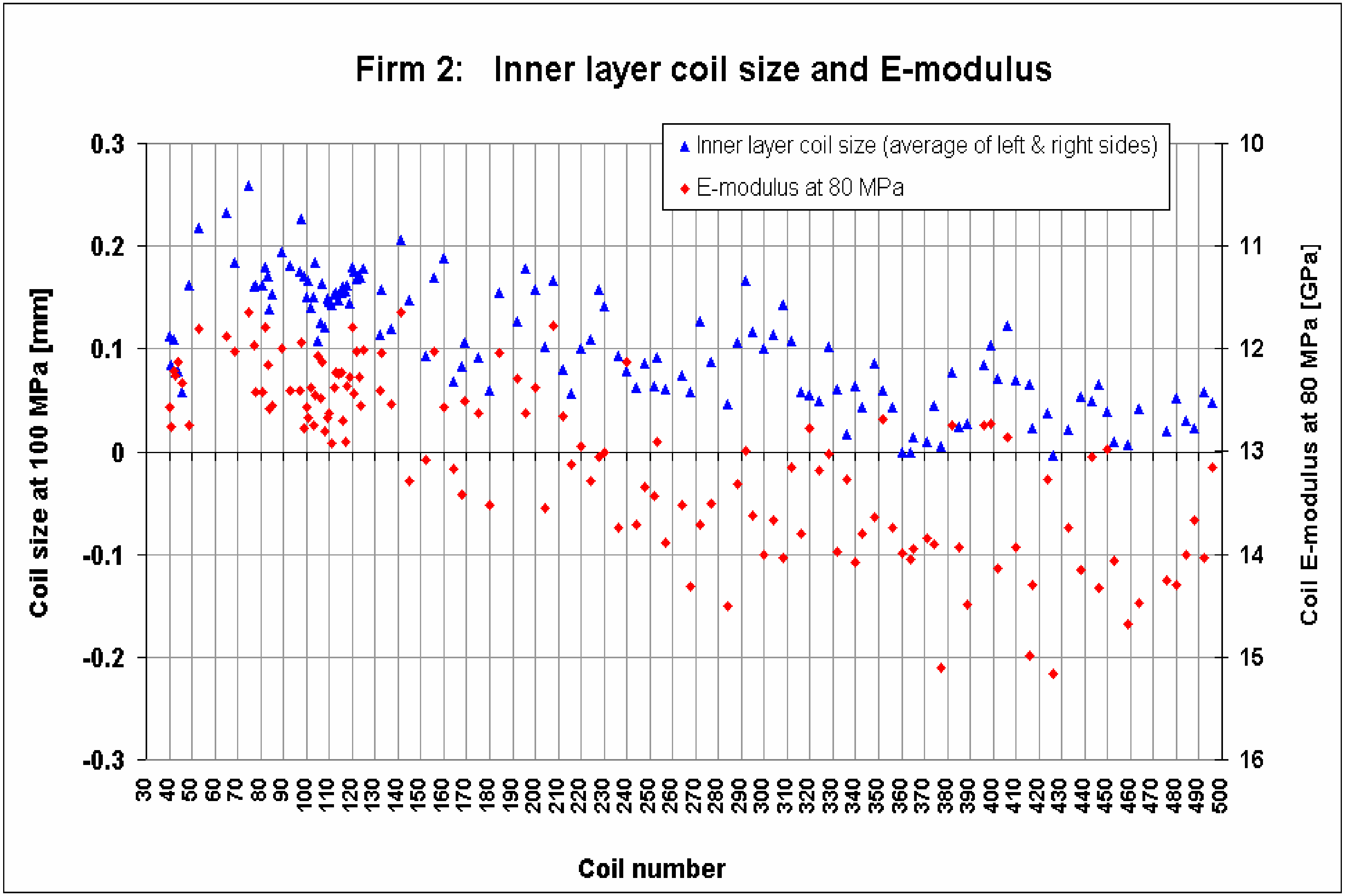

Fig. 8 Firm 2. Inner layer coil size (average) and E-modulus computed at 80 MPa.

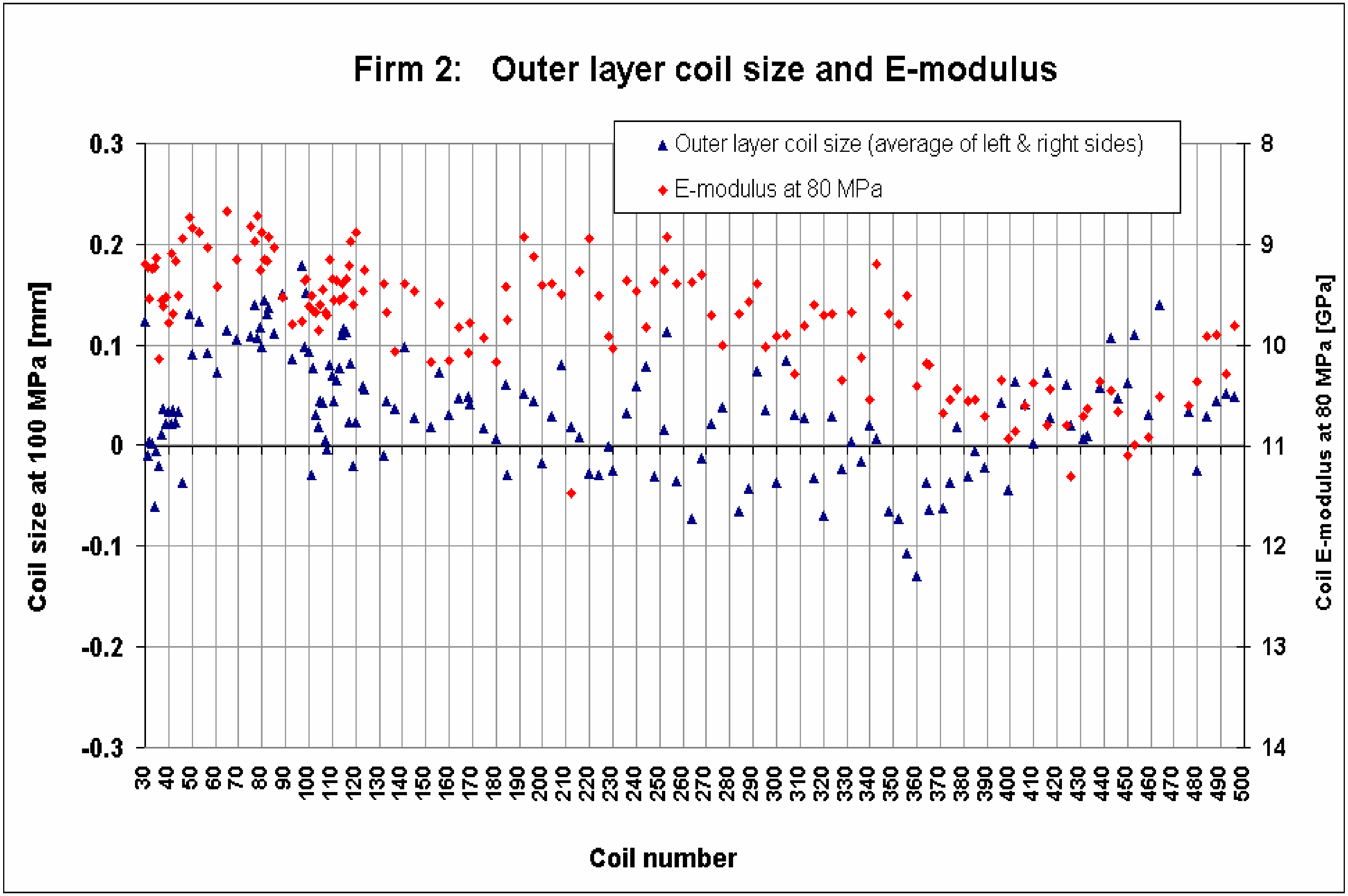

Fig. 9 Firm 2. Outer layer coil size (average) and E-modulus computed at 80 MPa.

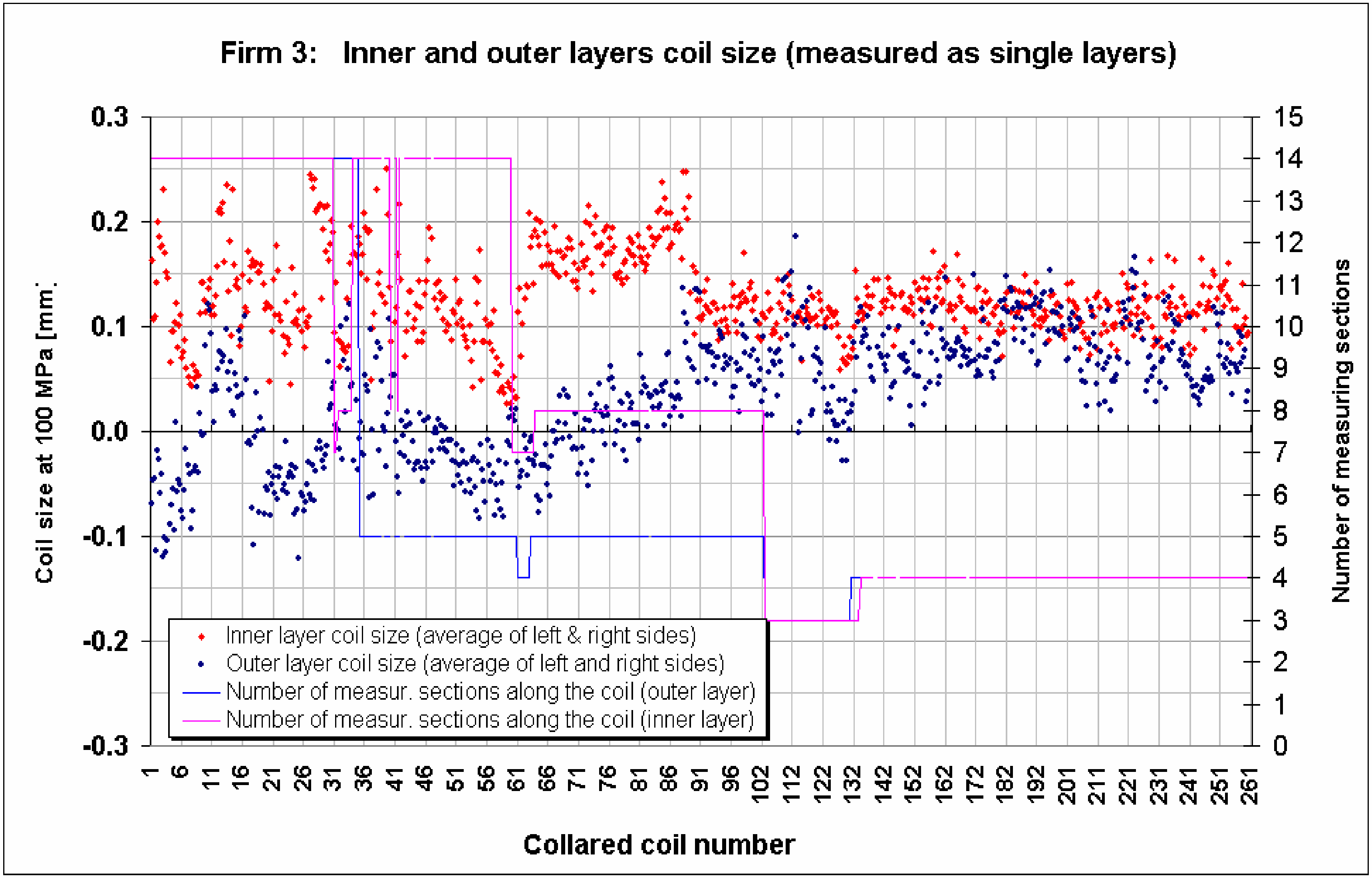

Fig. 10 Firm 3. Average coil size in the straight part of inner and outer layers.

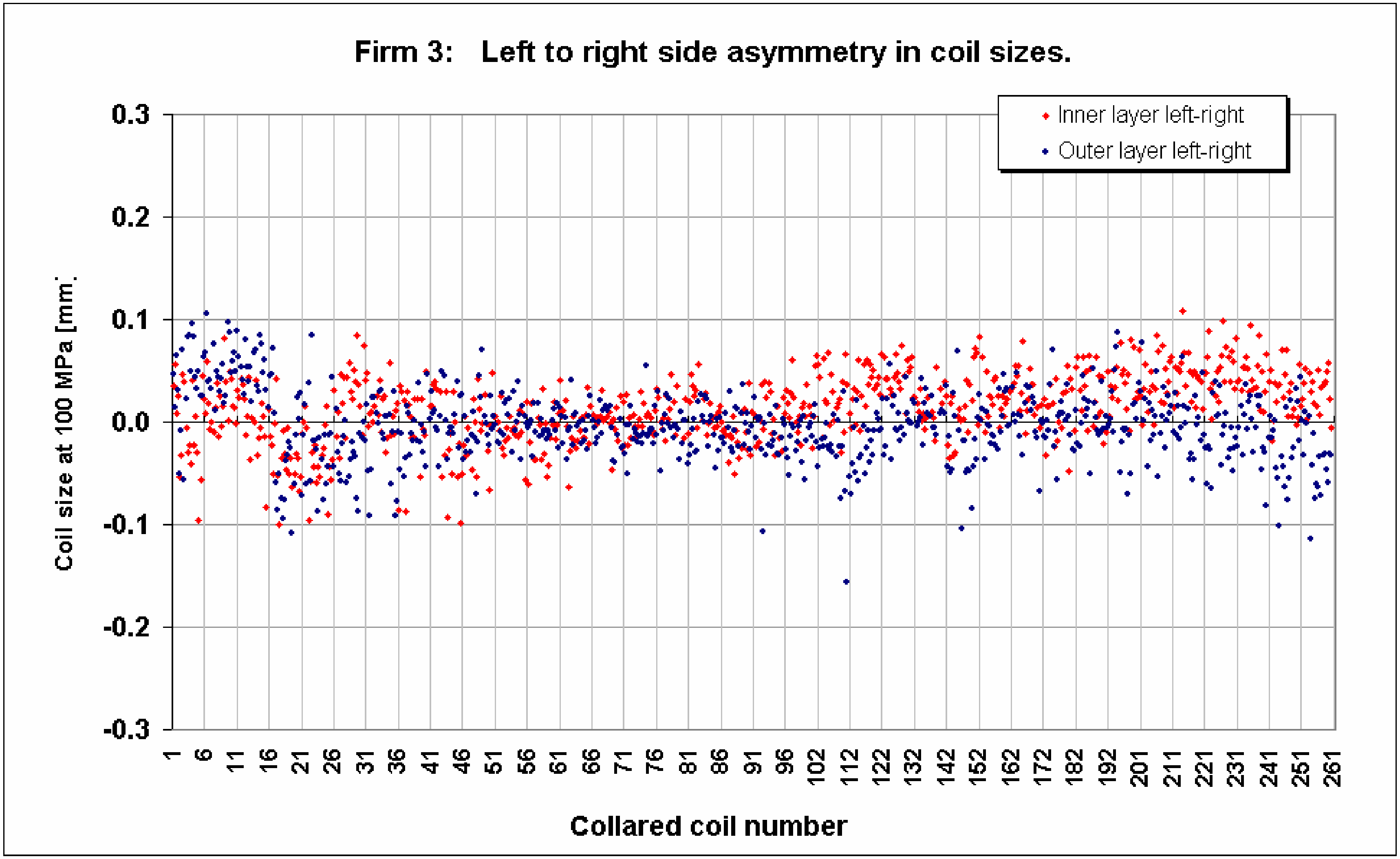

Fig.11 Firm 3. Difference in the coil size between left and right side of the coil on both layers.

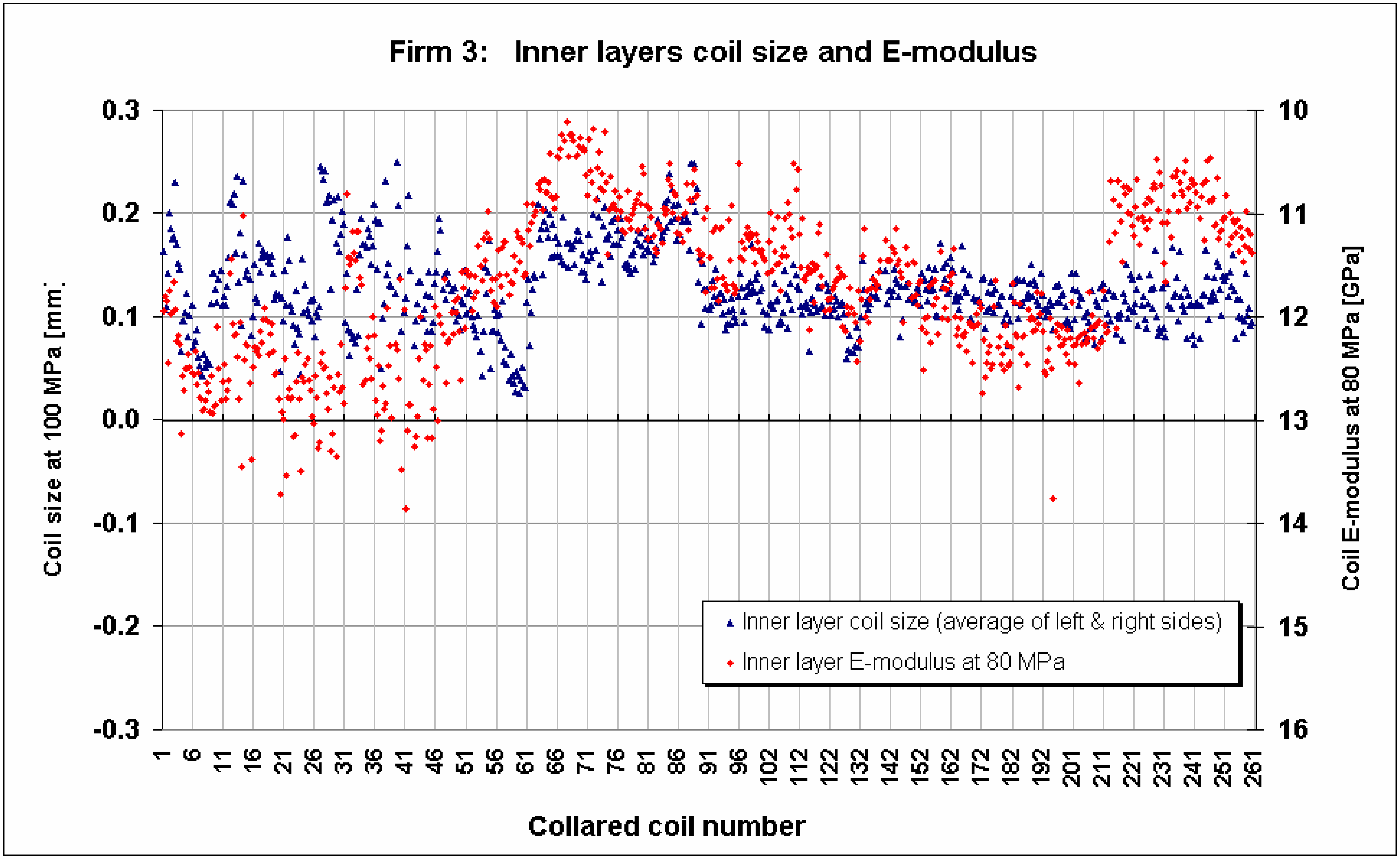

Fig. 12 Firm 3. Inner layer coil size (average) and E-modulus computed at 80 MPa.

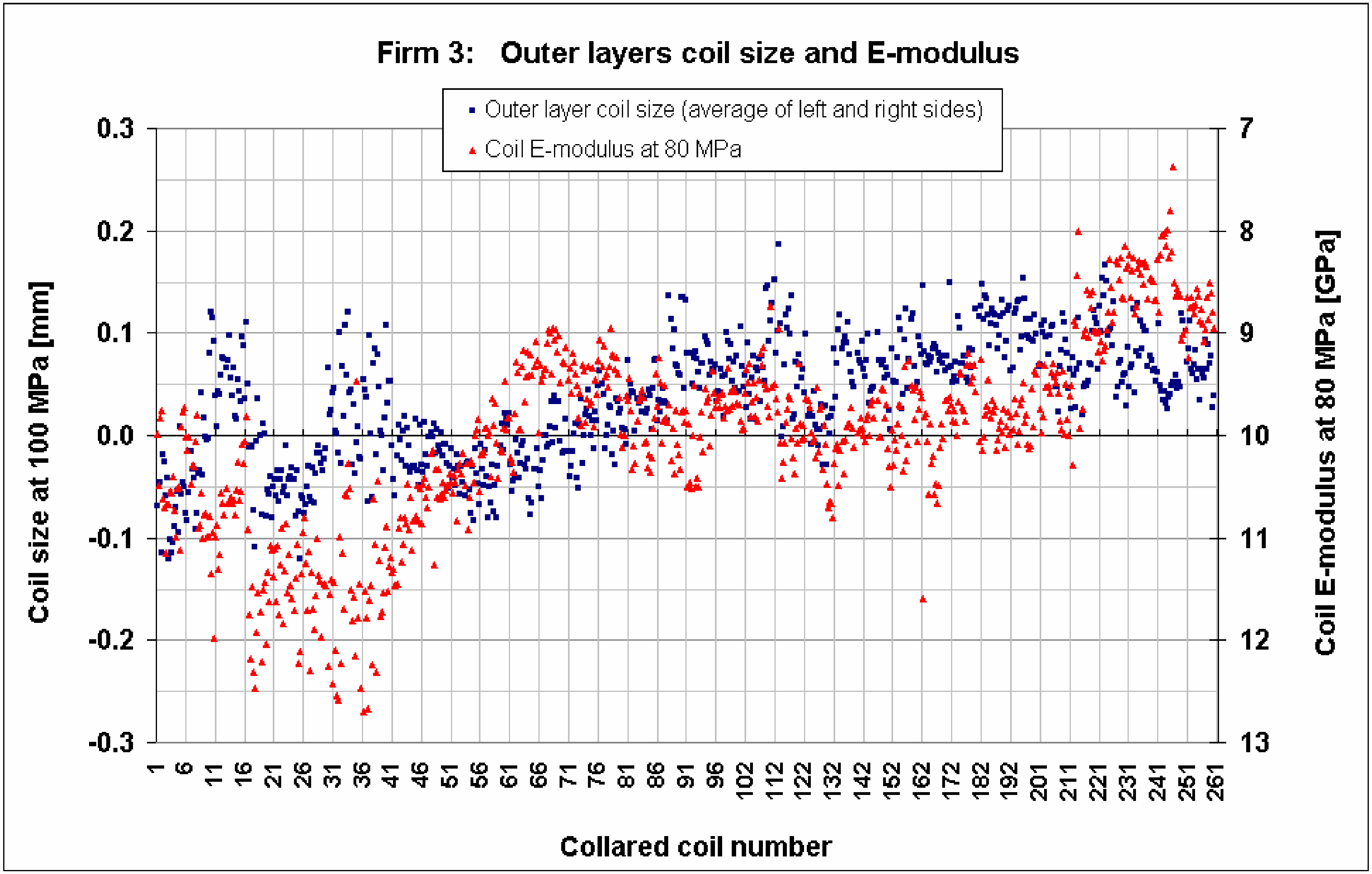

Fig. 13 Firm 3. Outer layer coil size (average) and E-modulus computed at 80 MPa.

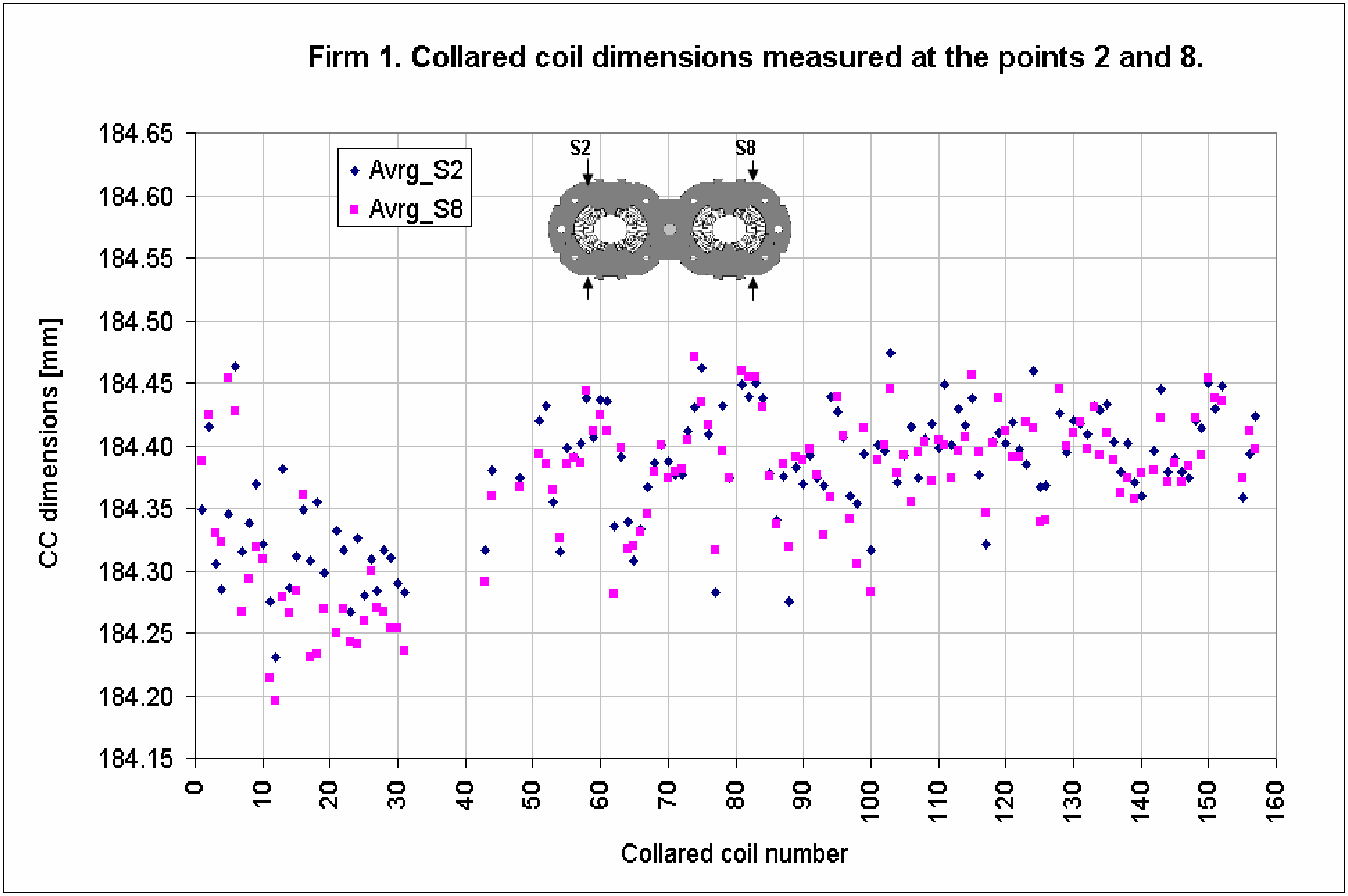

Fig. 14 Firm 1. Collared coil dimensions measured at the points S2 and S8.

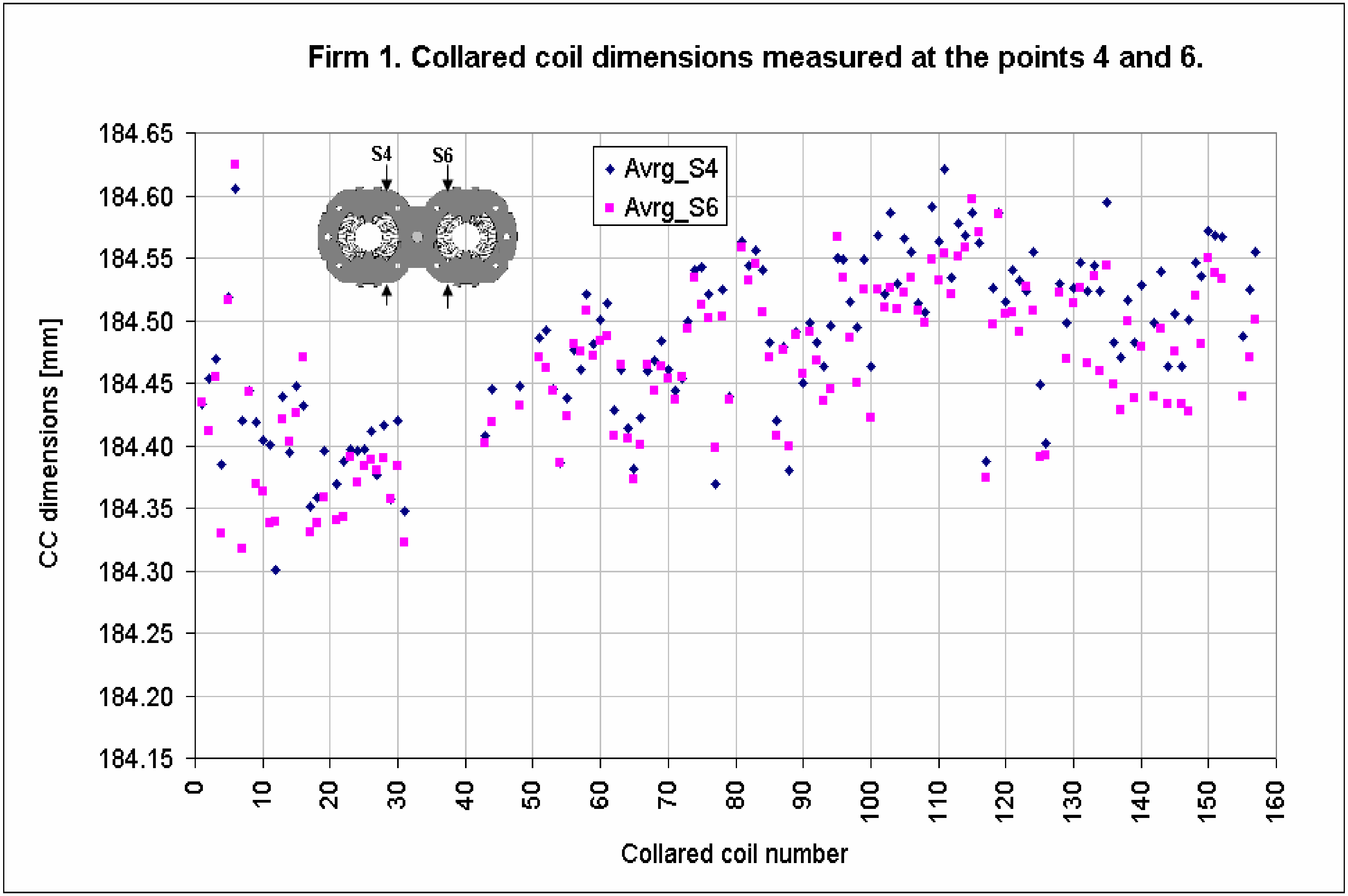

Fig. 15 Firm 1. Collared coil dimensions measured at the points S4 and S6.

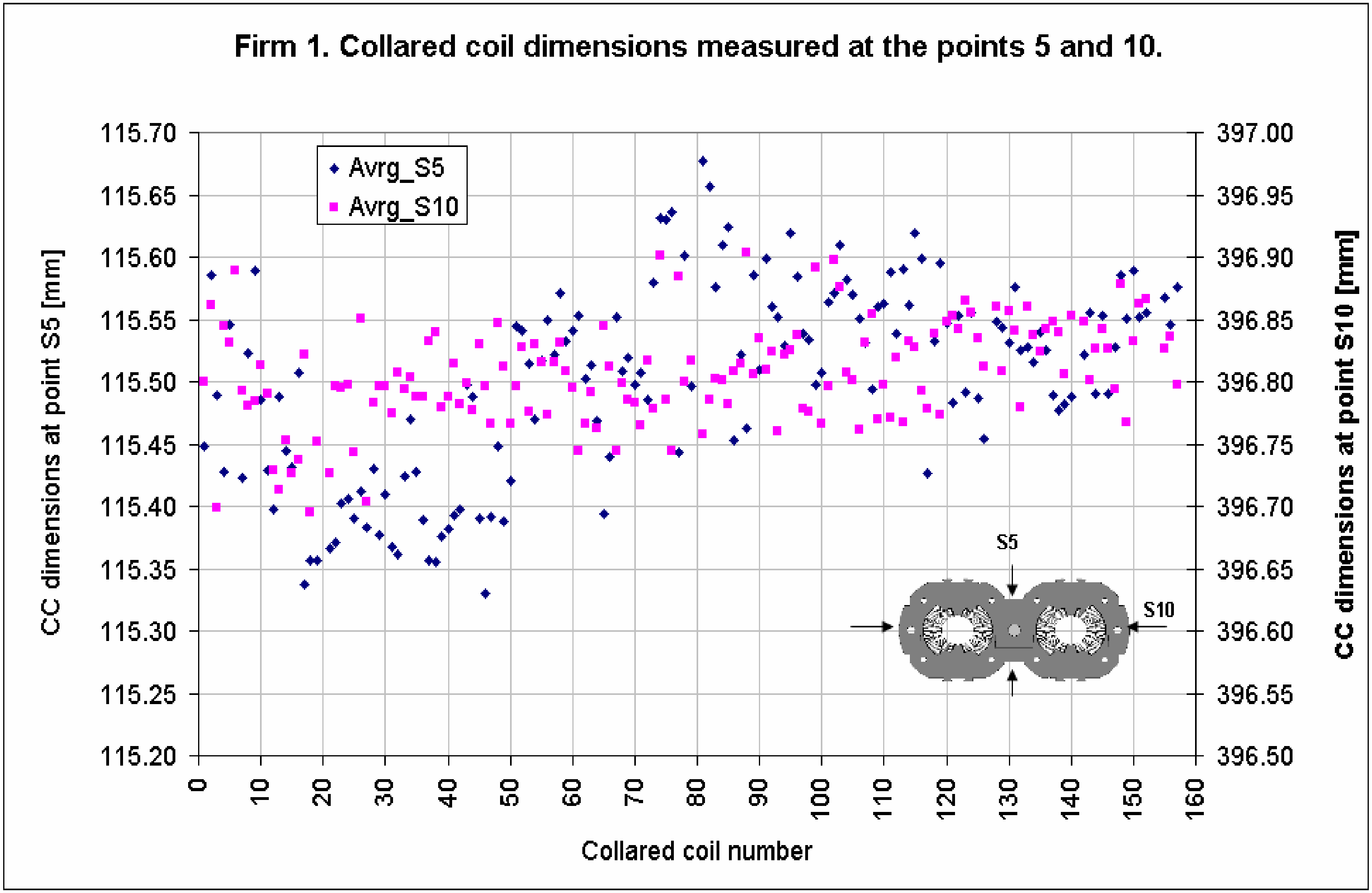

Fig. 16 Firm 1. Collared coil dimensions measured at the points S5 and S10.

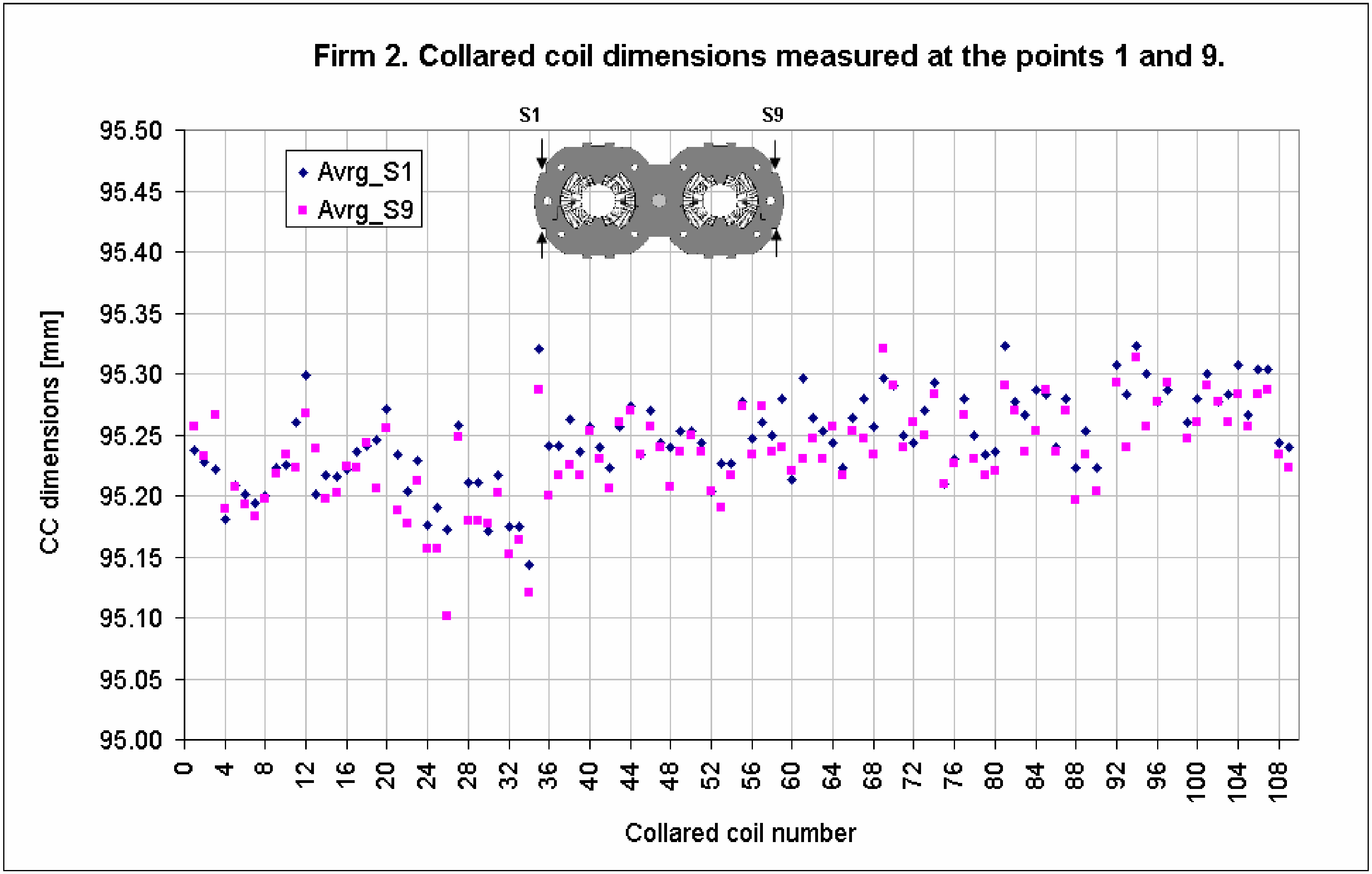

Fig. 17 Firm 2. Collared coil dimensions measured at the points S1 and S9.

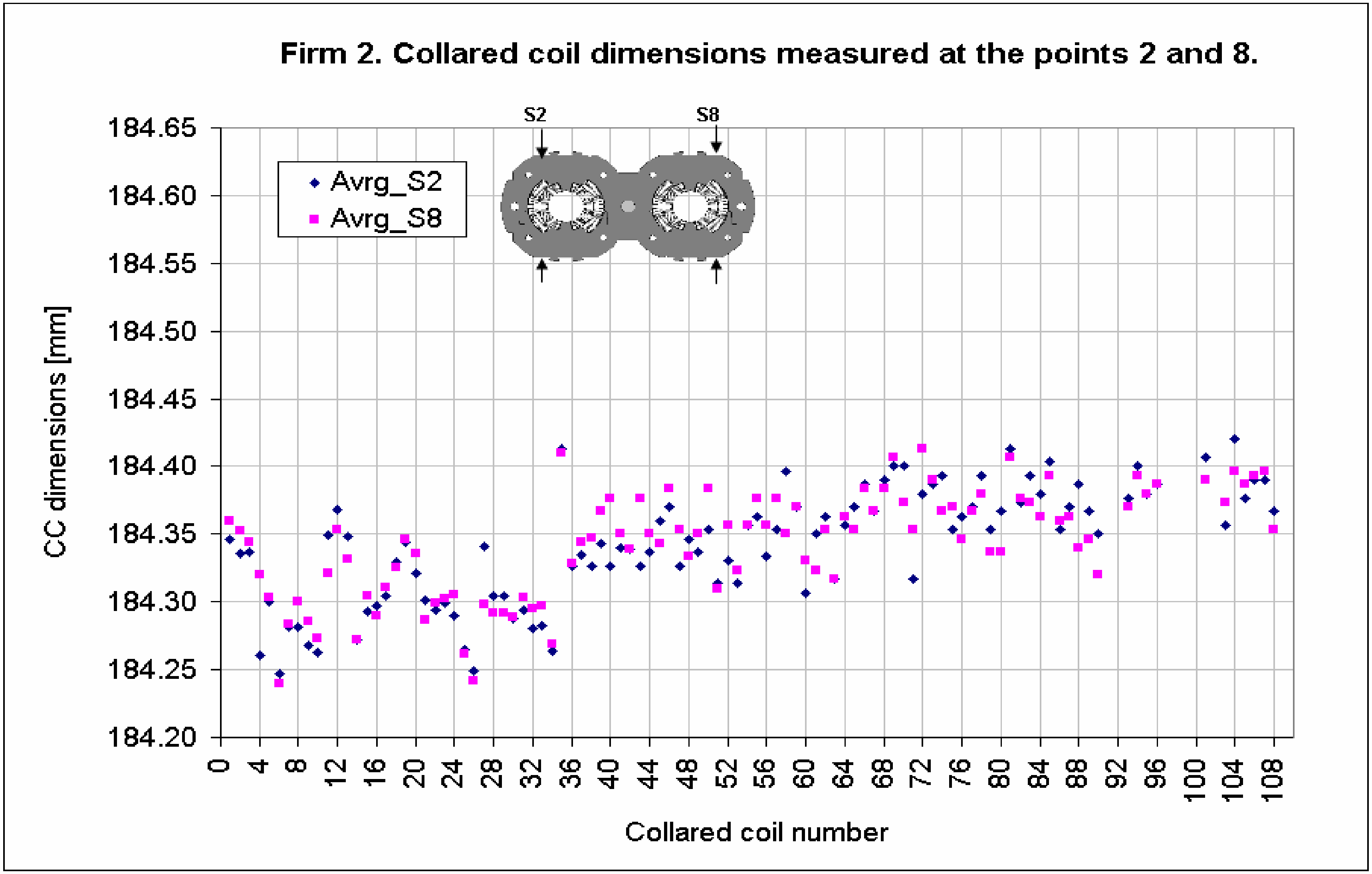

Fig. 18 Firm 2. Collared coil dimensions measured at the points S2 and S8.

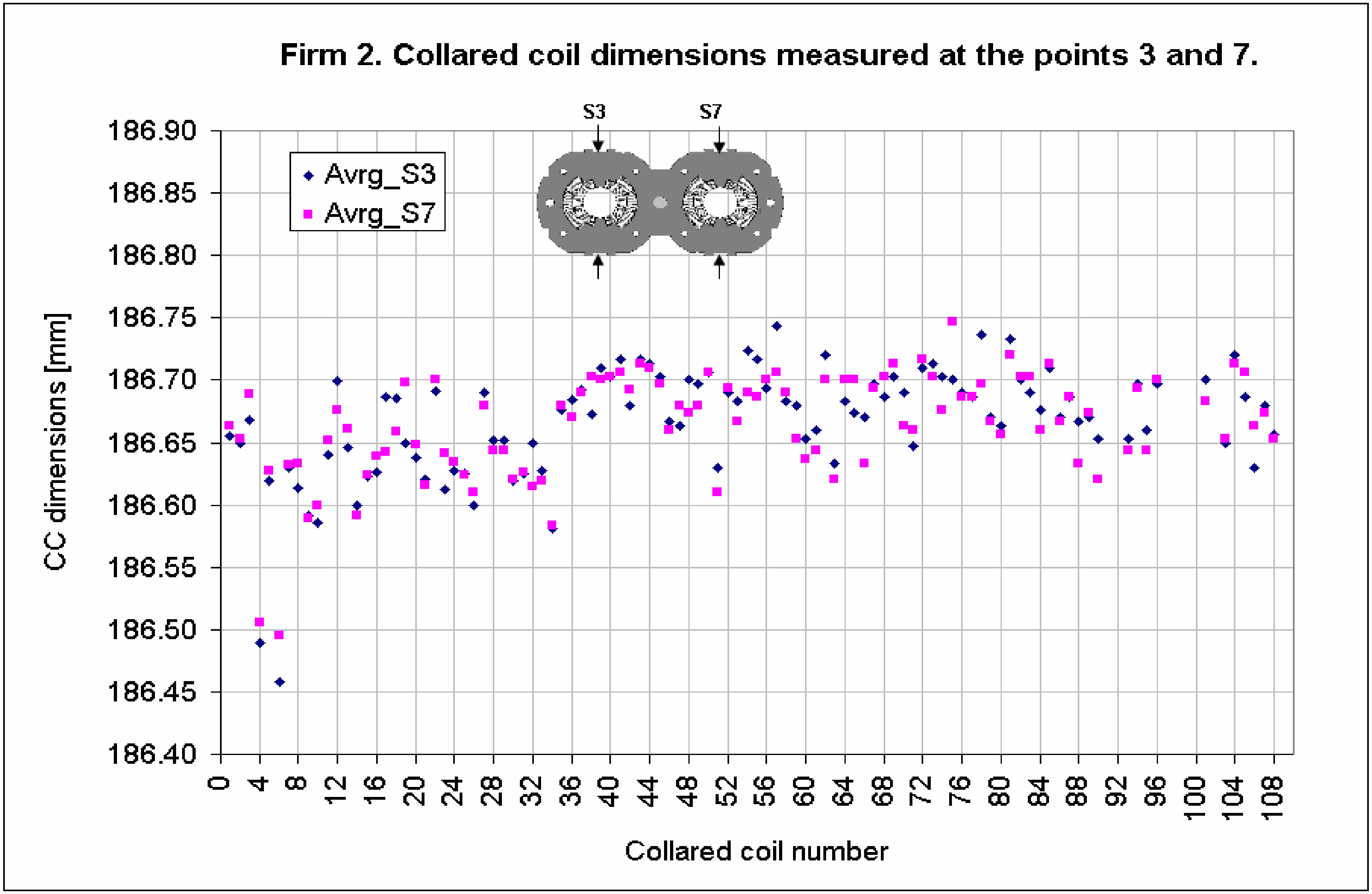

Fig. 19 Firm 2. Collared coil dimensions measured at the points S3 and S7.

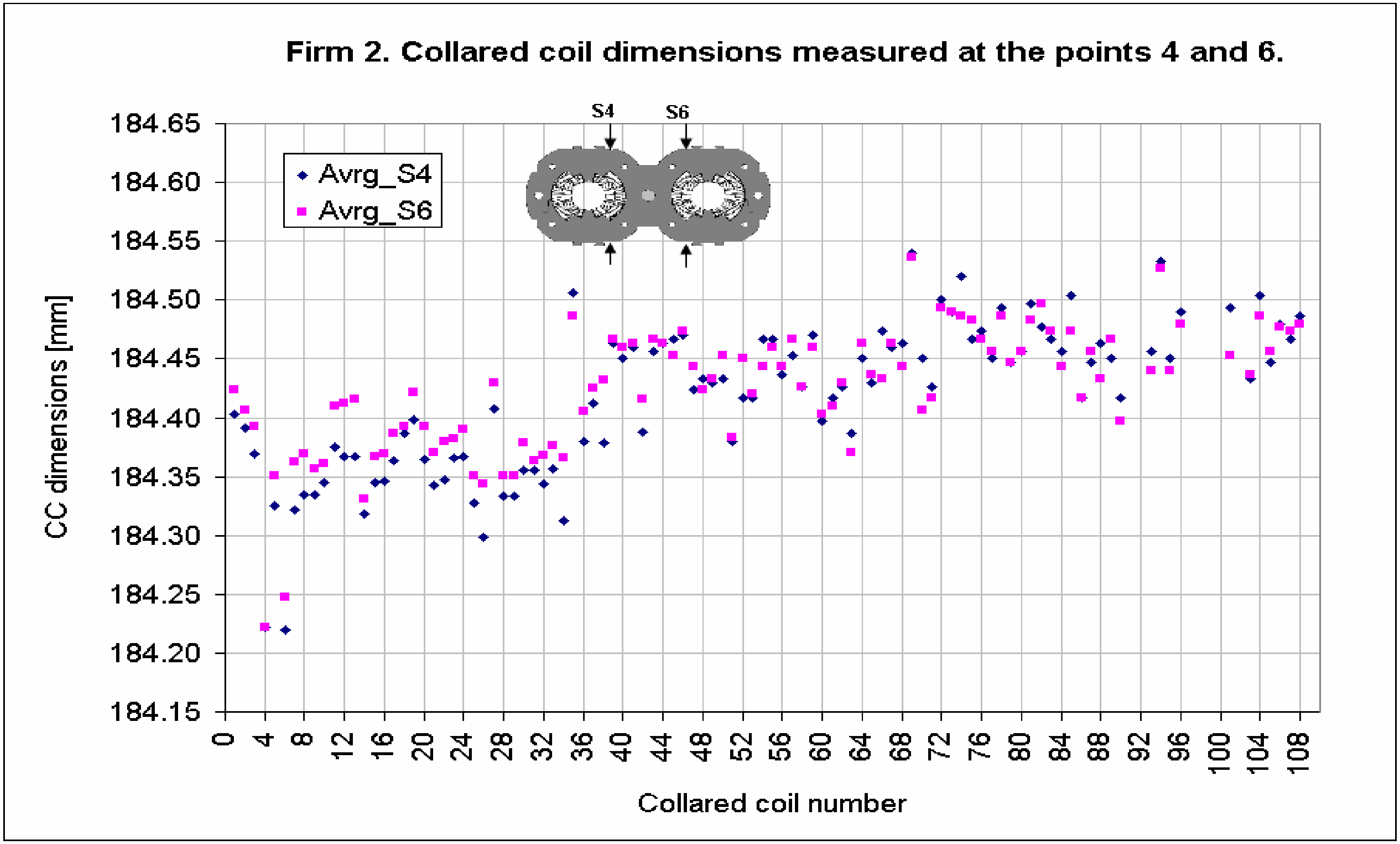

Fig. 20 Firm 2. Collared coil dimensions measured at the points S4 and S6.

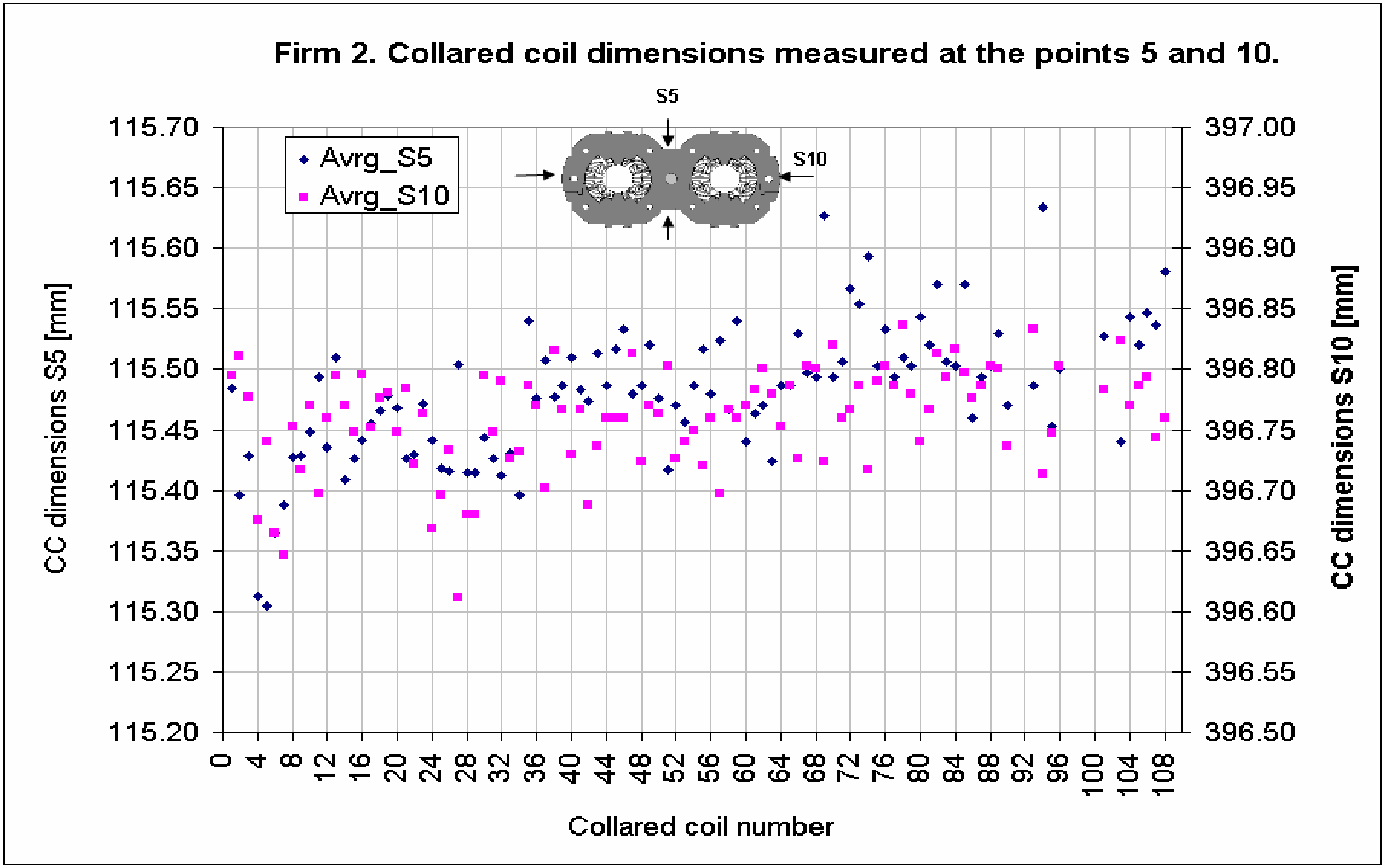

Fig. 21 Firm 2. Collared coil dimensions measured at the points S5 and S10.

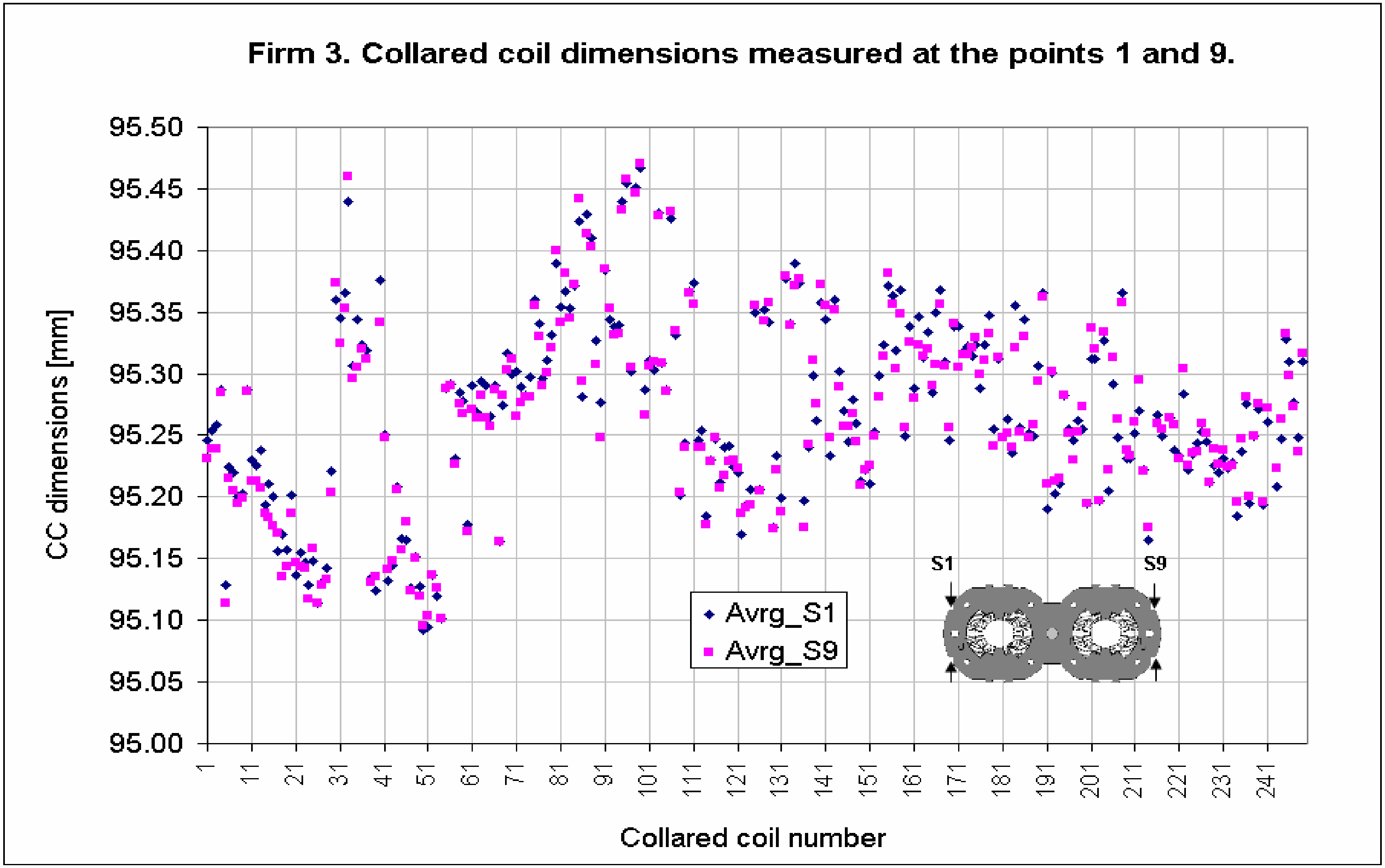

Fig. 22 Firm 3. Collared coil dimensions measured at the points S1 and S9.

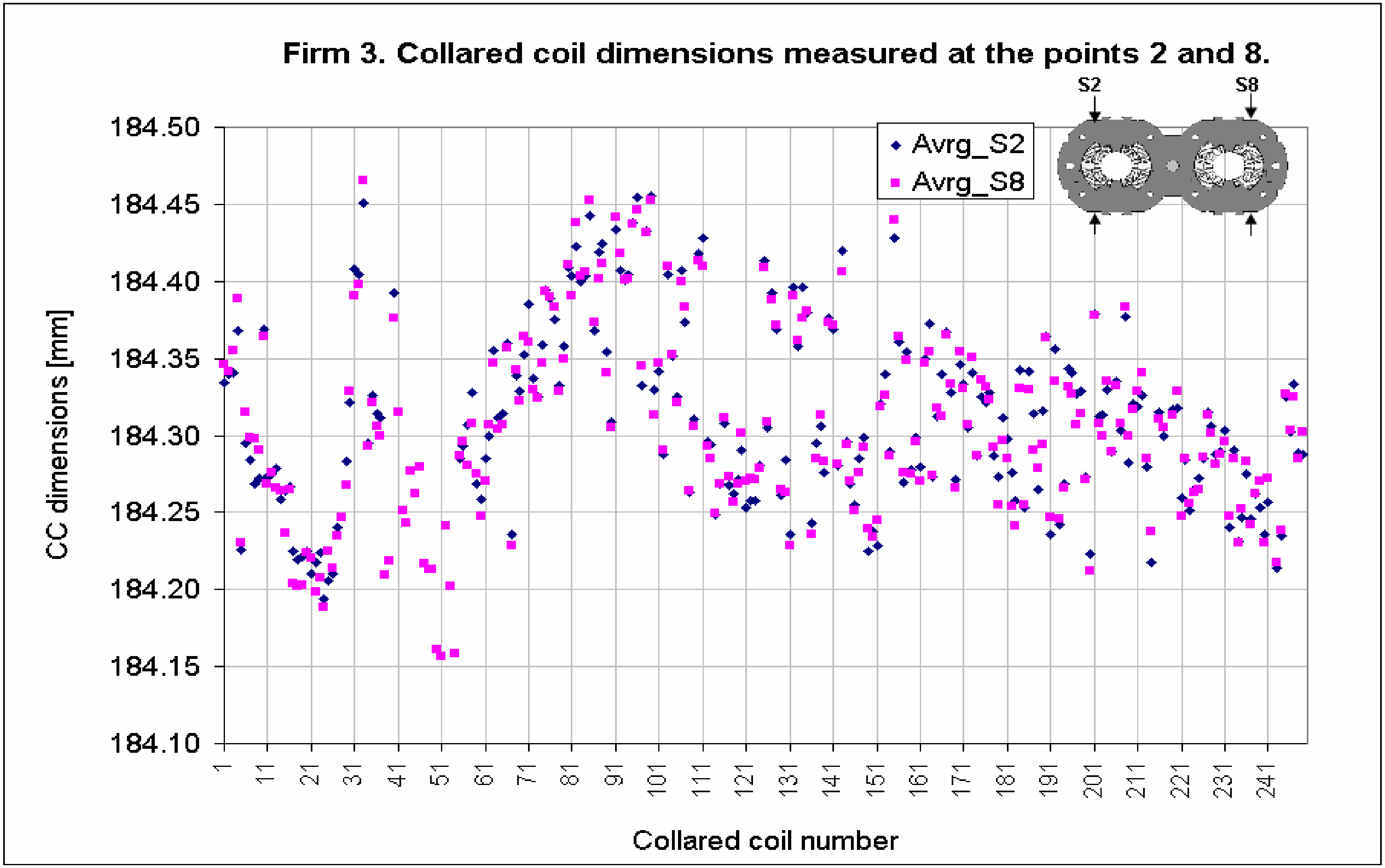

Fig. 23 Firm 3. Collared coil dimensions measured at the points S2 and S8.

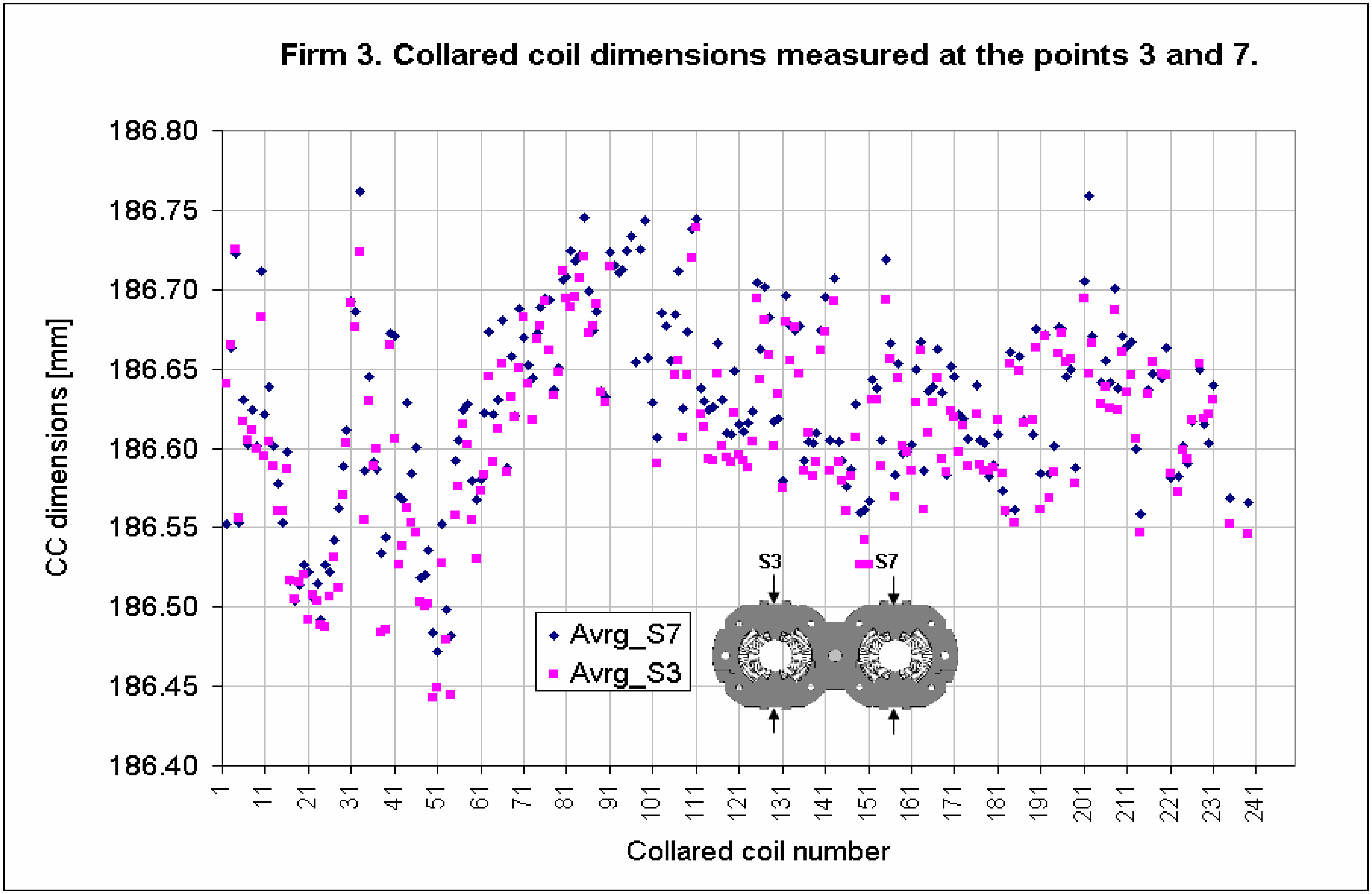

Fig. 24 Firm 3. Collared coil dimensions measured at the points S3 and S7.

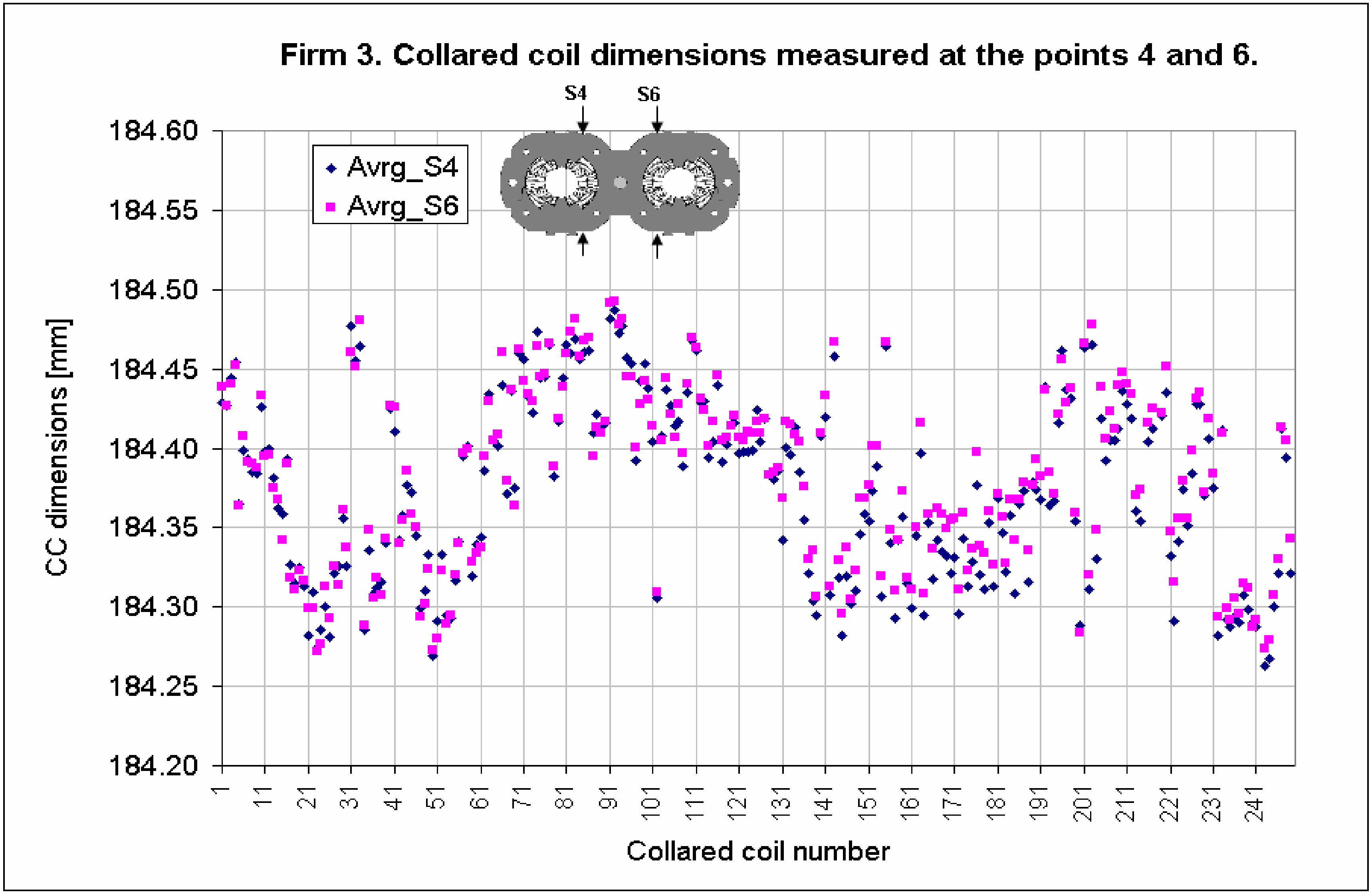

Fig. 25 Firm 3. Collared coil dimensions measured at the points S4 and S6.

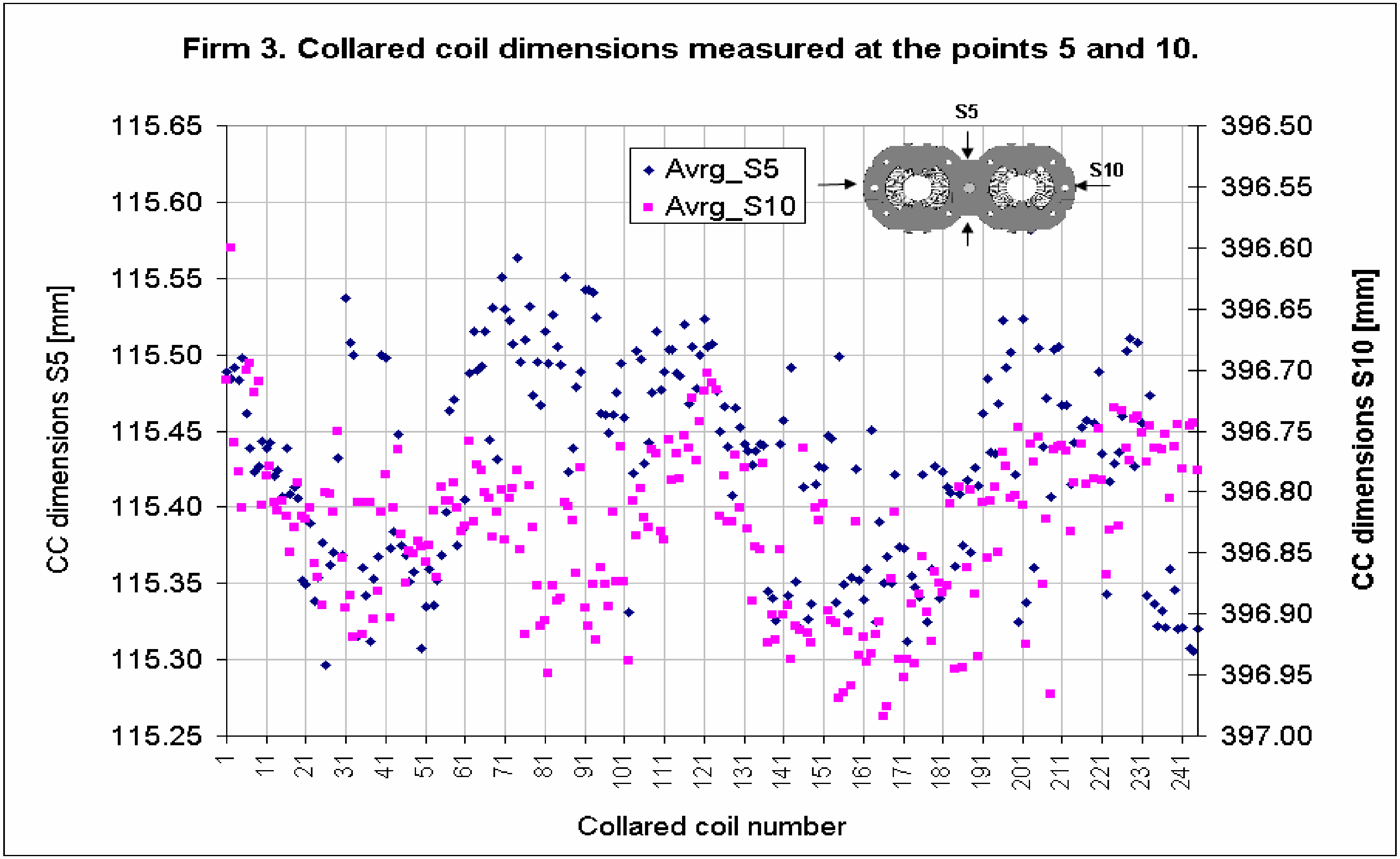

Fig. 26 Firm 3. Collared coil dimensions measured at the points S5 and S10 (notice that the scale for S10 axis is reversed).

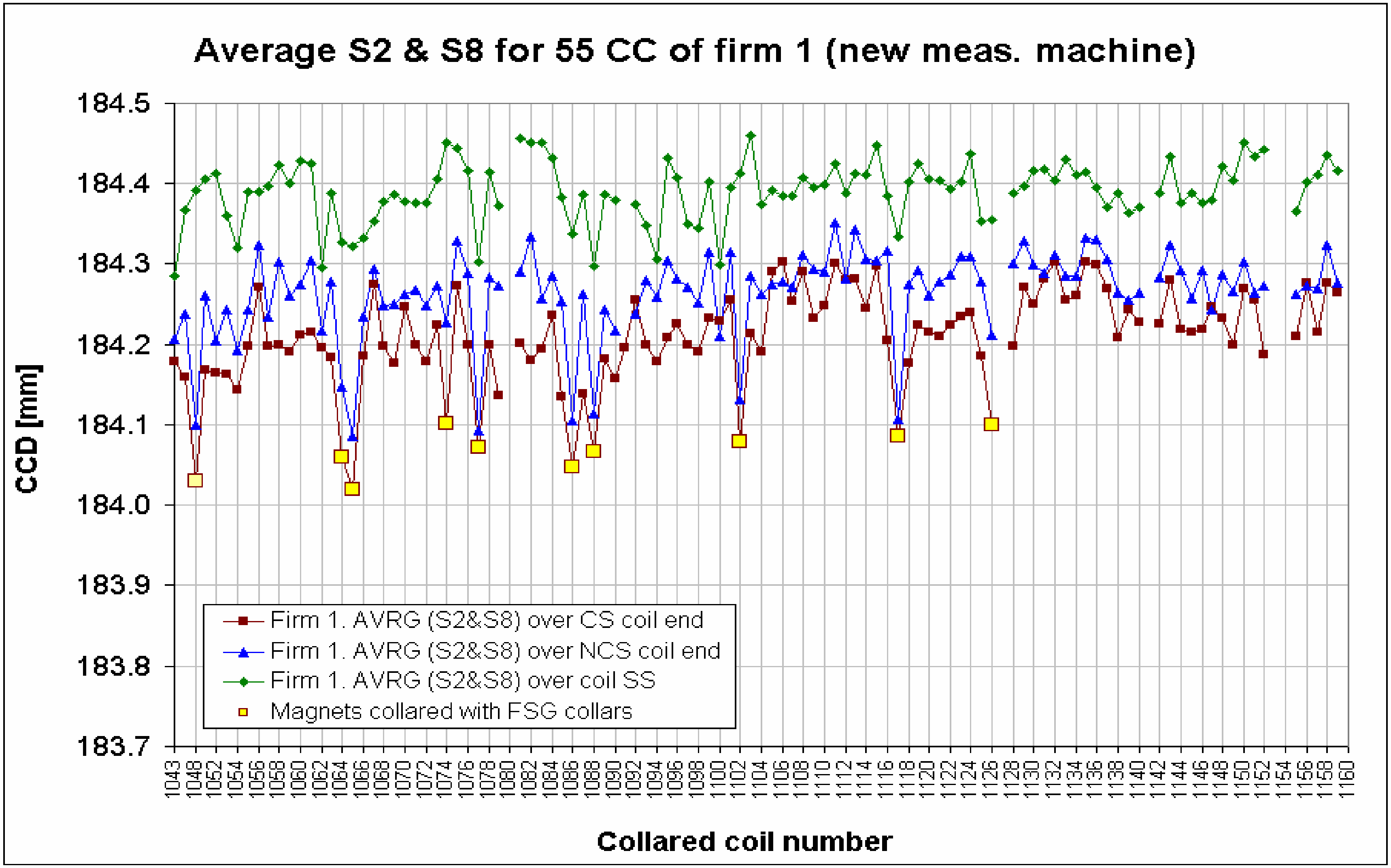

Fig. 27 Firm 1. Average of collared coil dimensions measured over coil ends and coil straight part at the points S2 and S8 (new measuring machine)

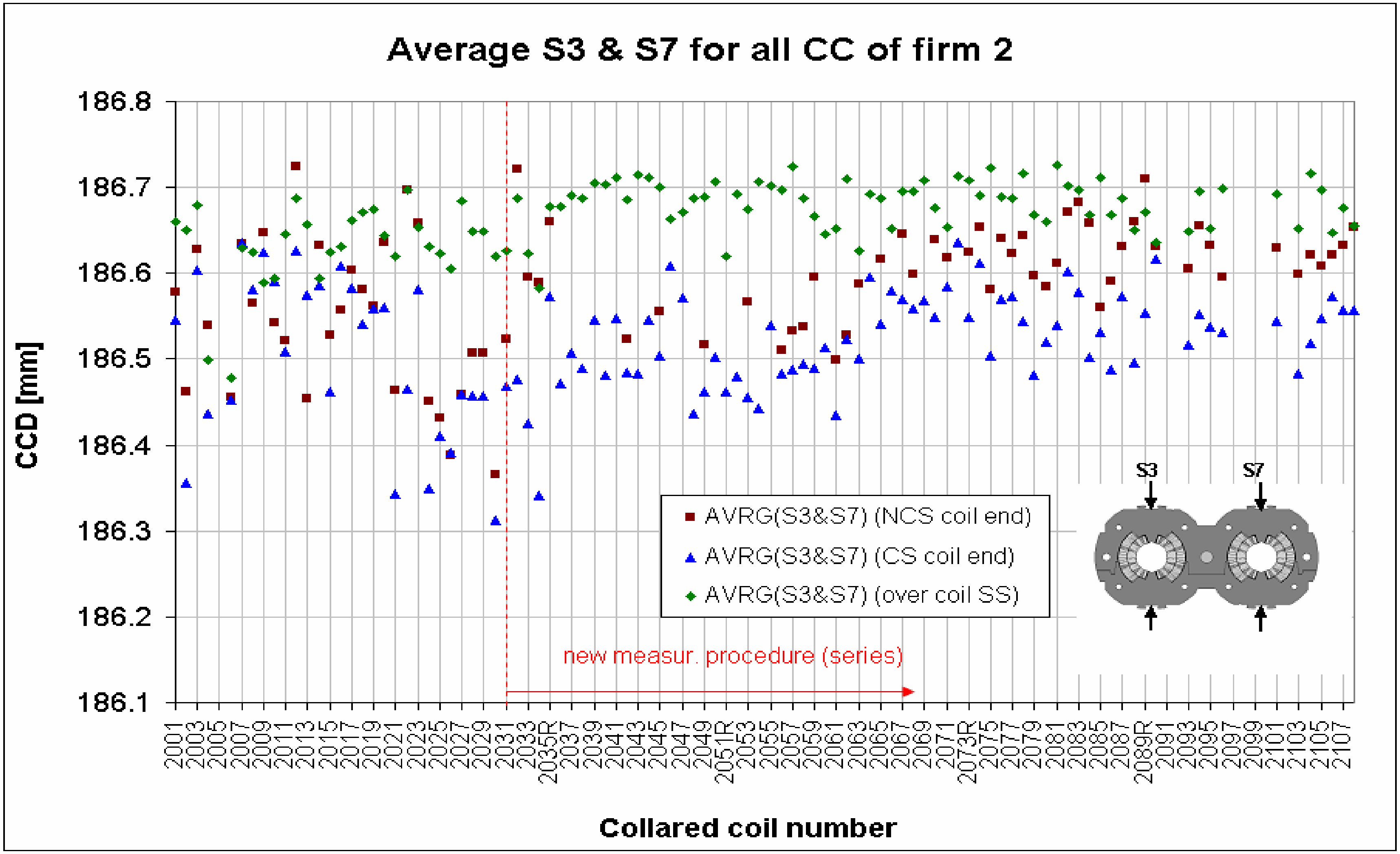

Fig. 28 Firm 2. Average of collared coil dimensions measured over coil ends and coil straight part at the points S2 and S8 (new measuring machine). For some of the magnets the measurements at NCS were done not correctly, therefore the data is not shown. Some of these magnets were re-measured and their IDs have an extension "R".

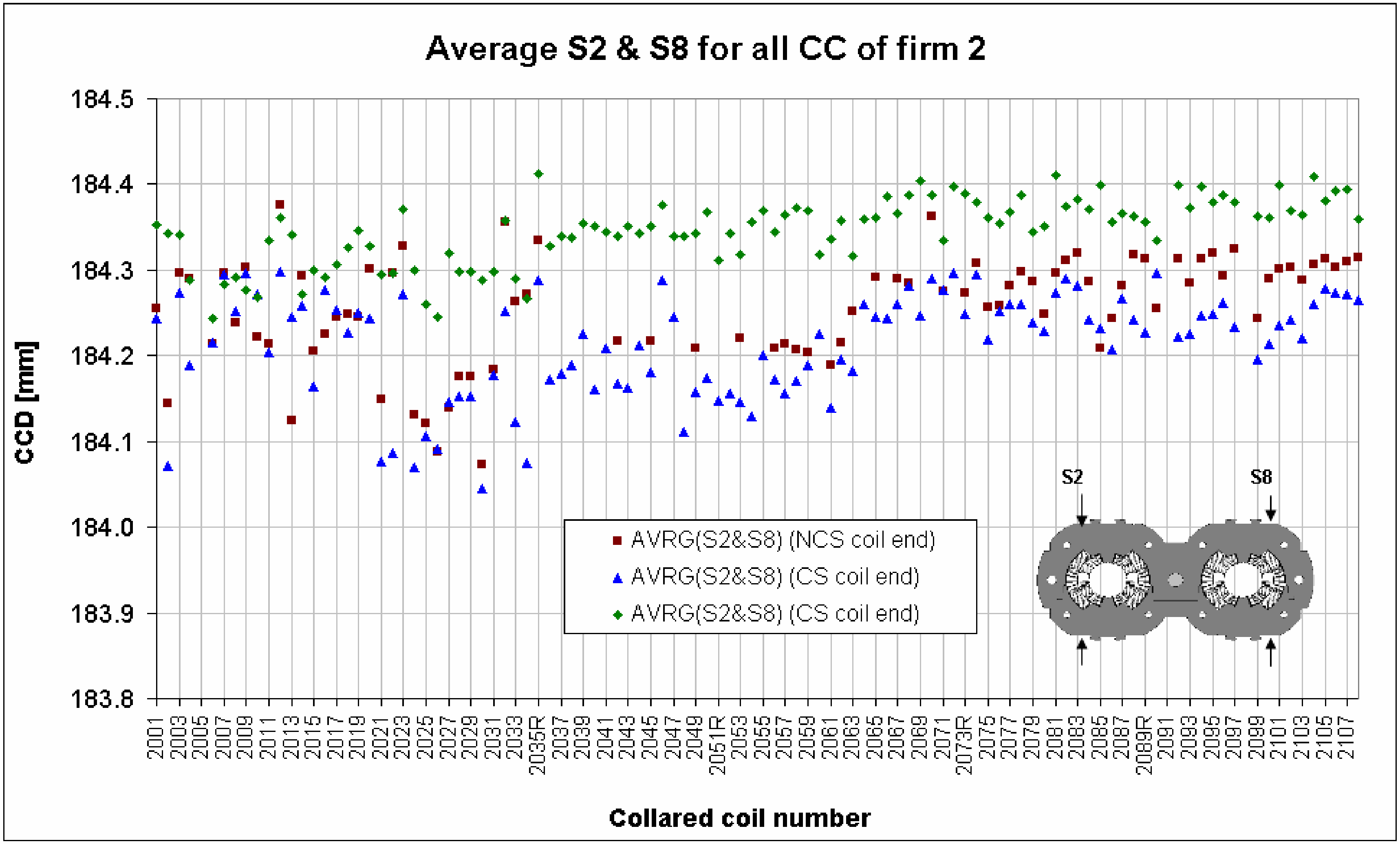

Fig. 29 Firm 2. Average of collared coil dimensions measured over coil ends and coil straight part at the points S2 and S8. For some of the magnets the measurements at NCS were done not correctly, therefore the data is not shown.

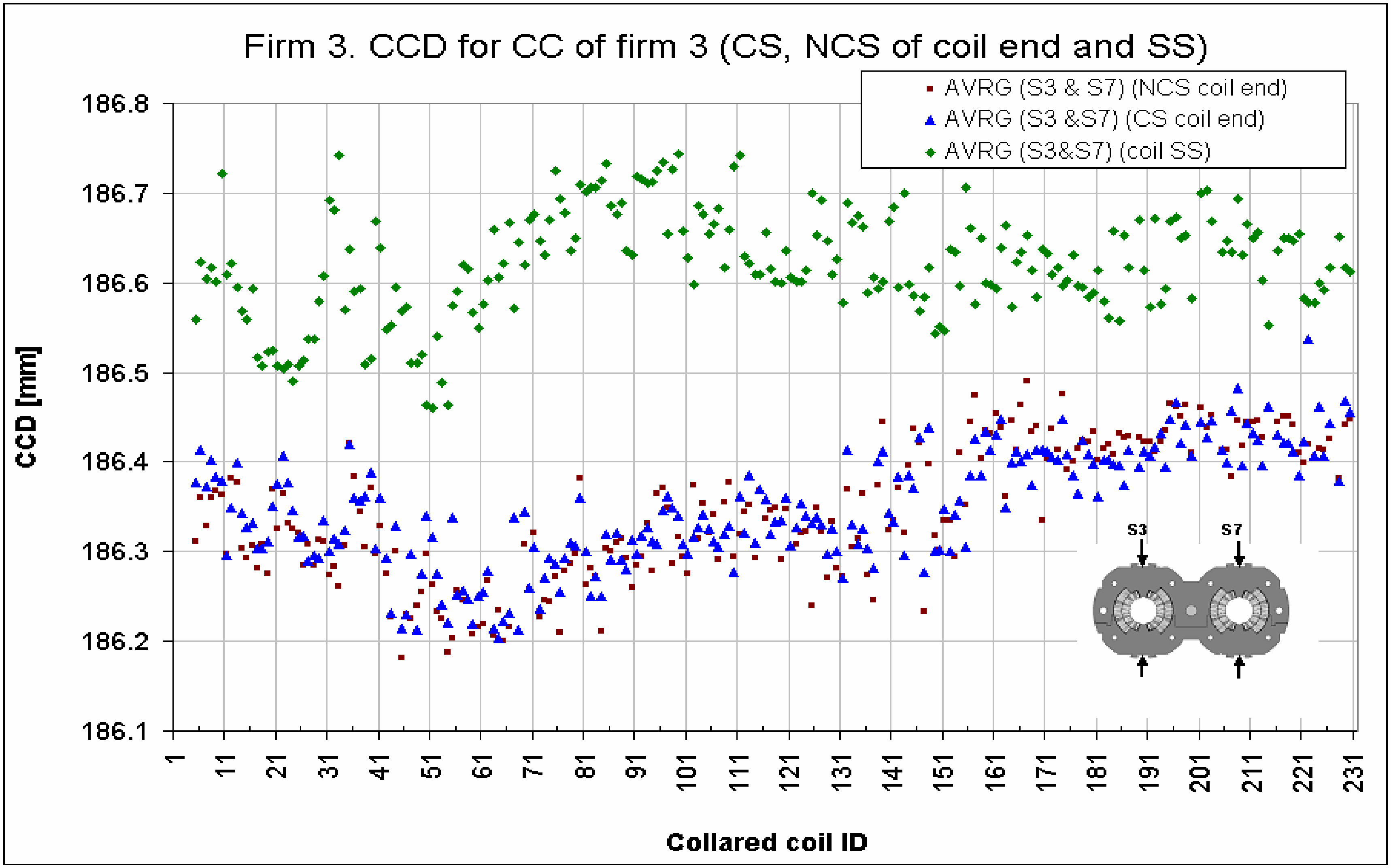

Fig. 30 Firm 3. Average of collared coil dimensions measured over coil ends and coil straight part at the points S3 and S7.

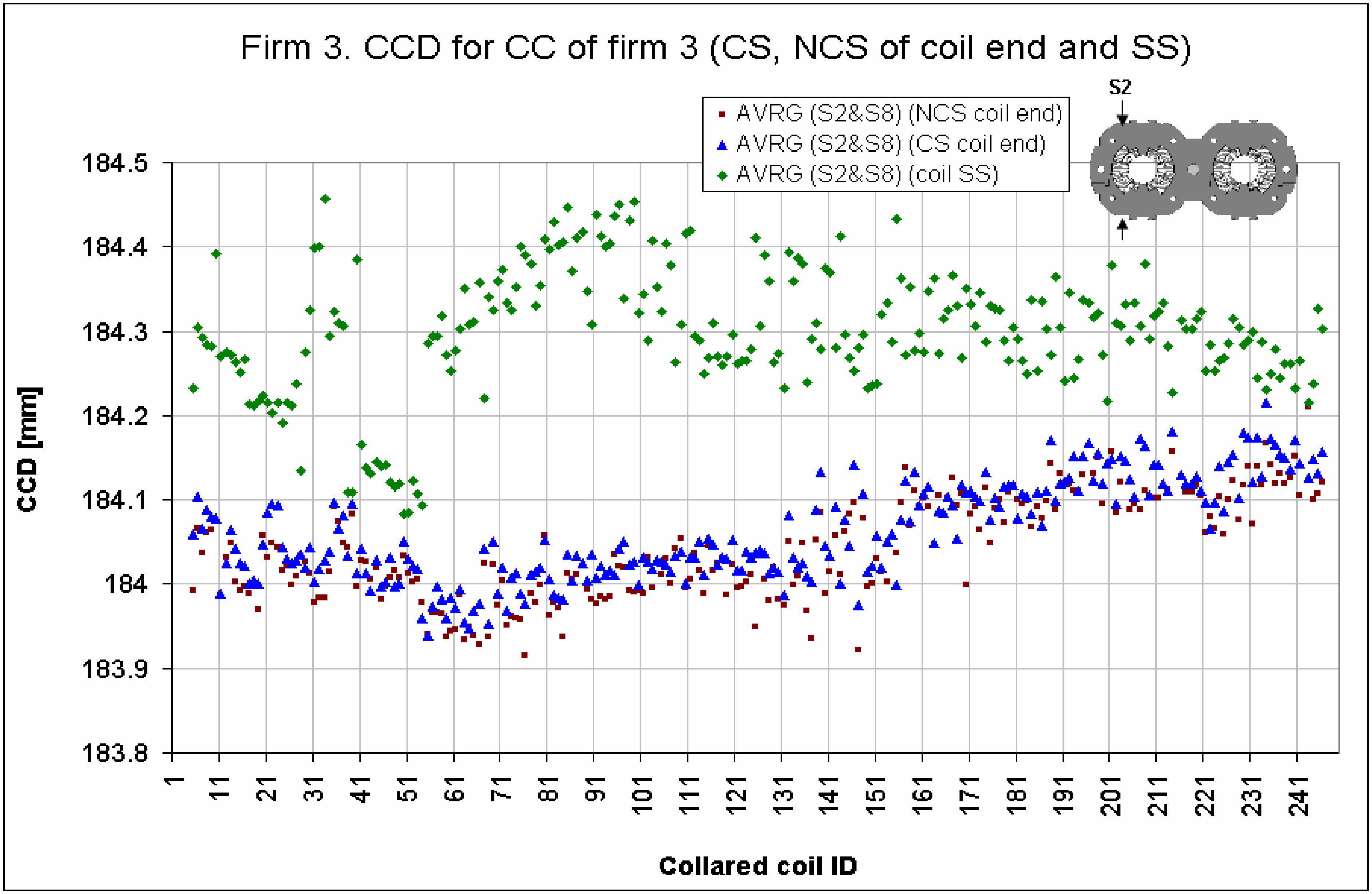

Fig. 31 Firm 3. Average of collared coil dimensions measured over coil ends and coil straight part at the points S2 and S8.

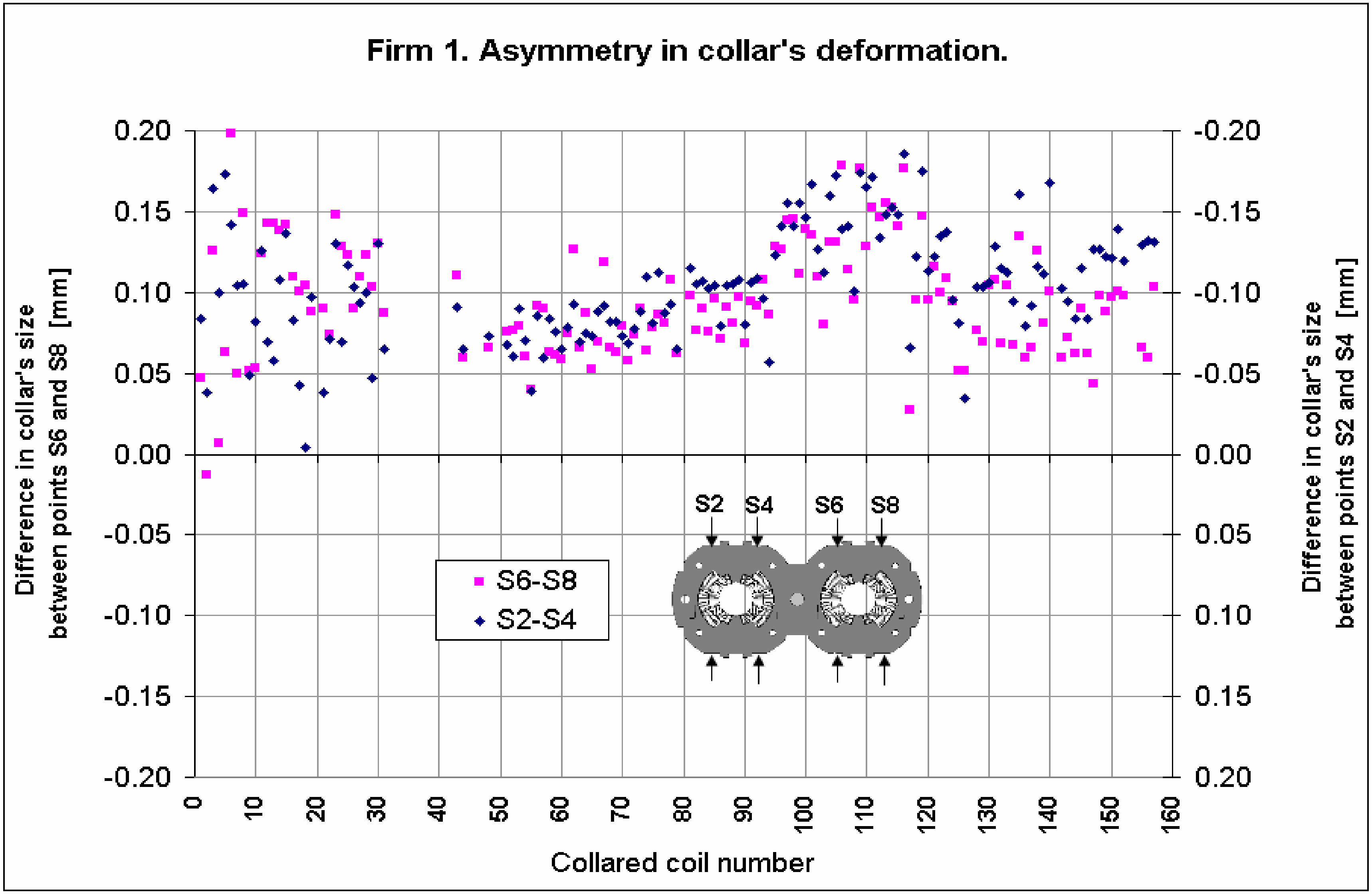

Fig. 32 Firm 1. Measured asymmetry in collared coil dimensions.

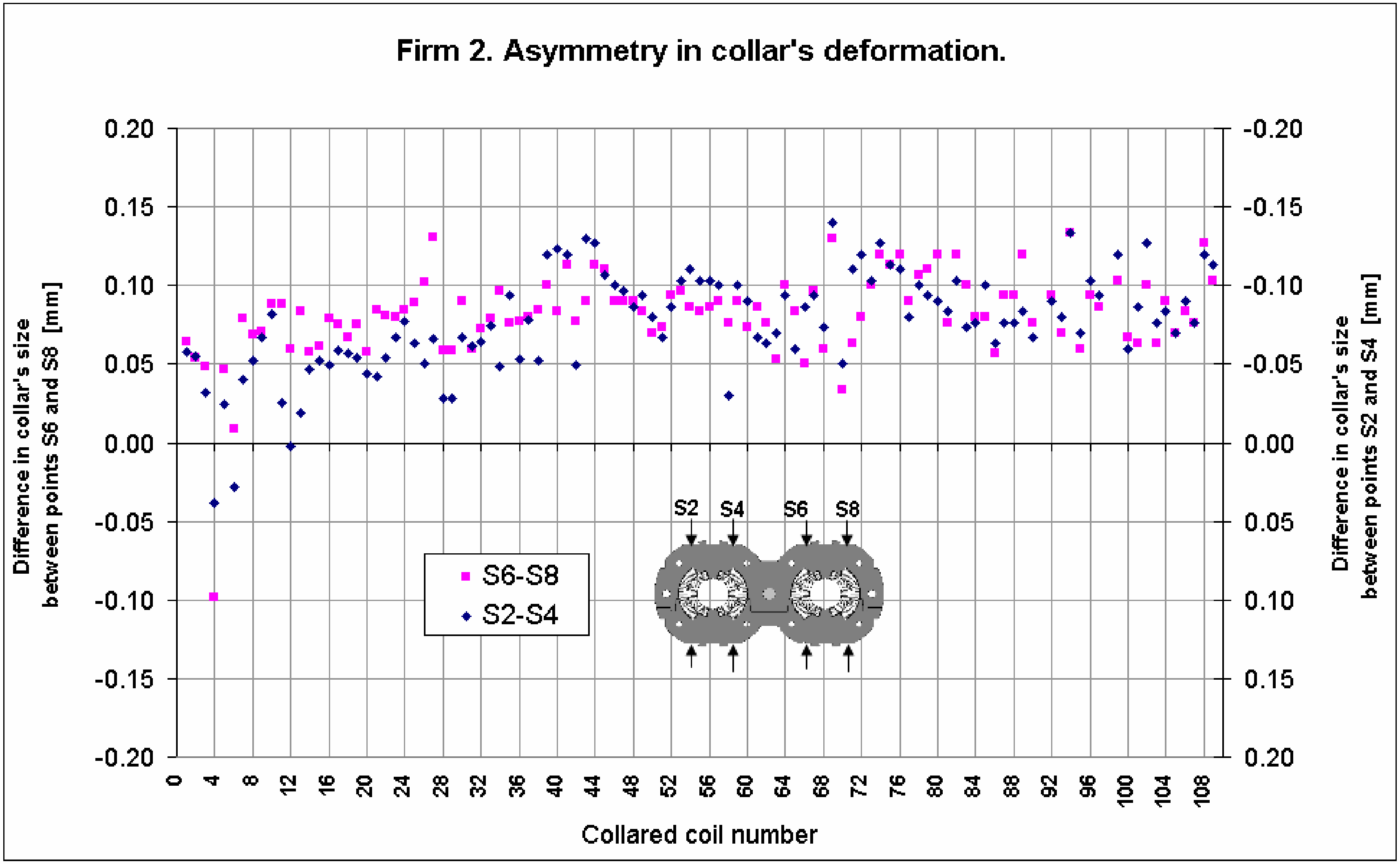

Fig. 33 Firm 2. Measured asymmetry in collared coil dimensions.

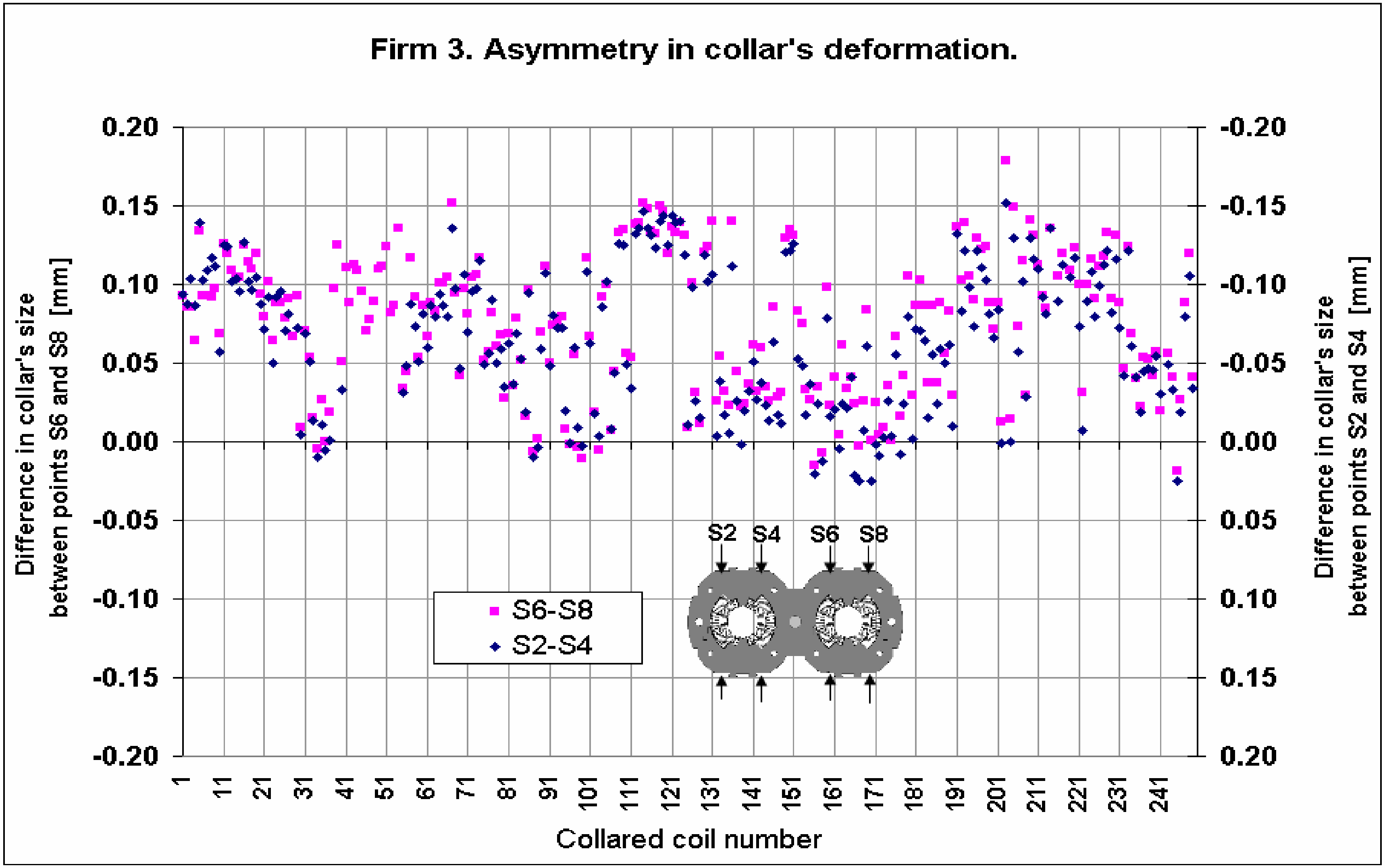

Fig. 34 Firm 3. Measured asymmetry in collared coil dimensions.