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

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

- **Firm 1 (ALSTOM-JEUMONT)** – Up to the end of June, in total 600 poles have been produced and 554 have been measured for coil size. During May-June period 68 poles were fabricated at Jeumont and half of them measured for coil size. Compared to the March-April period, the speed of coil production stay the same (8 pole sets per month, one pole set is needed for one collared coil), while the number of measured coils has been reduced by half. Now all poles are measured with reduced number of measuring sections along the coil (5 instead 15).
- **Firm 2 (ANSALDO)** – Up to the end of June, in total, about 450 inner and 440 outer layers have been produced, where 35 layers of each type in the last 2 months. Compared to the March-April period, the coil production speed is lower (~ 4,5 pole sets per month instead of 7,5. The highest production rate was achieved during January – February period: 8 pole sets per month). Up to date, 130 inner and 140 outer have been measured (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 650 inner and outer layers for 230 magnets is available at CERN (last delivery of data and of July). During May-June period 120 inner and outer layers have been produced (this corresponds to 30 magnets) and half of them were measured for coil sizes. The speed of coil production is 15 pole sets per month, which is a bit higher then during March-April period (13 pole sets per month). 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, each at 4 longitudinal positions (14 in the past).

What is new:

Trends in coil sizes. Periodic trends (with positive and negative slopes) are still present in the coils size data for firms 1 and 2, while at firm 3, after optimization of the curing shims, the amplitude of these trends has been significantly reduced it is almost twice smaller compared to others firms. Opposite, at firm 1, despite the curing shims modification, described in our previous report, the coils variation remains rather large, particularly on the outer layer.
Coil waviness. Due to significant reduction of the measuring points along the coils at firm 3, and firm 1 there is no more possibility to monitor the standard deviation of coil size along the coil for these firms. We present the graph on this parameter only for firm 2, which continues measure the coil size in 15 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, that in order to speed up the production, starting from the poles set 114 the number of measuring sections has been reduced to 5 (from 15). In figure 1 the average of all measuring points is used to show the coil size trends. Due to oversize of the coil, 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 (0.125mm). 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, the decision was taken, to minimize the use of non-nominal polar shims (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. A large random 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 3 and 4, the inner and outer layers coil sizes are plotted together with their E-modulus.

Firm 2. About 35 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), while sometime it is varied more, particularly on the outer layers. We remind, that at firm 2 starting from the inner layer № 75 (red dashed line in fig. 5) and from the outer layer № 98 (blue dashed line in fig. 5) the coils are cured with extra shims of 0.1 mm in the curing mould.
At firm 2 the coil size measurements are taken in 15 longitudinal positions along the coil (the only firm today who has kept all measuring points along the coil, two other firms are measuring at fewer positions). By measuring the coils at all positions the firm keeps control on the coil production tooling. 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 a significant trend 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 650 inner and outer layers for 230 magnets is available at CERN (last delivery of data and of July). 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 coils 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 others firms (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 we observe significant trend in the coil E-modulus data on both coil layers. Usually the trends coil size are following the trends on coil E-modulus, while this is not a case for the coils of last 15 magnets at firm 3. 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).

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. 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. More details can be found in the minutes of QWU meeting at http://lhc-div-mms.web.cern.ch/lhc-div-mms/Quench%20working%20unit/. 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 27÷32 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 27÷28 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 figures 27 and 28, the magnets, collared with collars from FSG, systematically shows smaller CC dimensions over coil ends. The investigations on the collars shape are still going on in collaboration of MA and CC sections, for tracing the source of this variance.

Firm 2. In figure 29 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 30 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 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). In figure 32 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. Compare the CCD data for three firms (figures 28 and 32) once again we notice that the CC dimensions taken over coil ends are systematically smaller for the magnets, collared with FSG collars. The difference is in order of 0.1÷0.2 mm, but starting from the CC 155, due to some changes of coil ends computation policy, the CC dimensions data has been shifted up by almost 0.1 of mm (towards higher pre-stress in coil ends). Worth to mention that there is also an improvement in quench performance has been noticed for magnets, starting from the magnet 160 (1).

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 33÷35 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.

(1) P. Fessia, private communications.

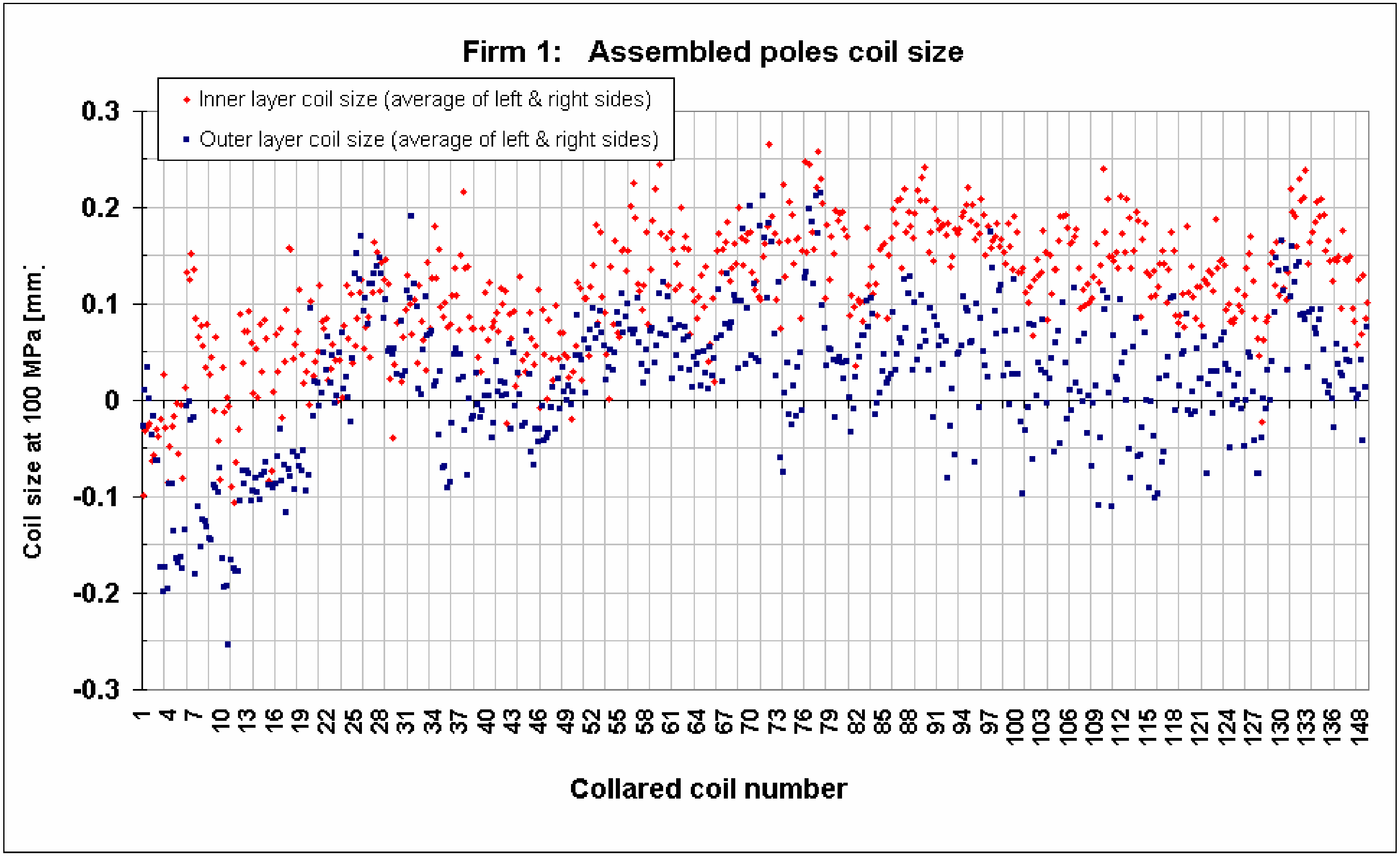

Fig. 1 Firm 1. Average coil size in the straight part of the assembled poles (554 poles).

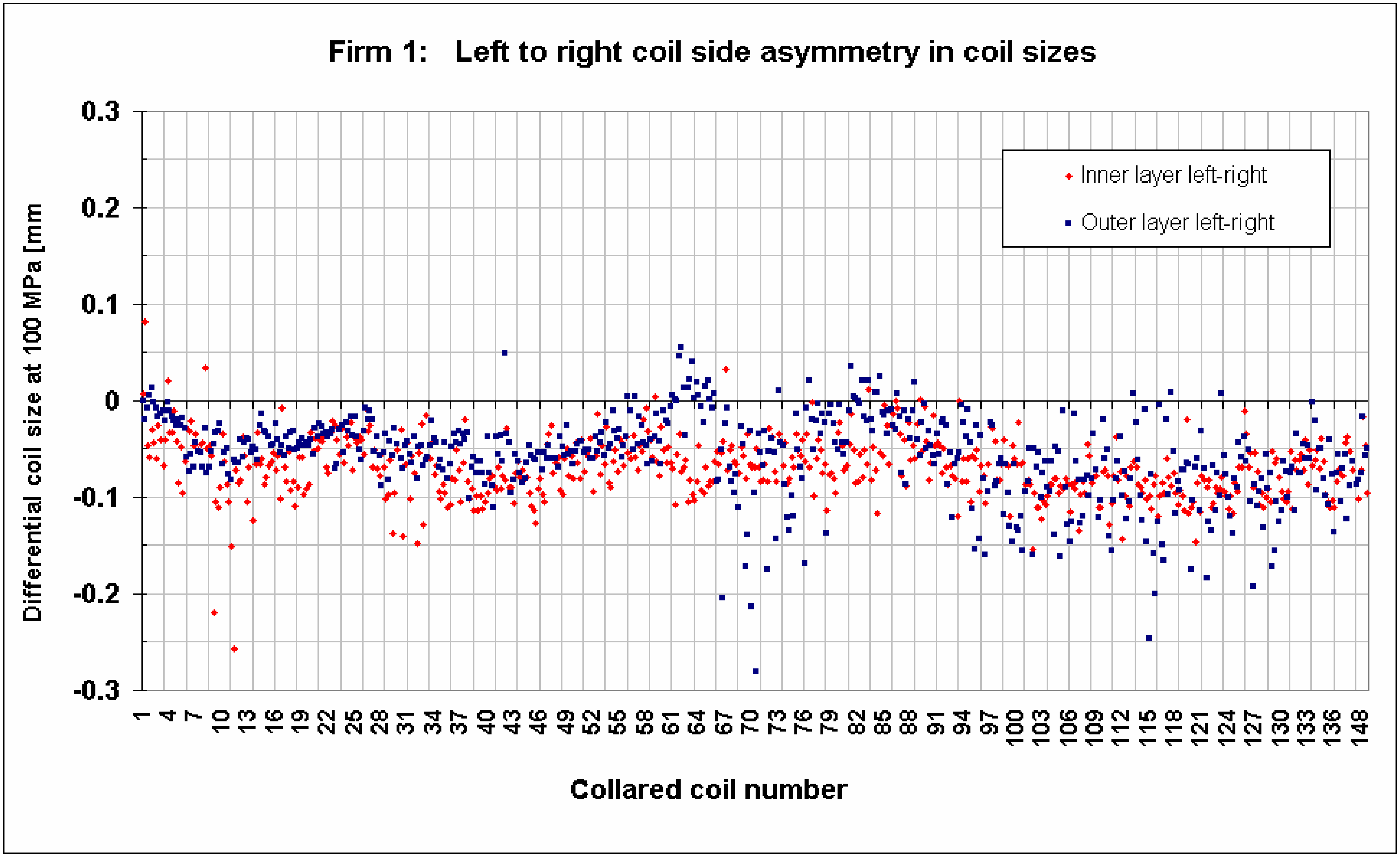

Fig. 2 Firm 1. Difference in the coil size between left and right sides of the coil on both layers.

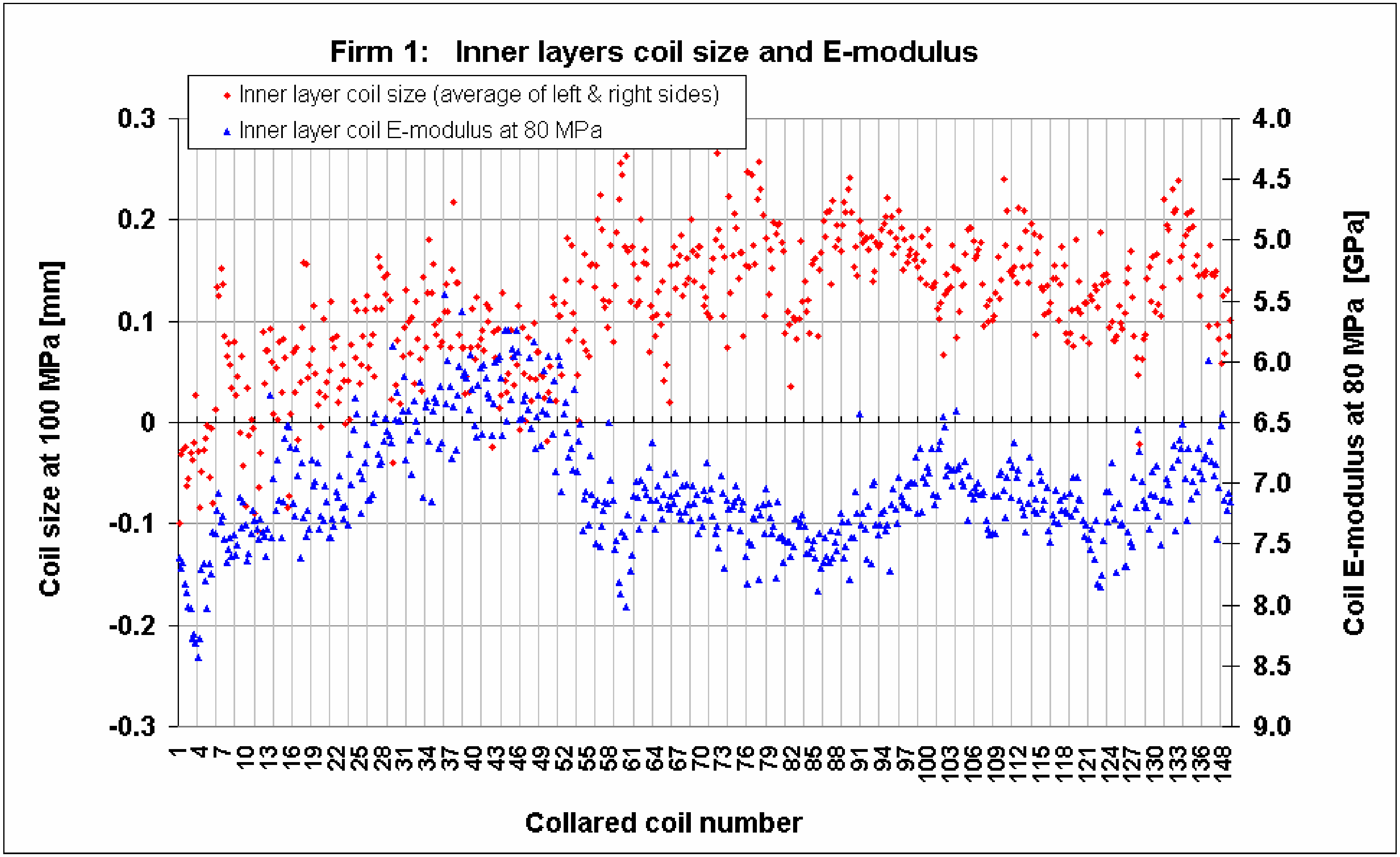

Fig. 3 Firm 1. Inner layer coil size (average) and E-modulus computed at 80 MPa. (Data extracted from pole size measurements).

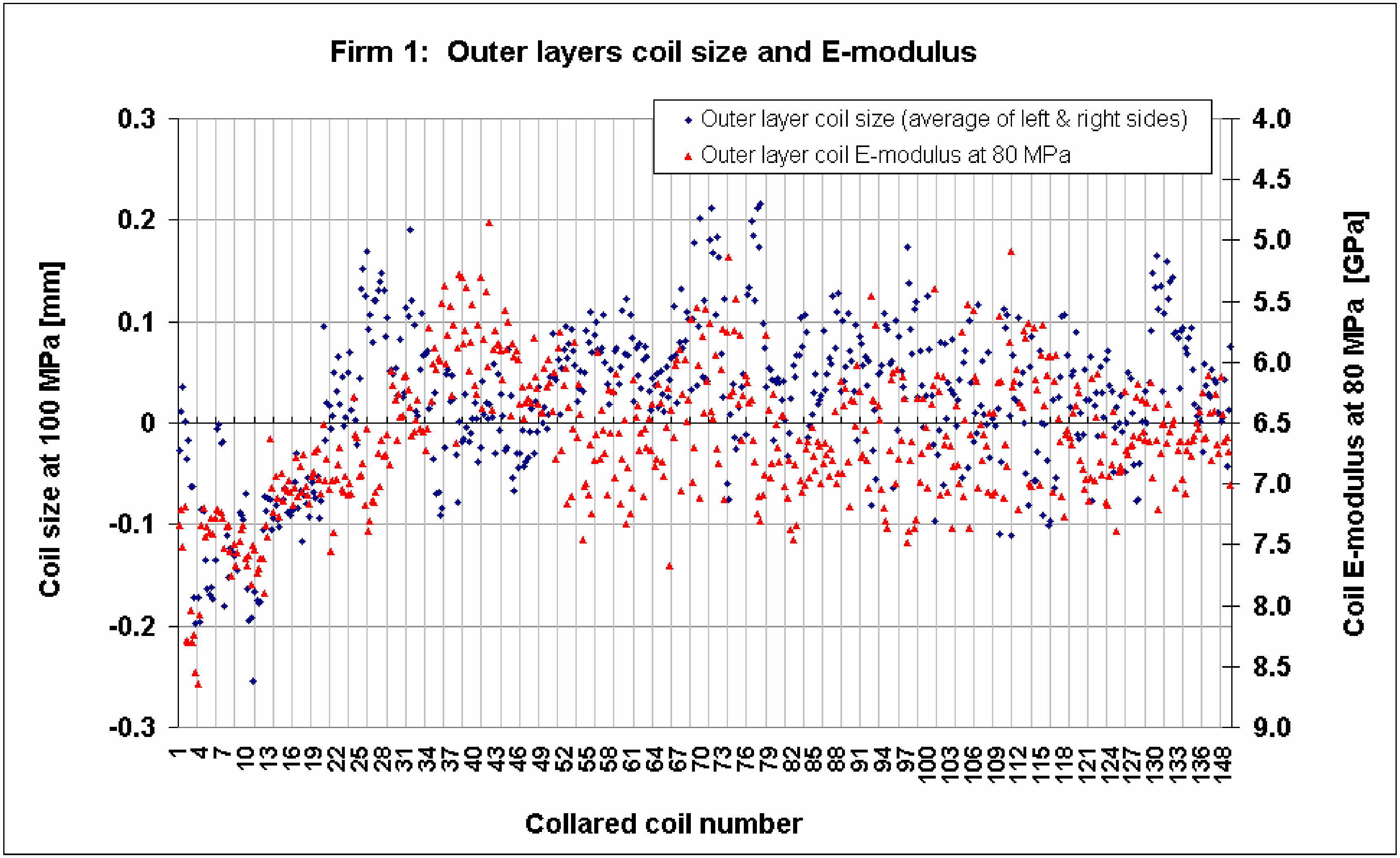

Fig. 4 Firm 1. Outer layer coil size (average) and E-modulus computed at 80 MPa.
(Data extracted from pole size measurements).

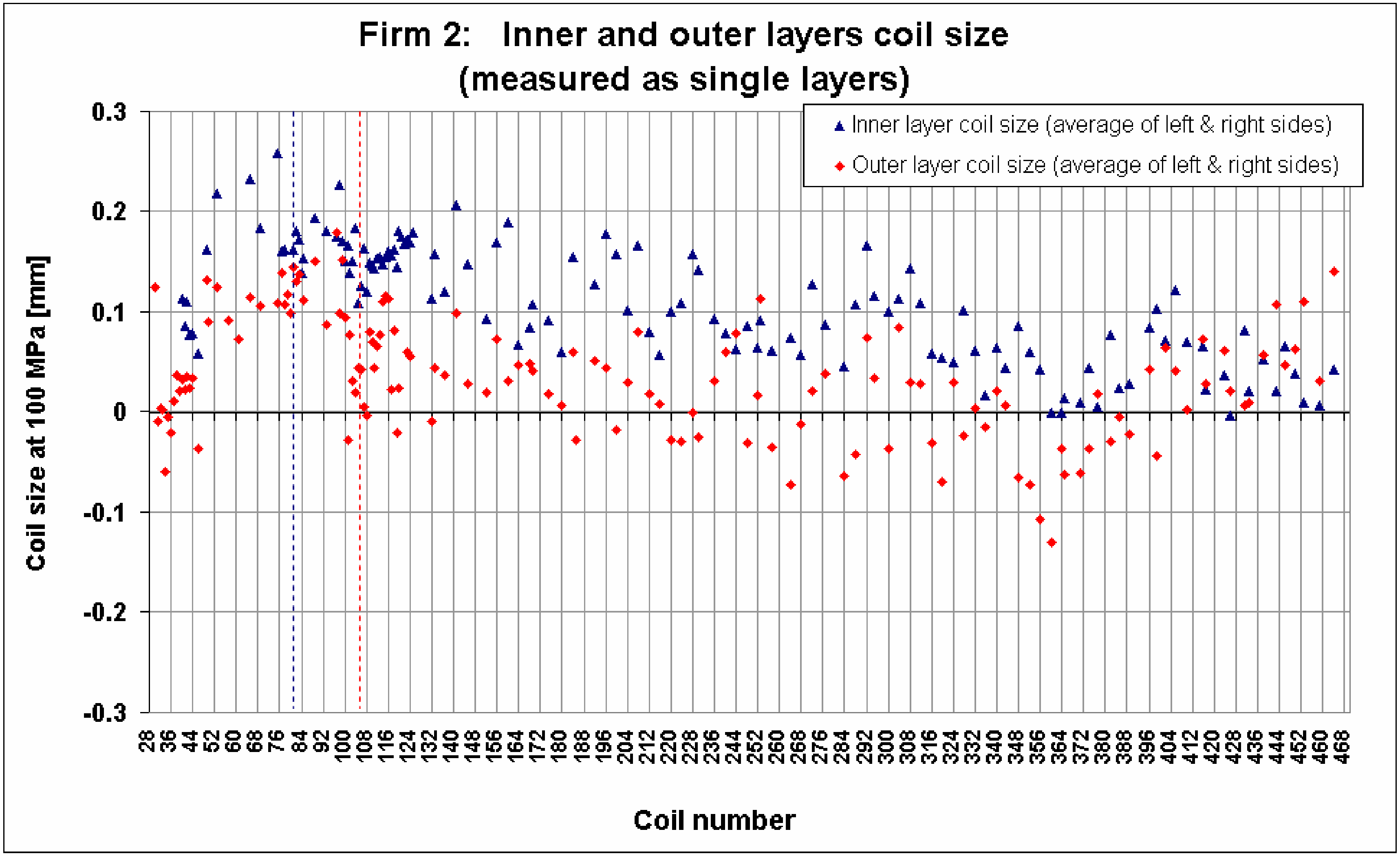

Fig. 5 Firm 2. Average coil size in the straight part of the inner and outer layers.

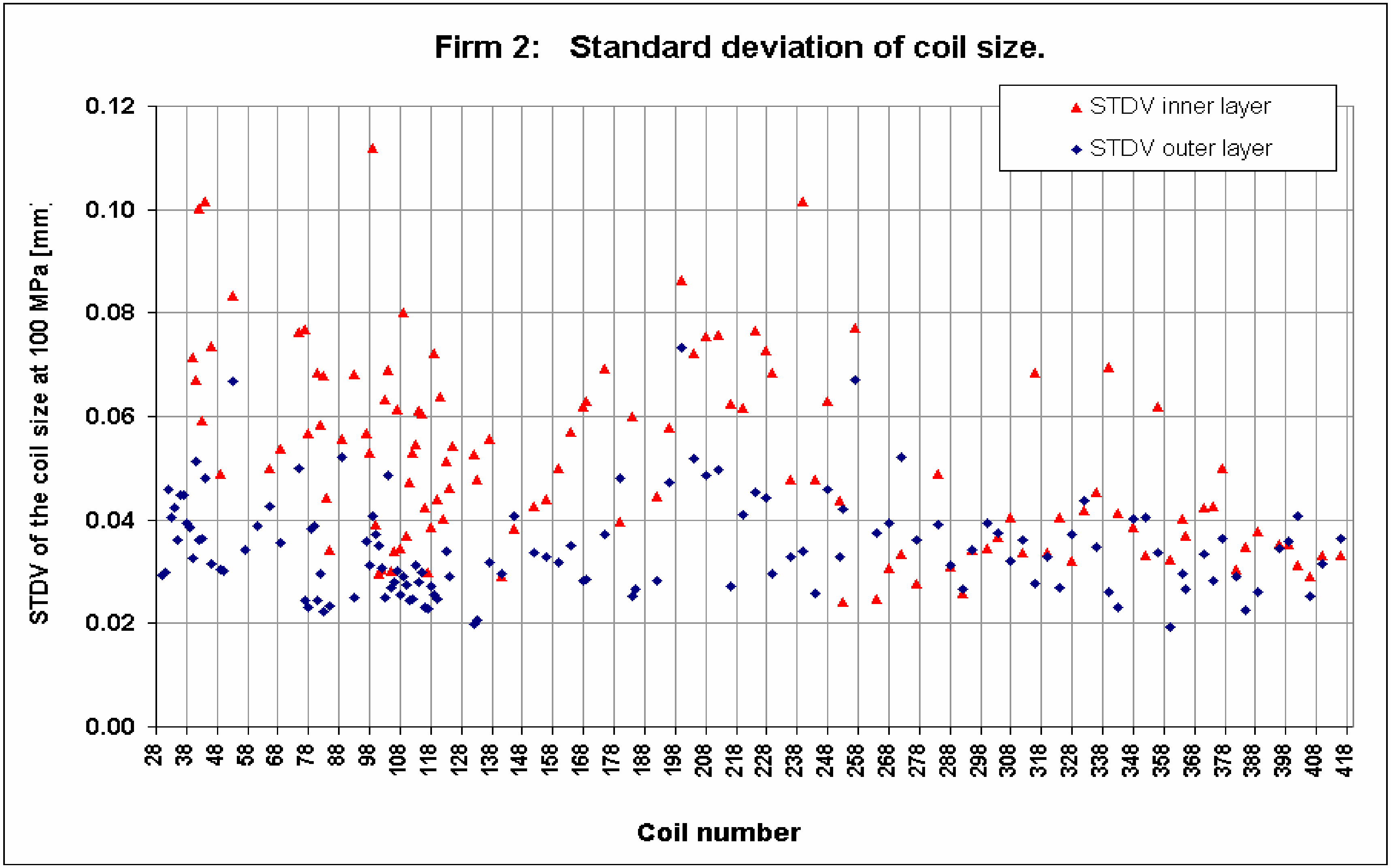

Fig. 6 Firm 2. Standard deviation of coil sizes measured in 15 positions along the coil (left and right coil sides in average).

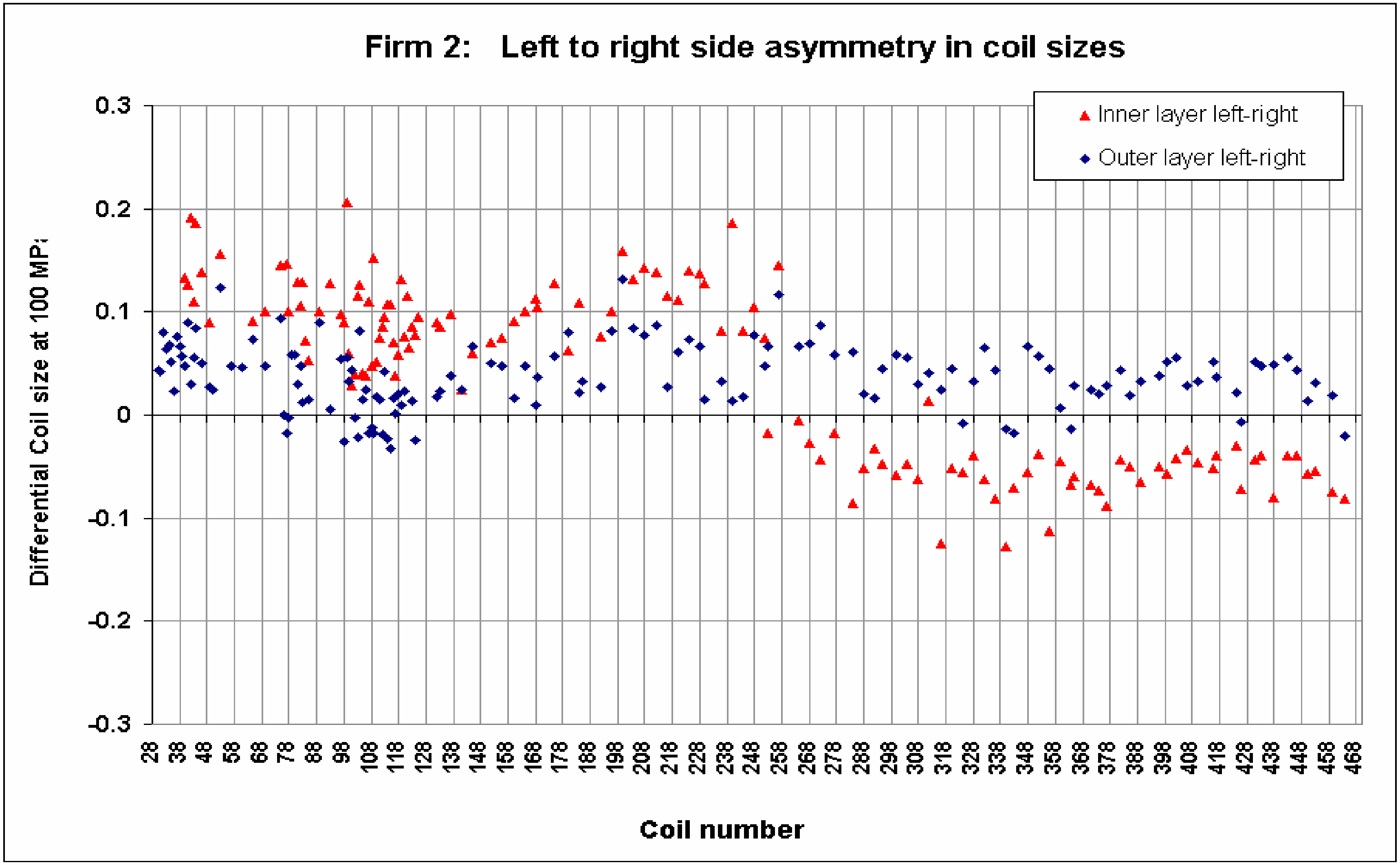

Fig. 7 Firm 2. Difference in the coil size between left and right sides of the coil on both layers.

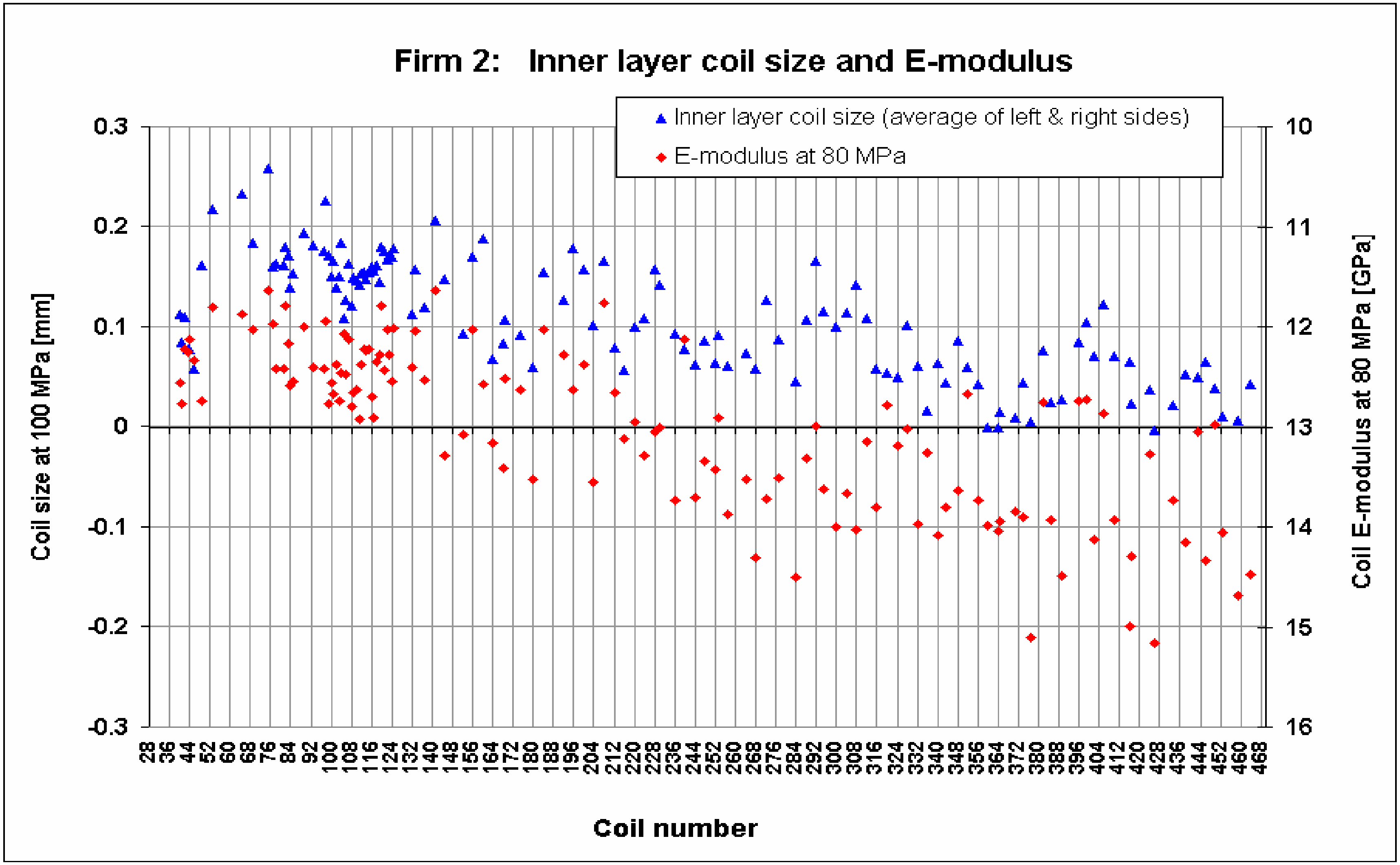

Fig. 8 Firm 2. Inner layer coil size (average) and E-modulus computed at 80 MPa.

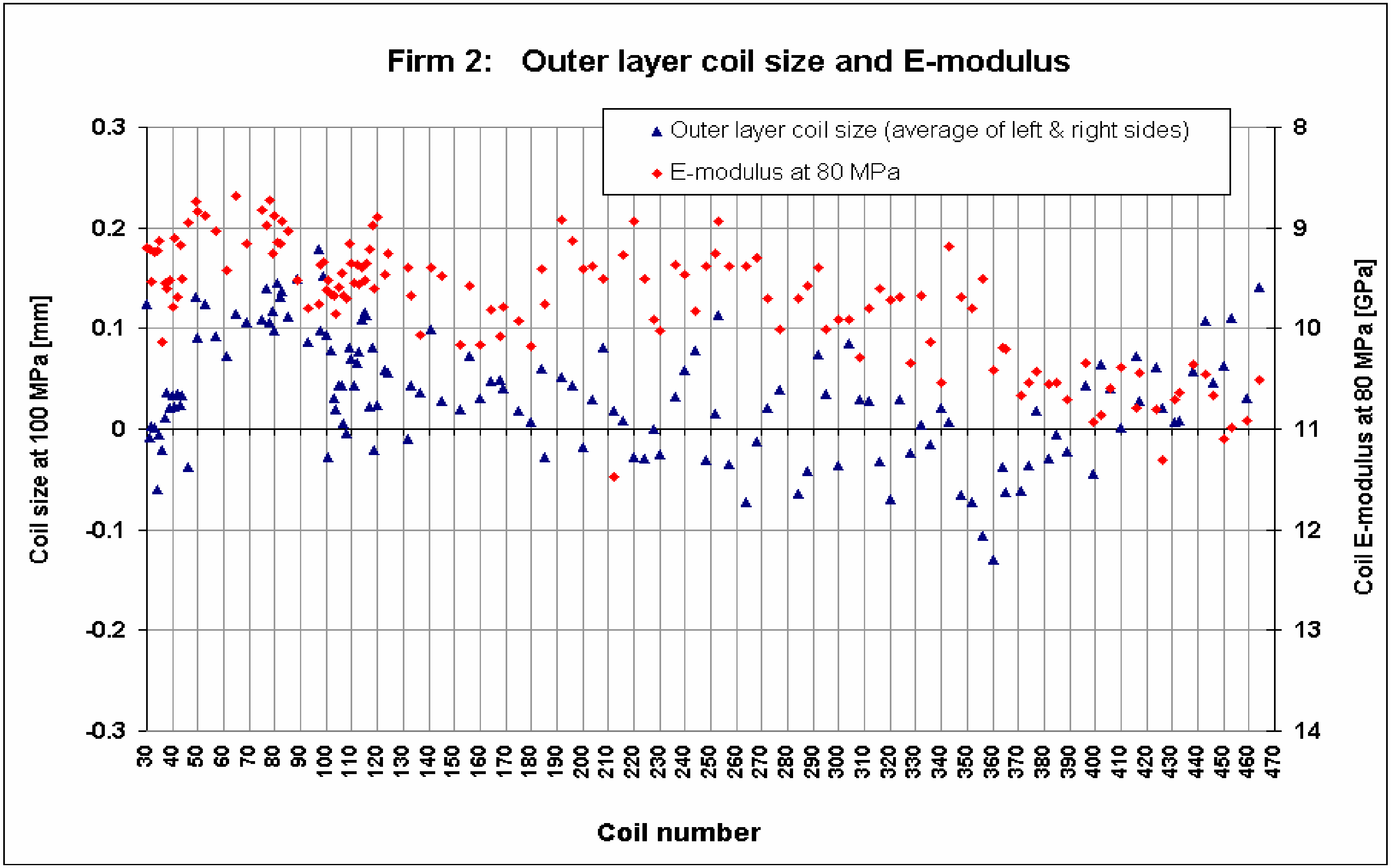

Fig. 9 Firm 2. Outer layer coil size (average) and E-modulus computed at 80 MPa.

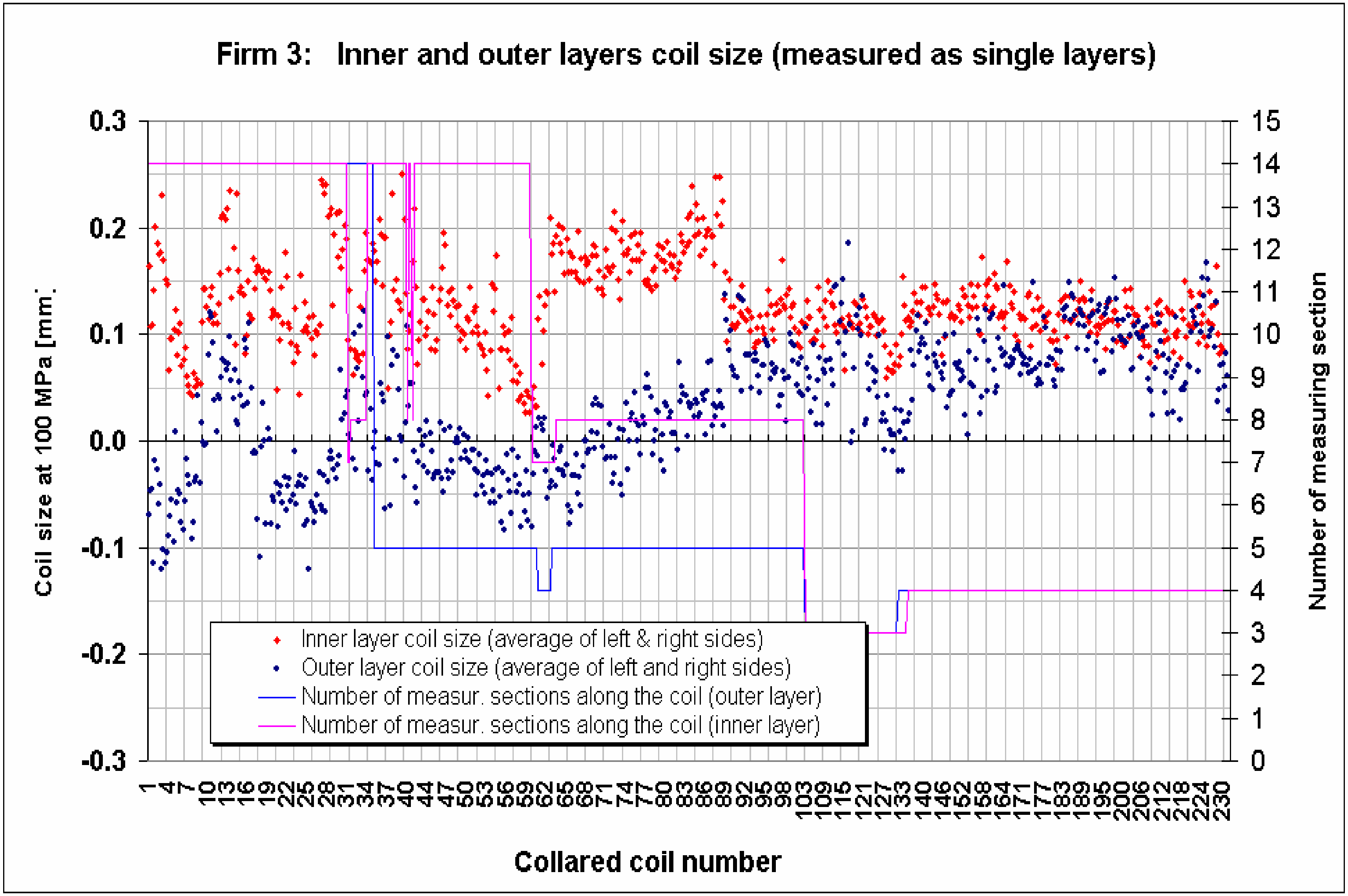

Fig. 10 Firm 3. Average coil size in the straight part of inner and outer layers.

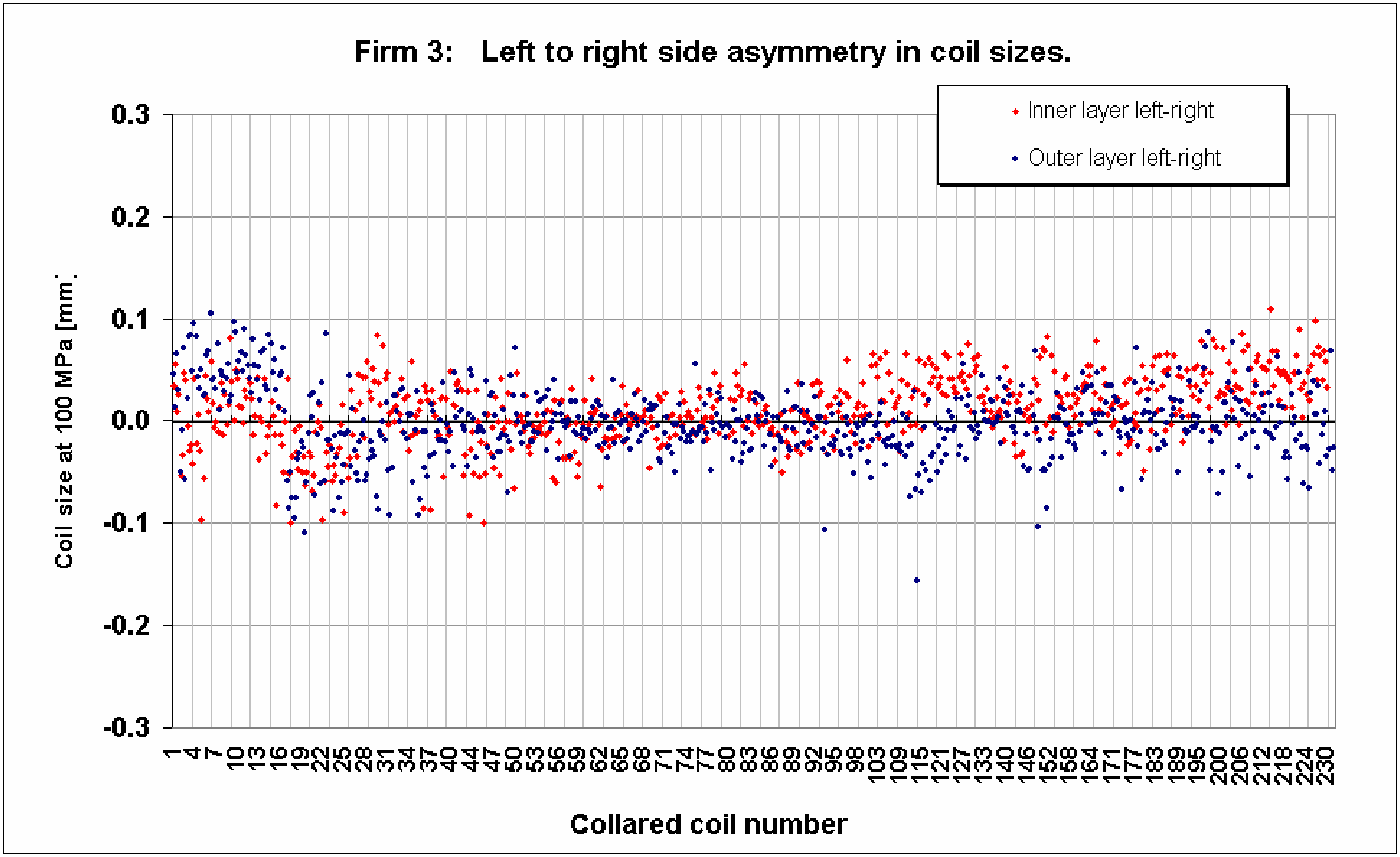

Fig.11 Firm 3. Difference in the coil size between left and right side of the coil on both layers.

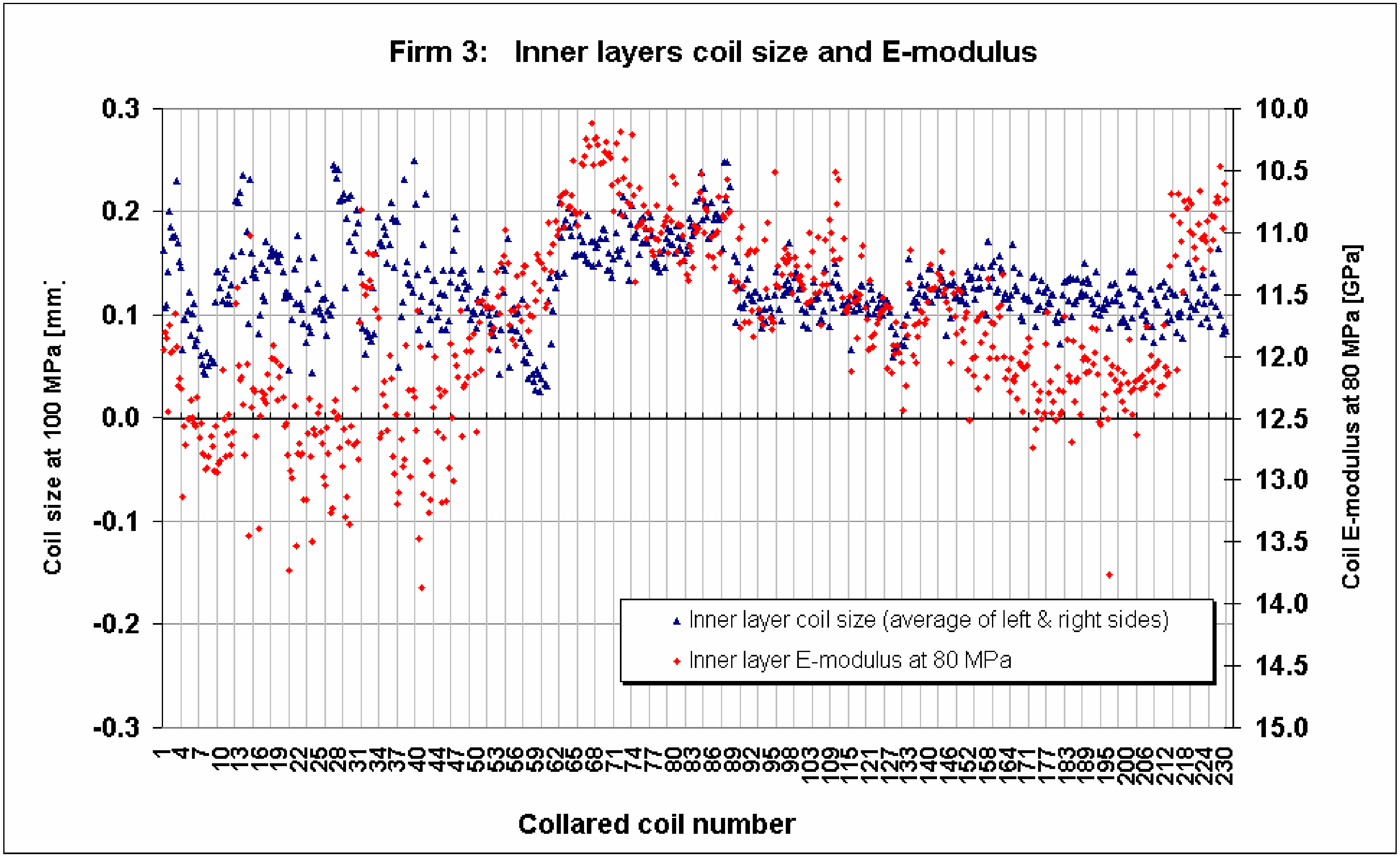

Fig. 12 Firm 3. Inner layer coil size (average) and E-modulus computed at 80 MPa.

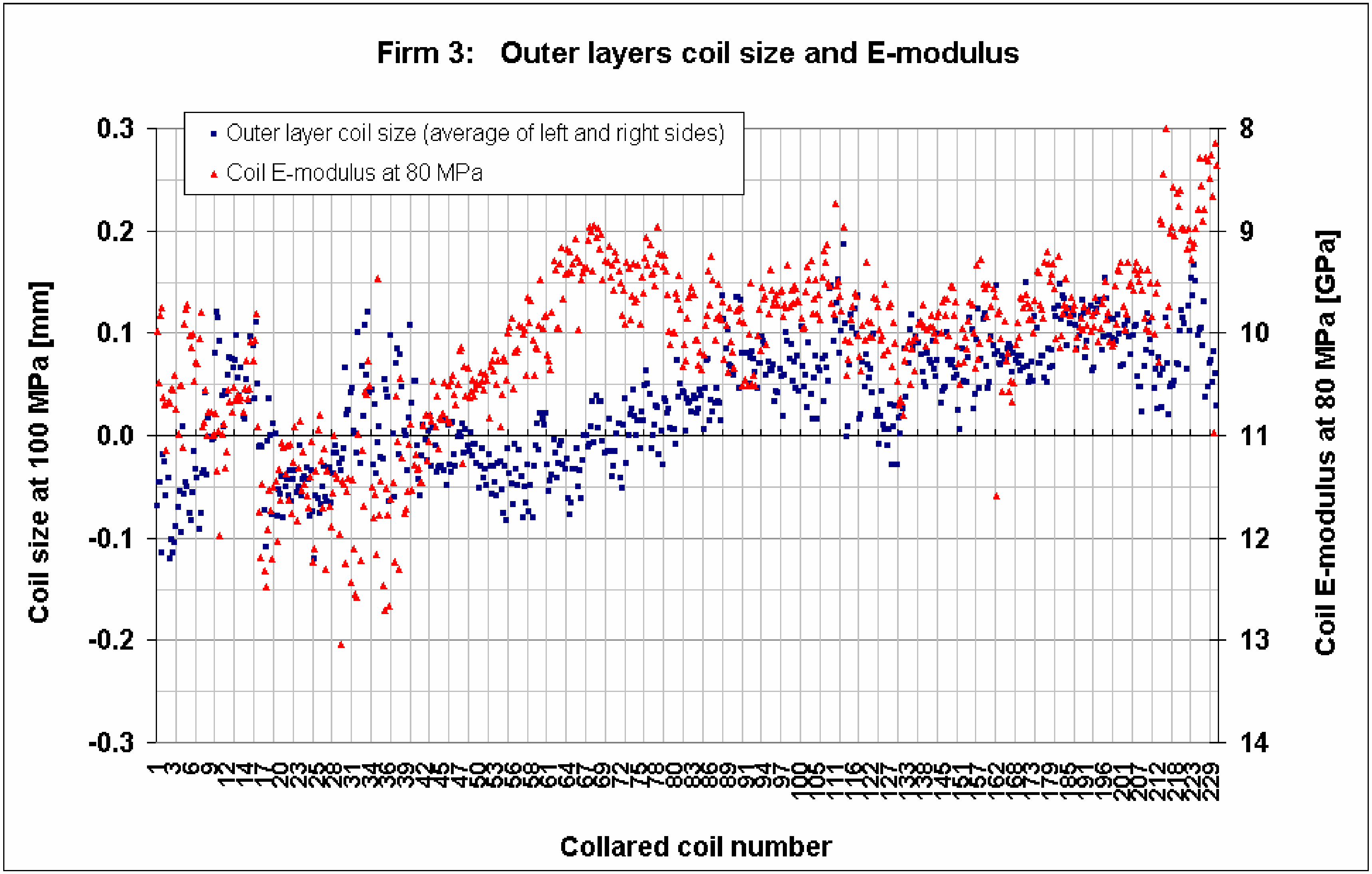

Fig. 13 Firm 3. Outer layer coil size (average) and E-modulus computed at 80 MPa.

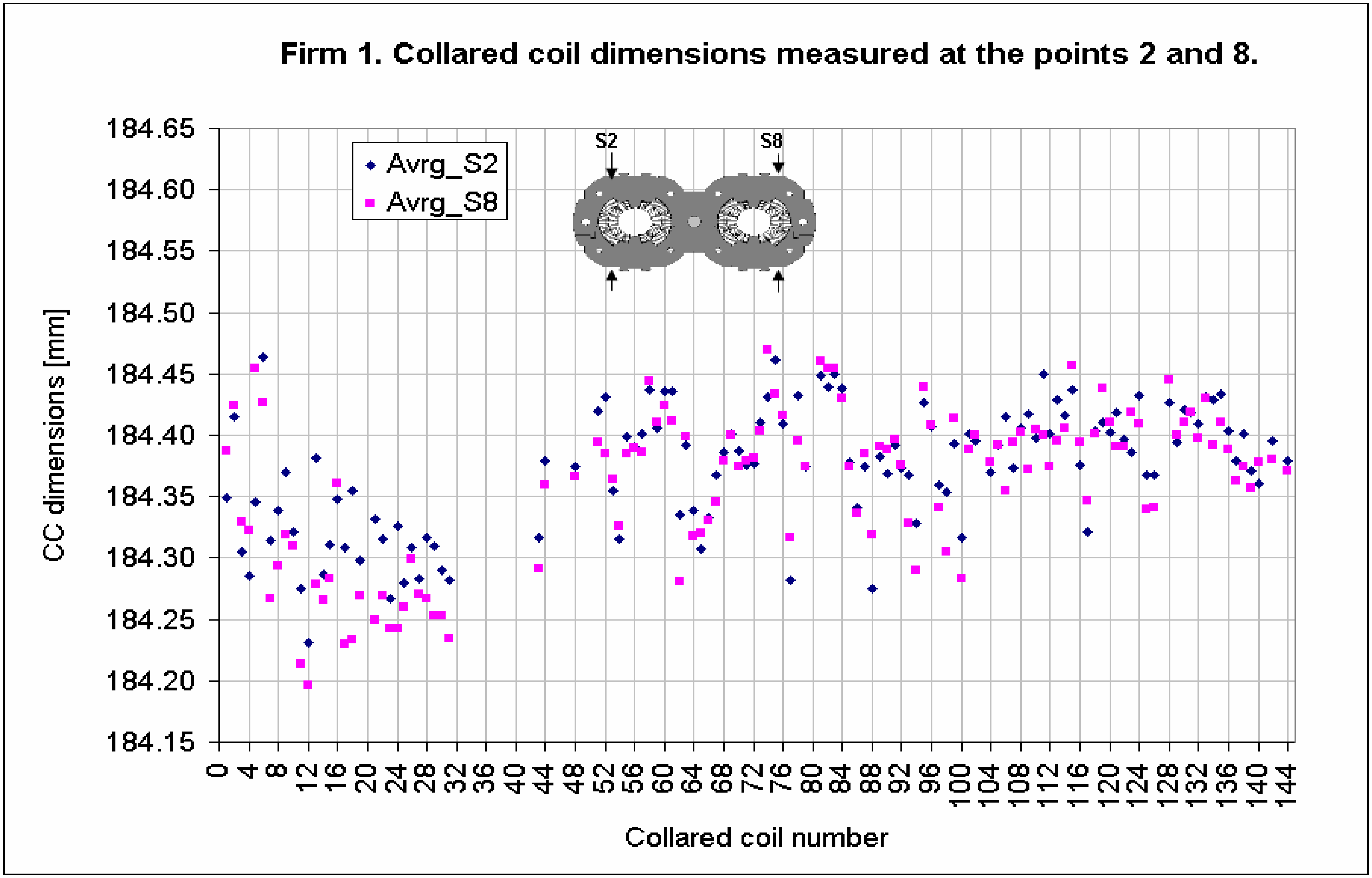

Fig. 14 Firm 1. Collared coil dimensions measured at the points S2 and S8.

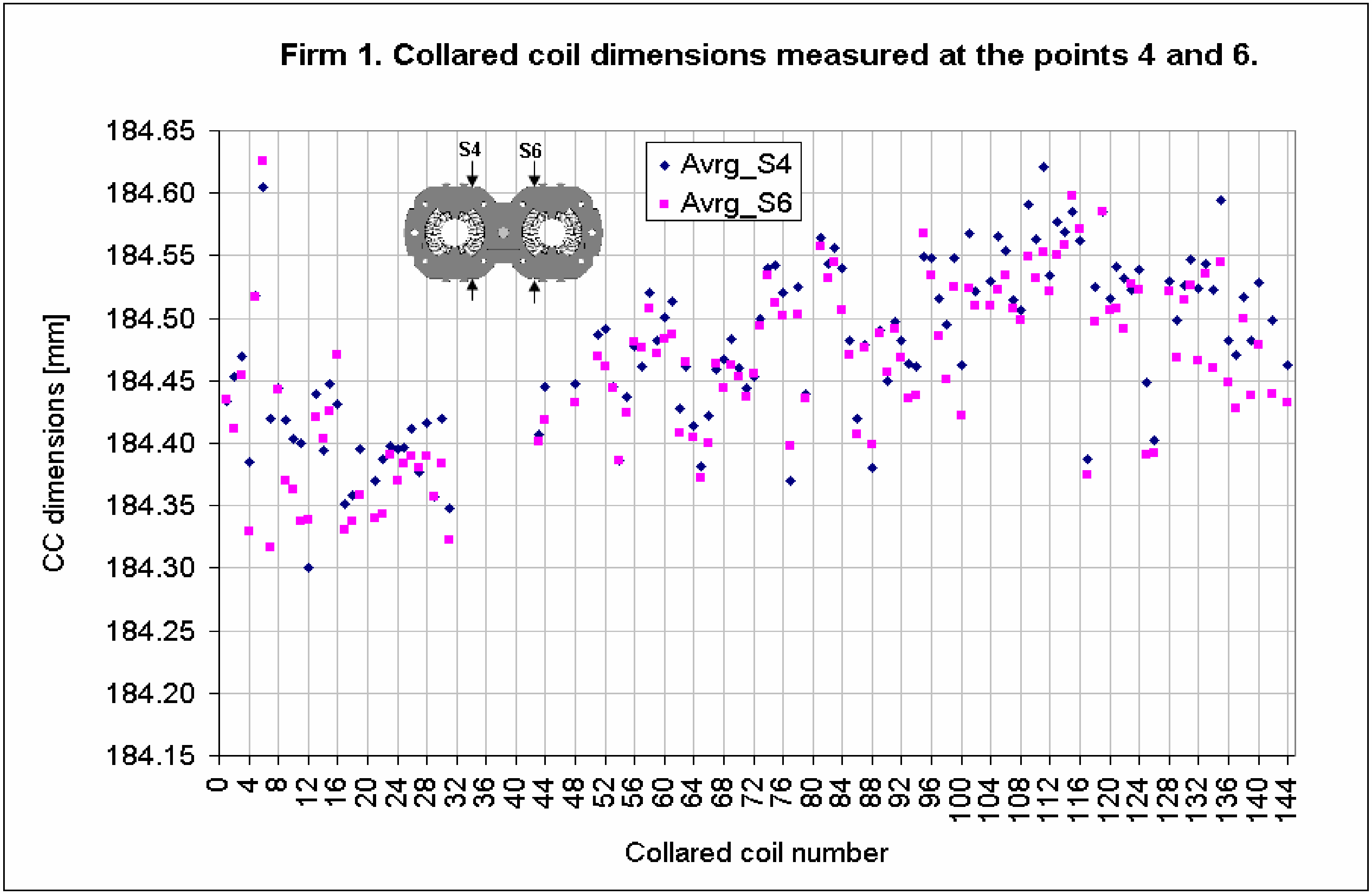

Fig. 15 Firm 1. Collared coil dimensions measured at the points S4 and S6.

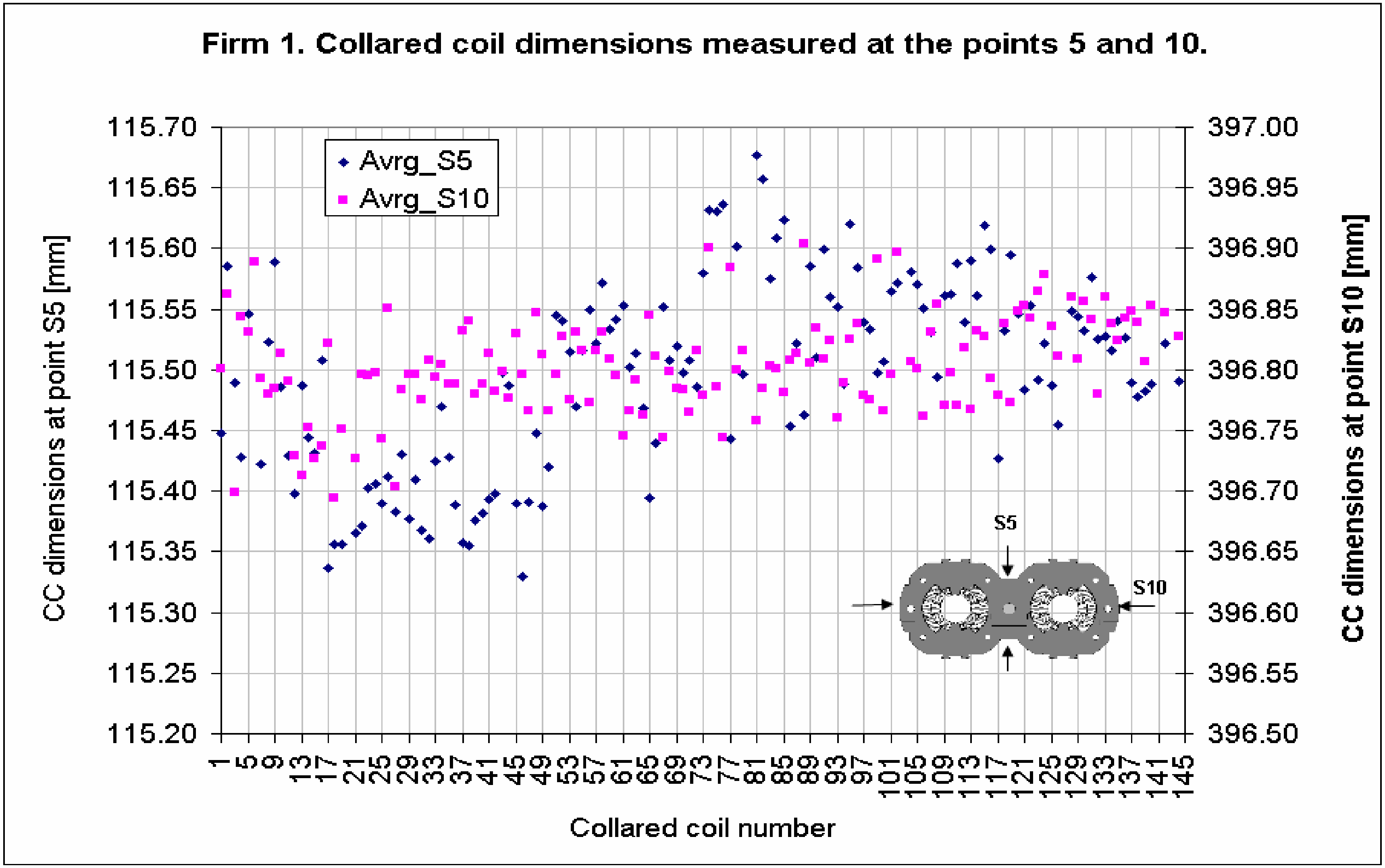

Fig. 16 Firm 1. Collared coil dimensions measured at the points S5 and S10.

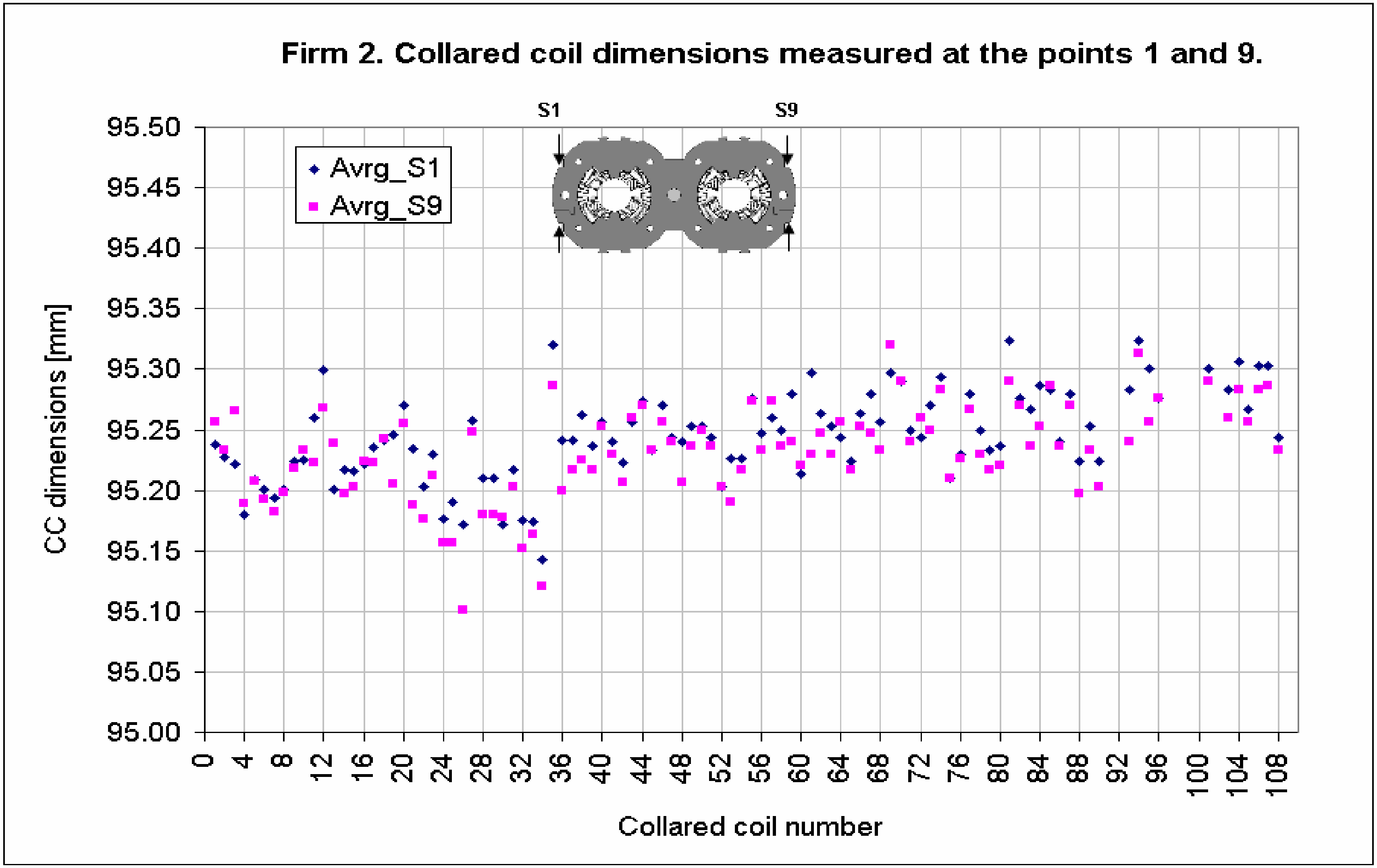

Fig. 17 Firm 2. Collared coil dimensions measured at the points S1 and S9.

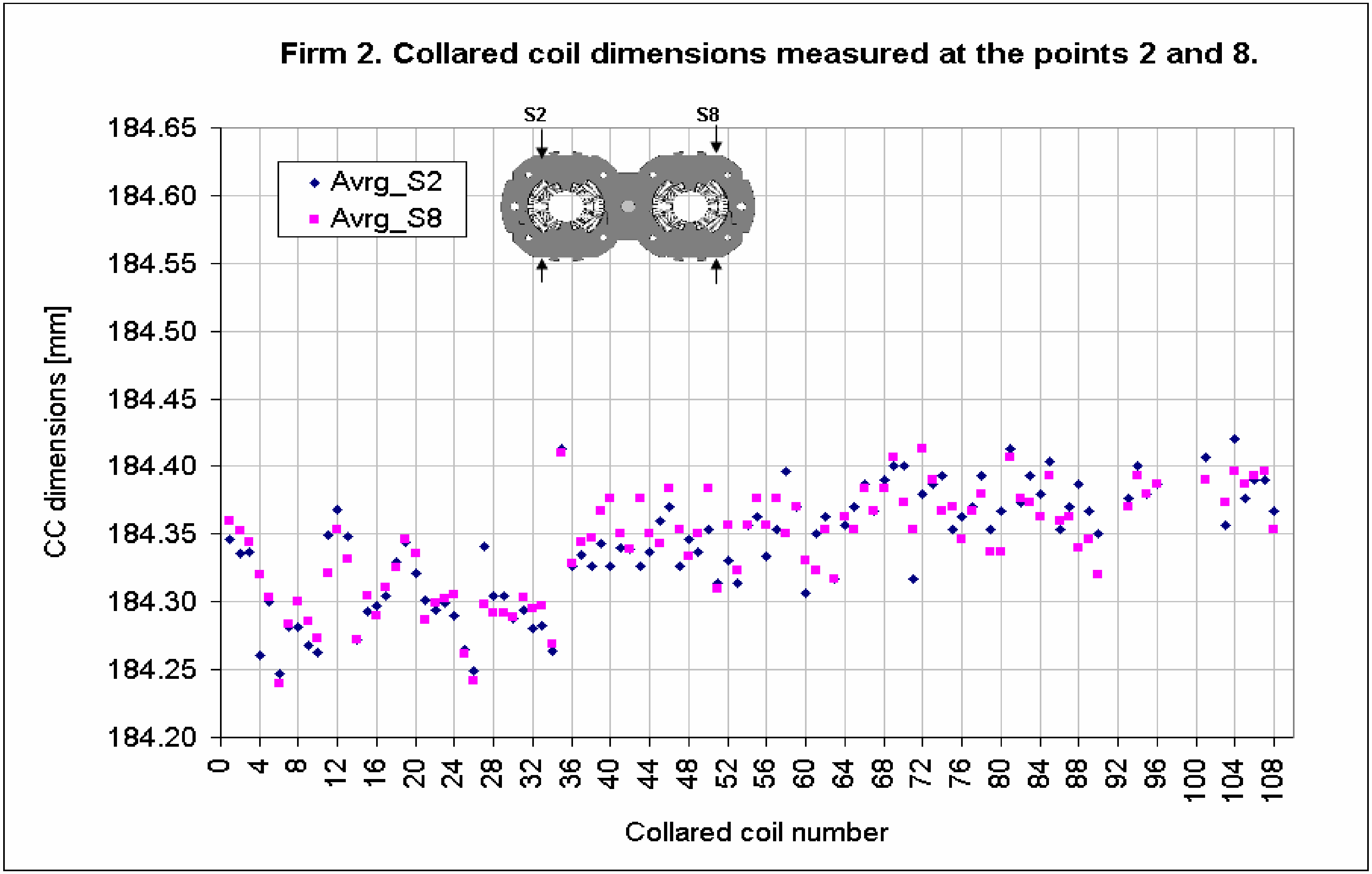

Fig. 18 Firm 2. Collared coil dimensions measured at the points S2 and S8.

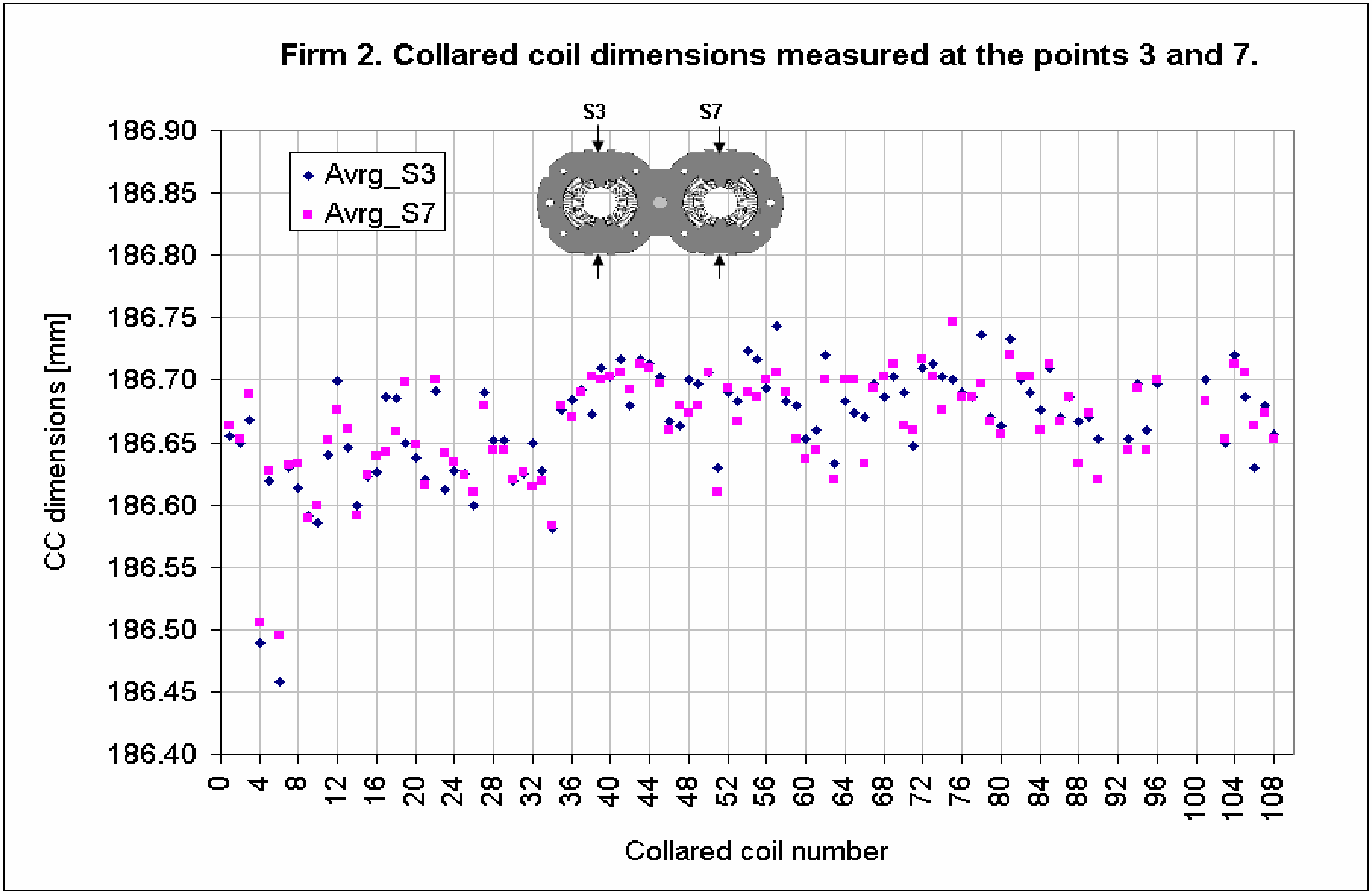

Fig. 19 Firm 2. Collared coil dimensions measured at the points S3 and S7.

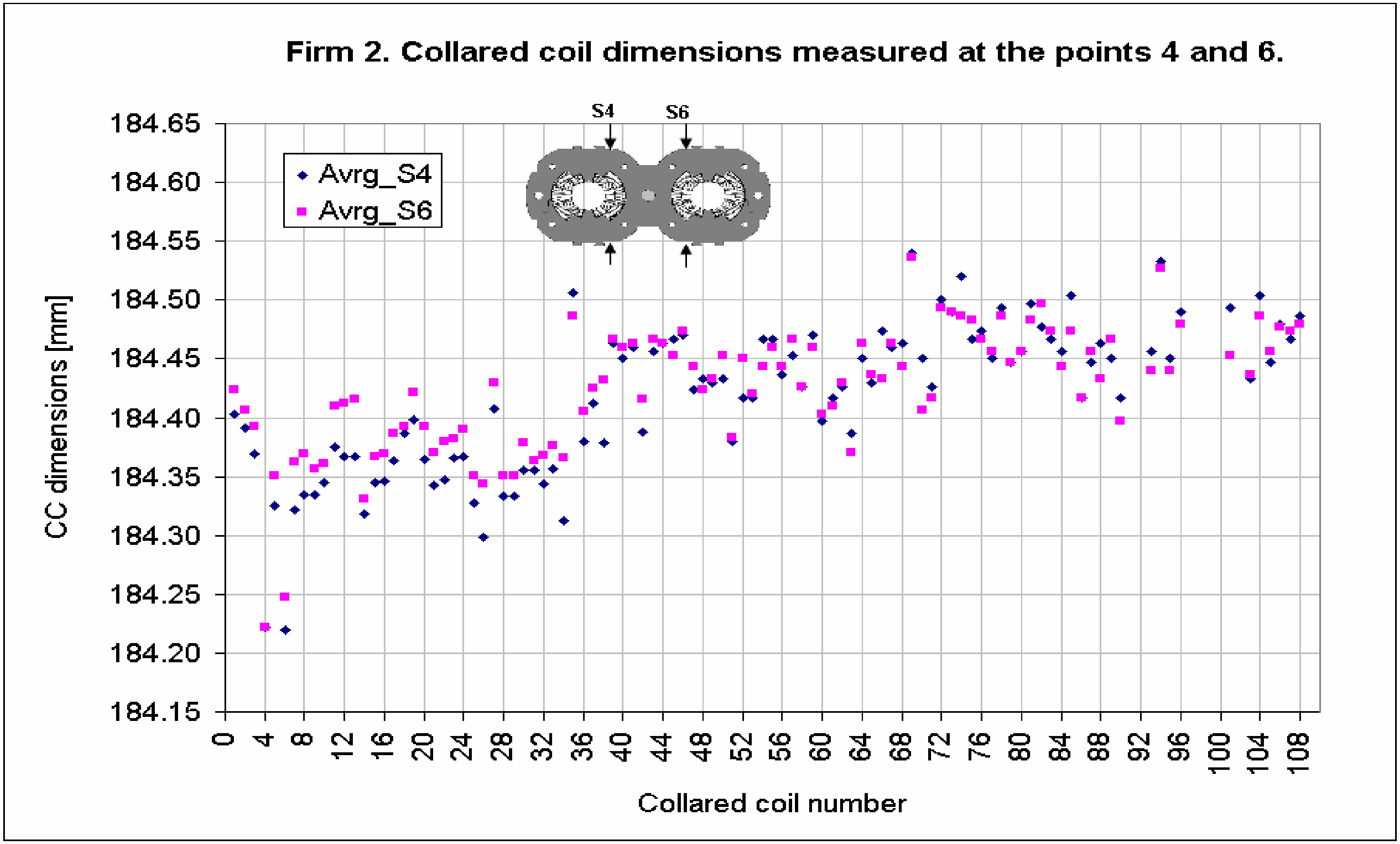

Fig. 20 Firm 2. Collared coil dimensions measured at the points S4 and S6.

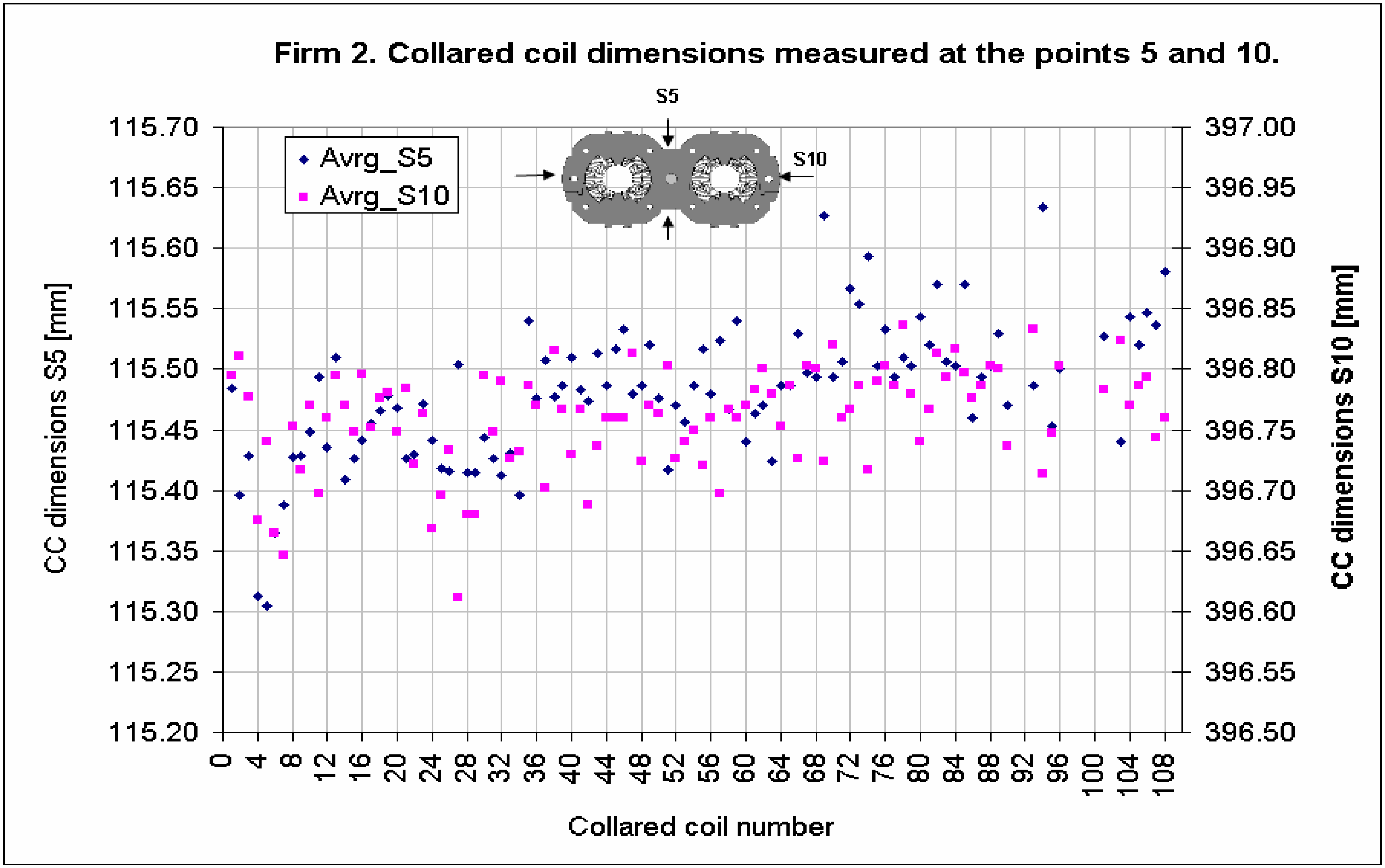

Fig. 21 Firm 2. Collared coil dimensions measured at the points S5 and S10.

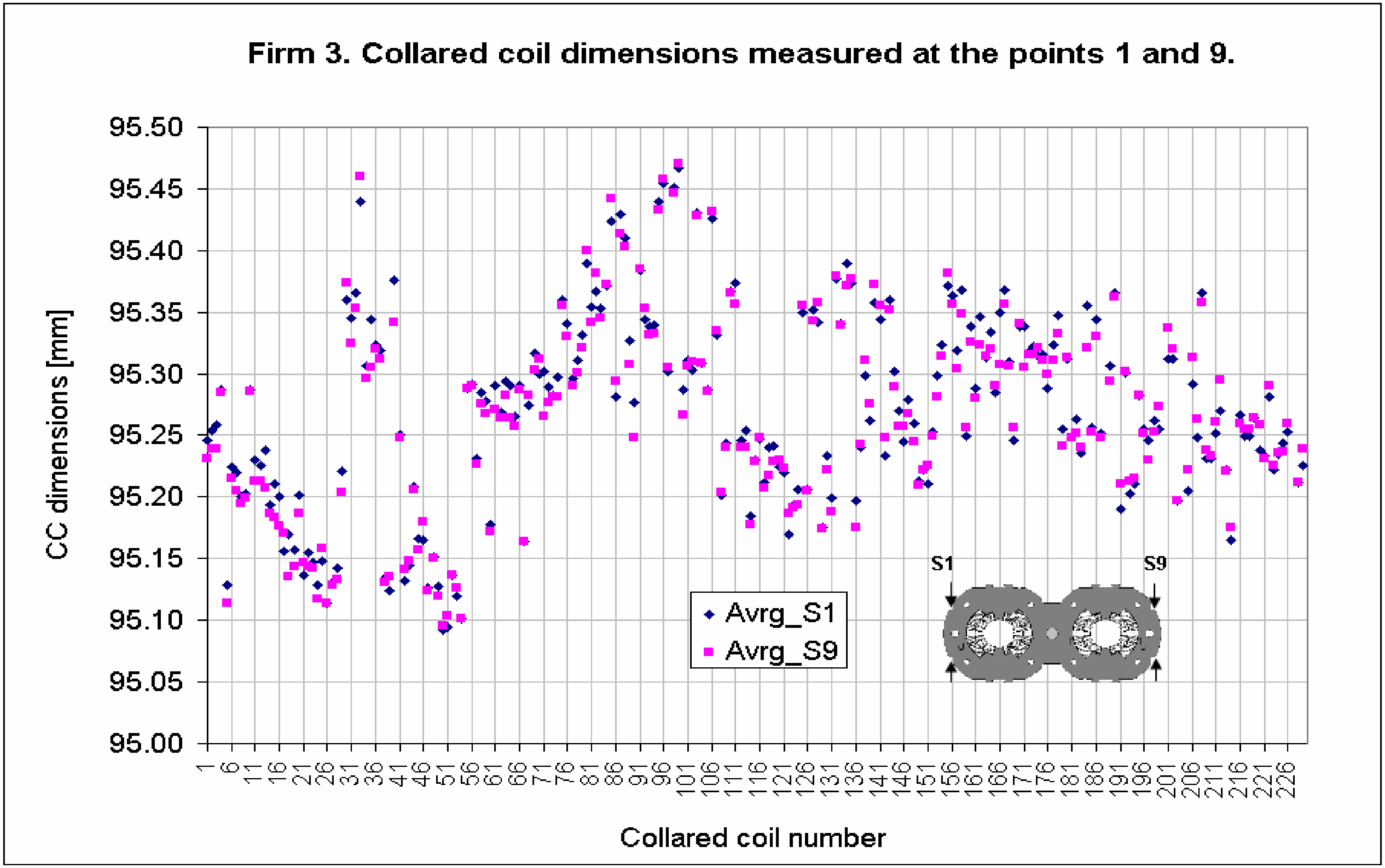

Fig. 22 Firm 3. Collared coil dimensions measured at the points S1 and S9.

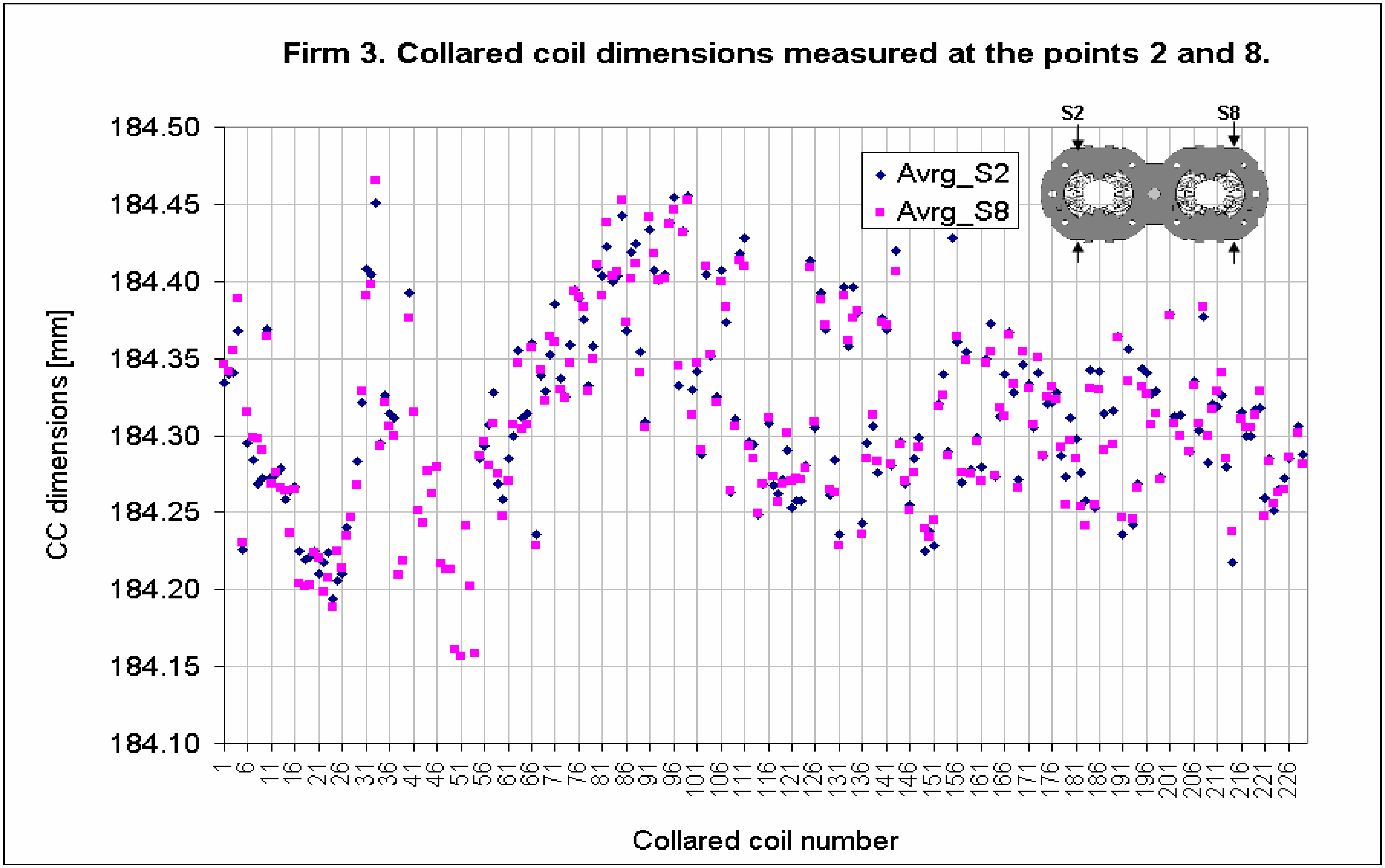

Fig. 23 Firm 3. Collared coil dimensions measured at the points S2 and S8.

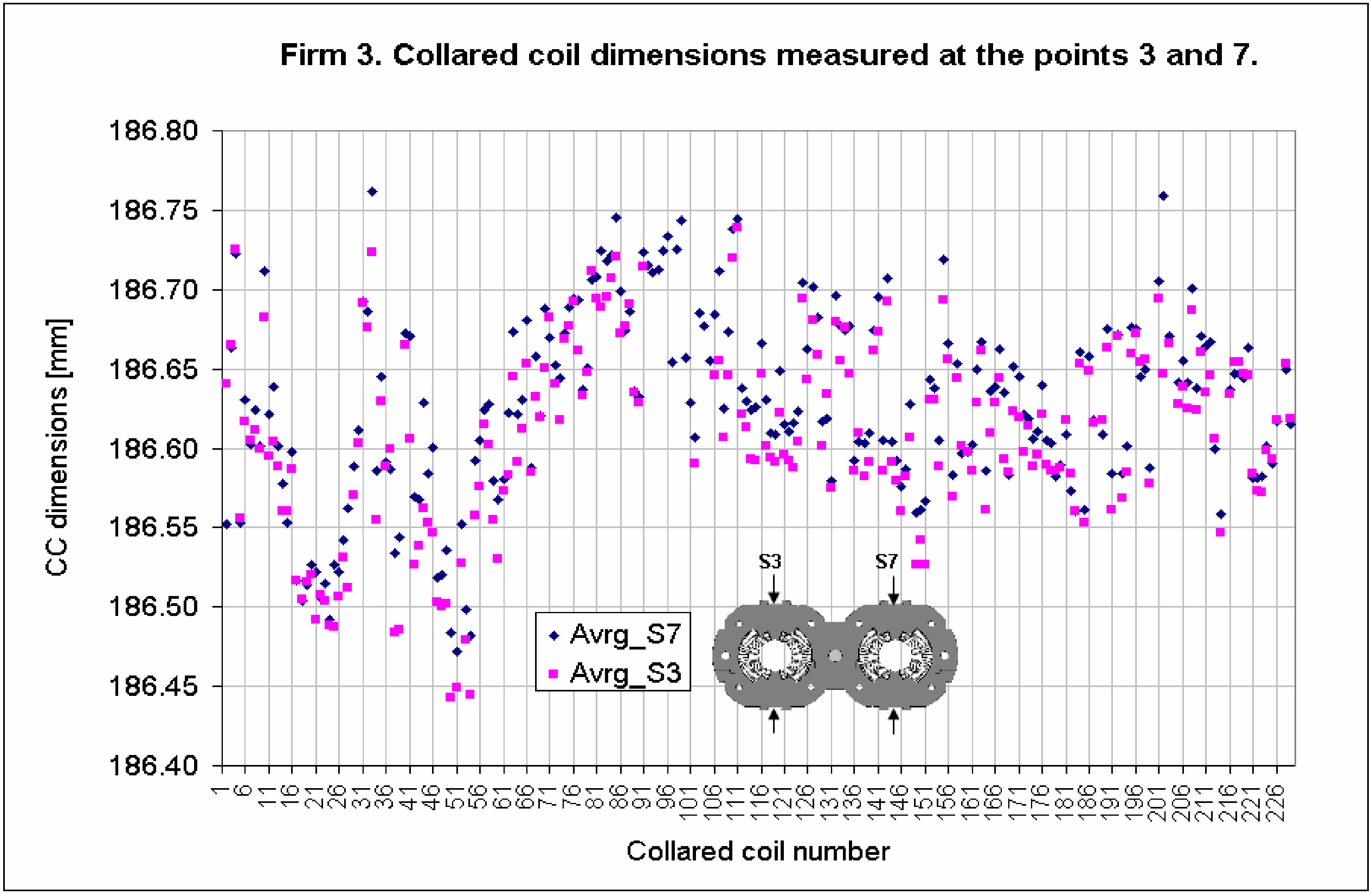

Fig. 24 Firm 3. Collared coil dimensions measured at the points S3 and S7.

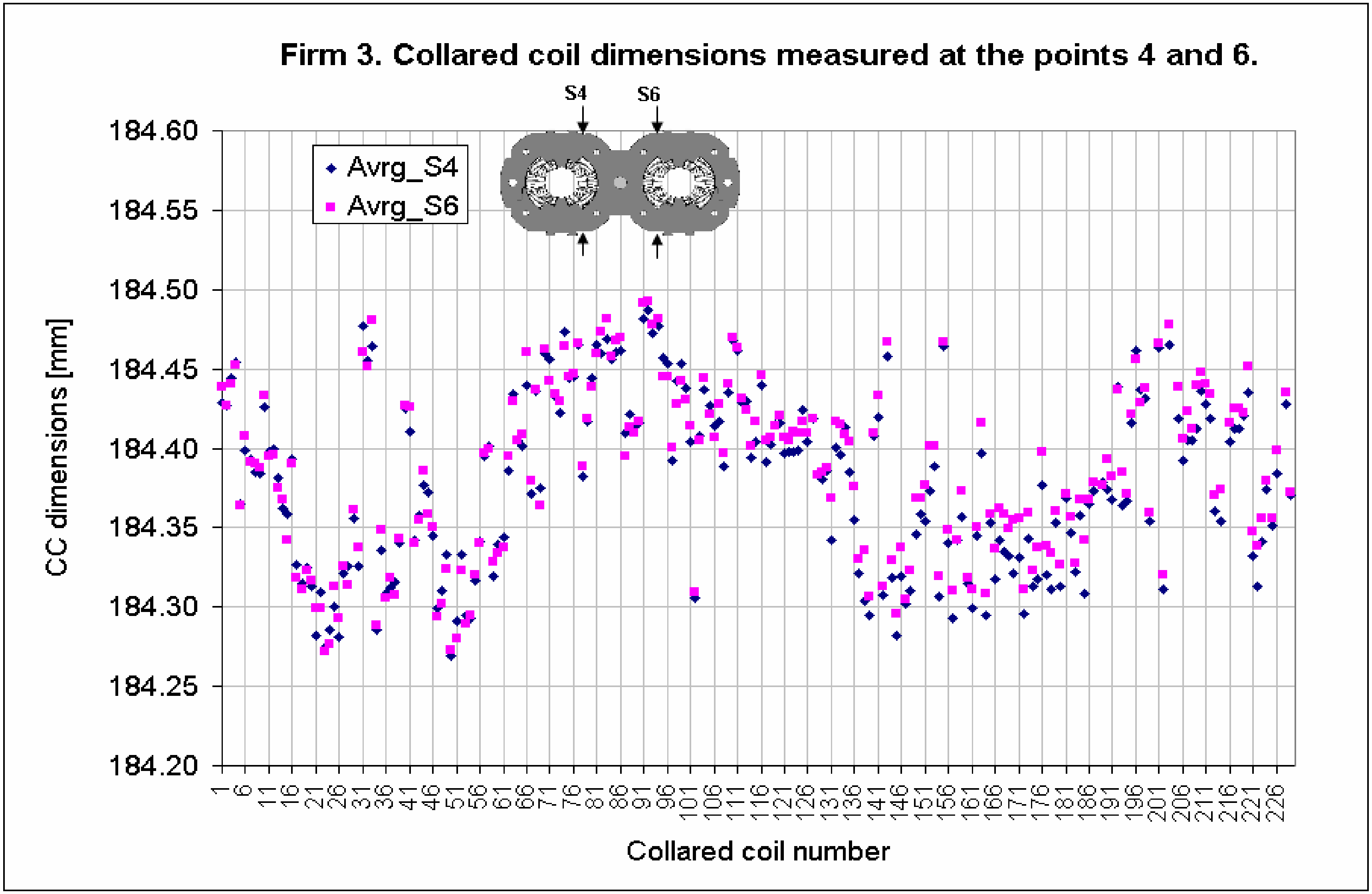

Fig. 25 Firm 3. Collared coil dimensions measured at the points S4 and S6.

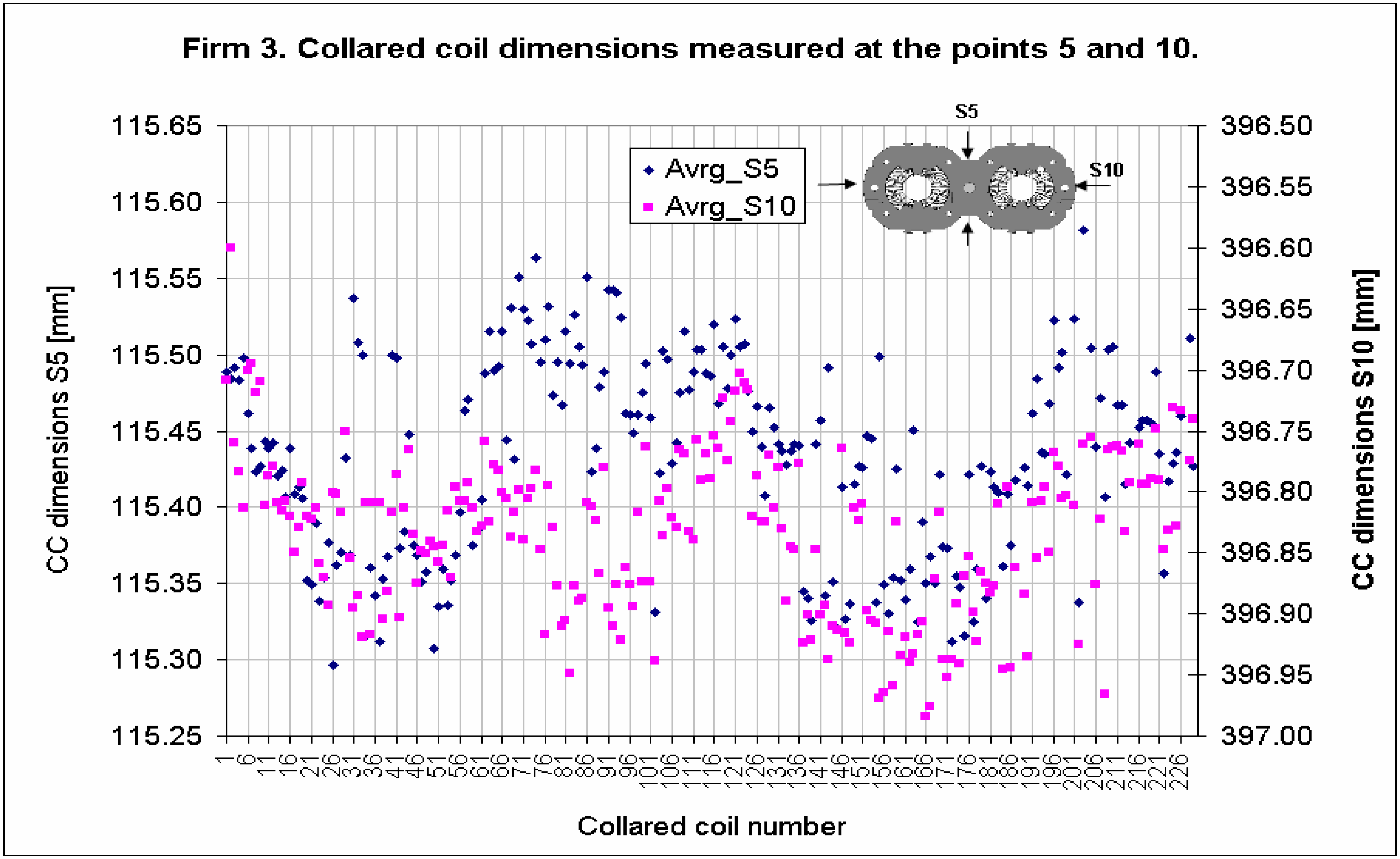

Fig. 26 Firm 3. Collared coil dimensions measured at the points S5 and S10 (notice that the scale for S10 axis is reversed).

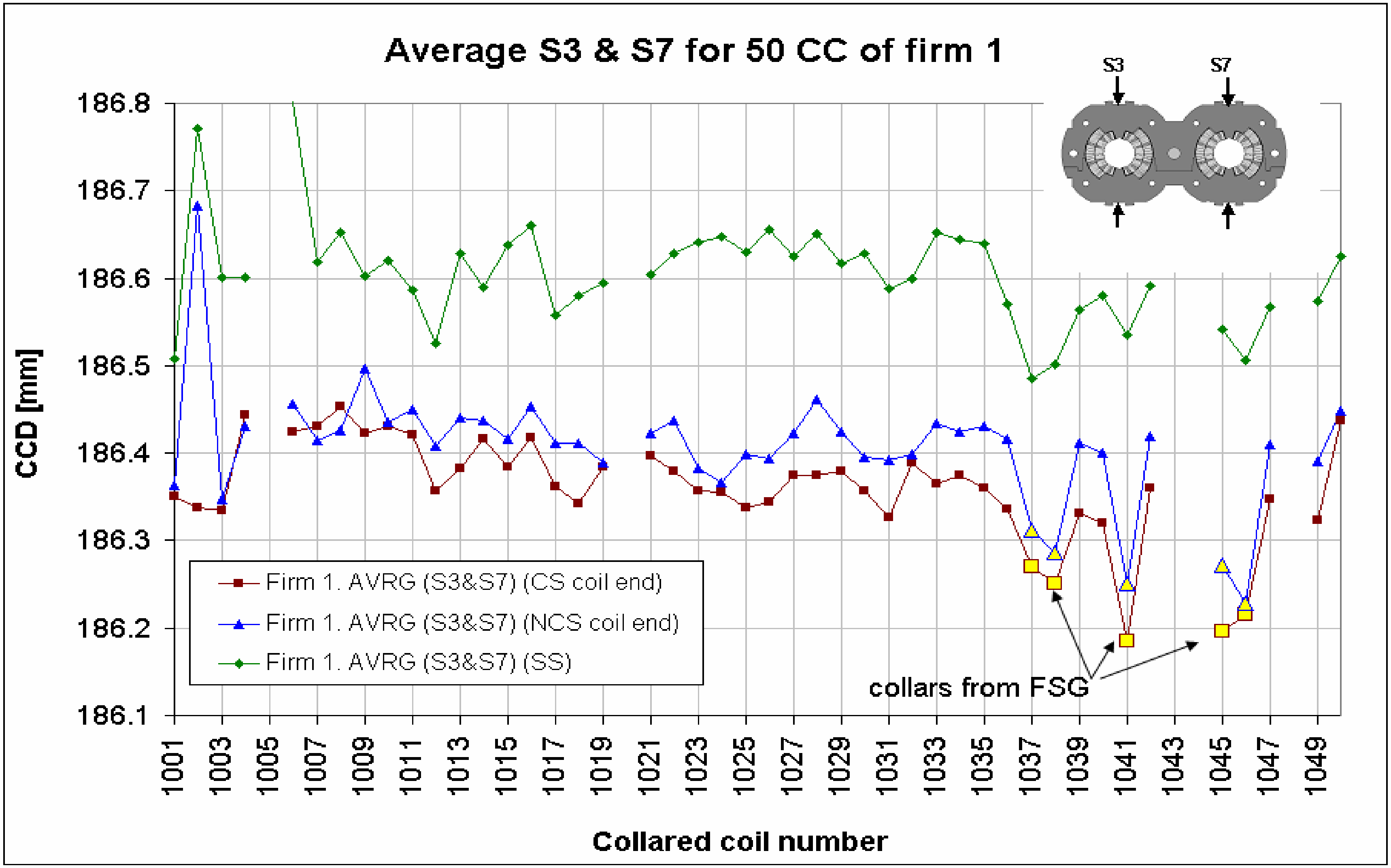

Fig. 27 Firm 1. Average of collared coil dimensions measured over coil ends and coil straight part at the points S3 and S7 (old measuring machine)

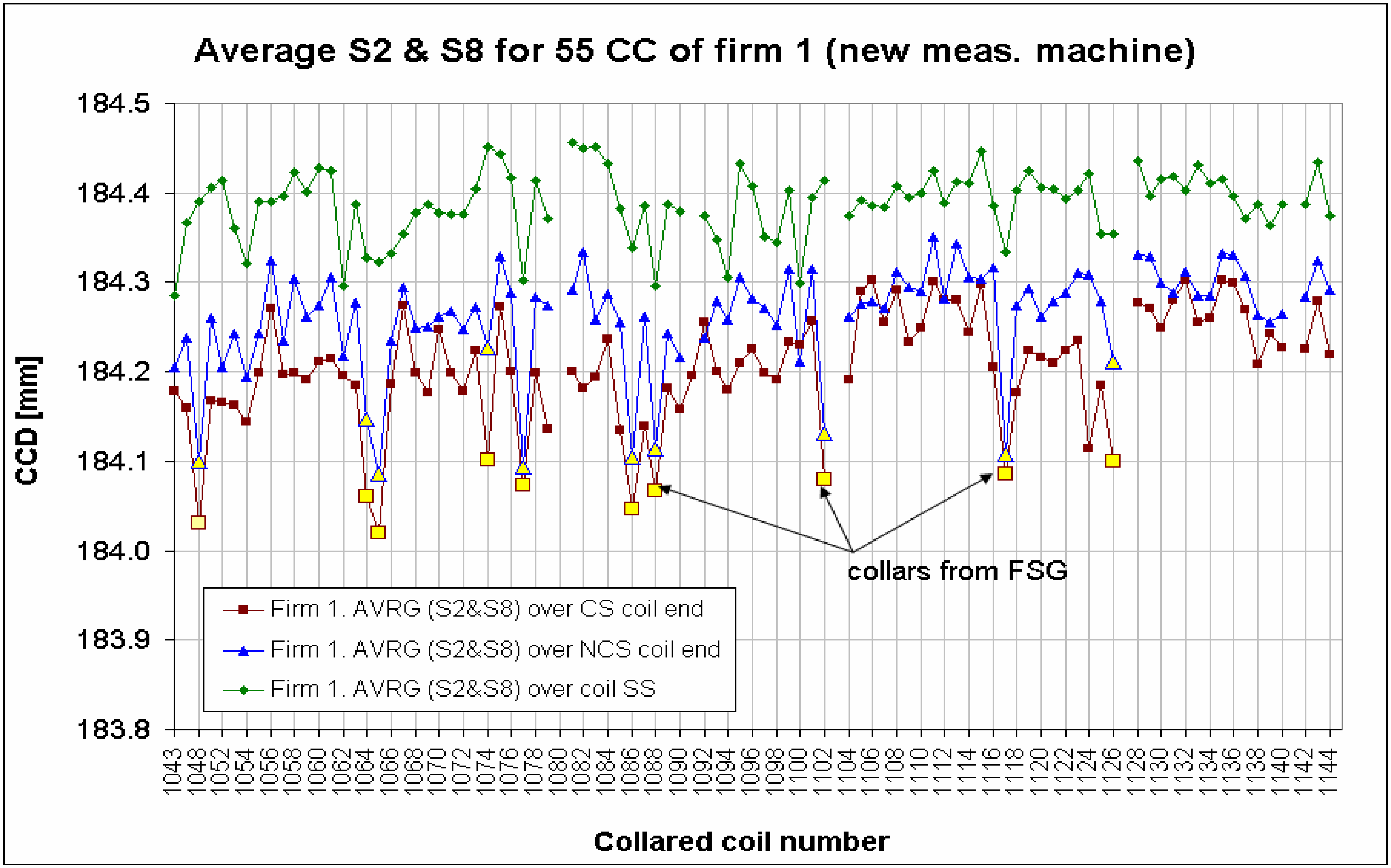

Fig. 28 Firm 1. Average of collared coil dimensions measured over coil ends and coil straight part at the points S2 and S8 (new measuring machine)

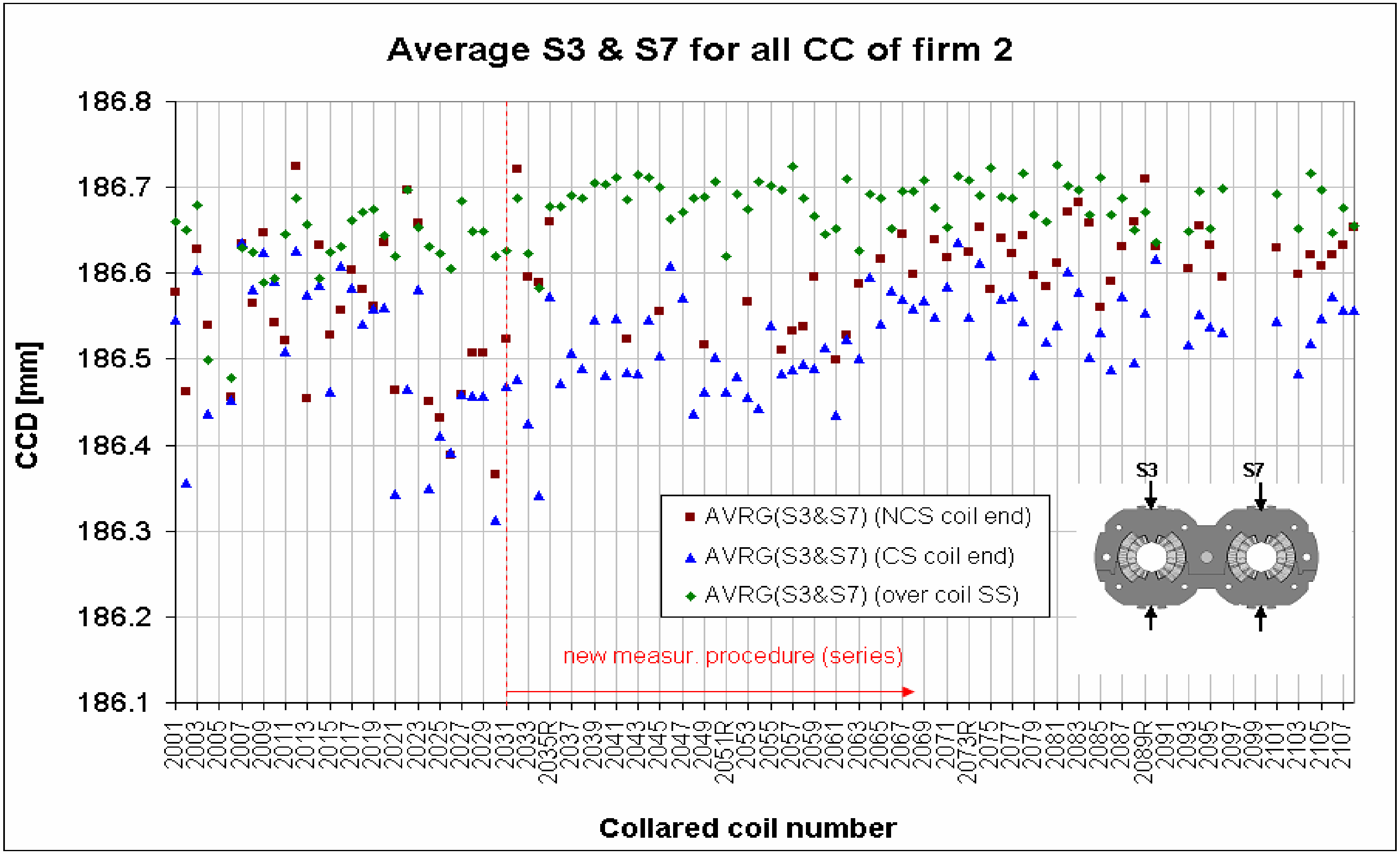

Fig. 29 Firm 2. Average of collared coil dimensions measured over coil ends and coil straight part at the points S2 and S8 (new measuring machine). For some of the magnets the measurements at NCS were done not correctly, therefore the data is not shown. Some of these magnets were re-measured and their IDs have an extension "R".

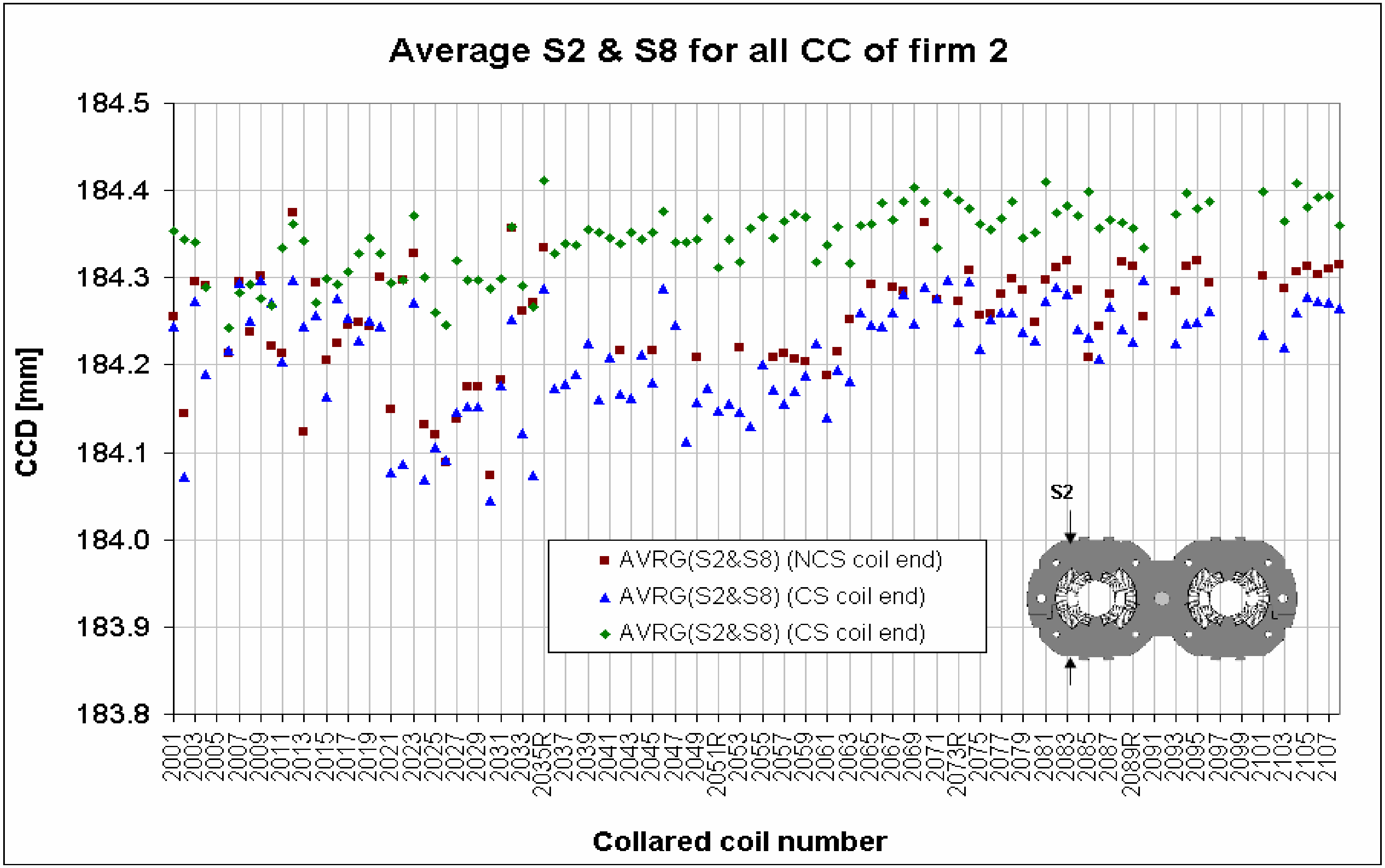

Fig. 30 Firm 2. Average of collared coil dimensions measured over coil ends and coil straight part at the points S2 and S8. For some of the magnets the measurements at NCS were done not correctly, therefore the data is not shown.

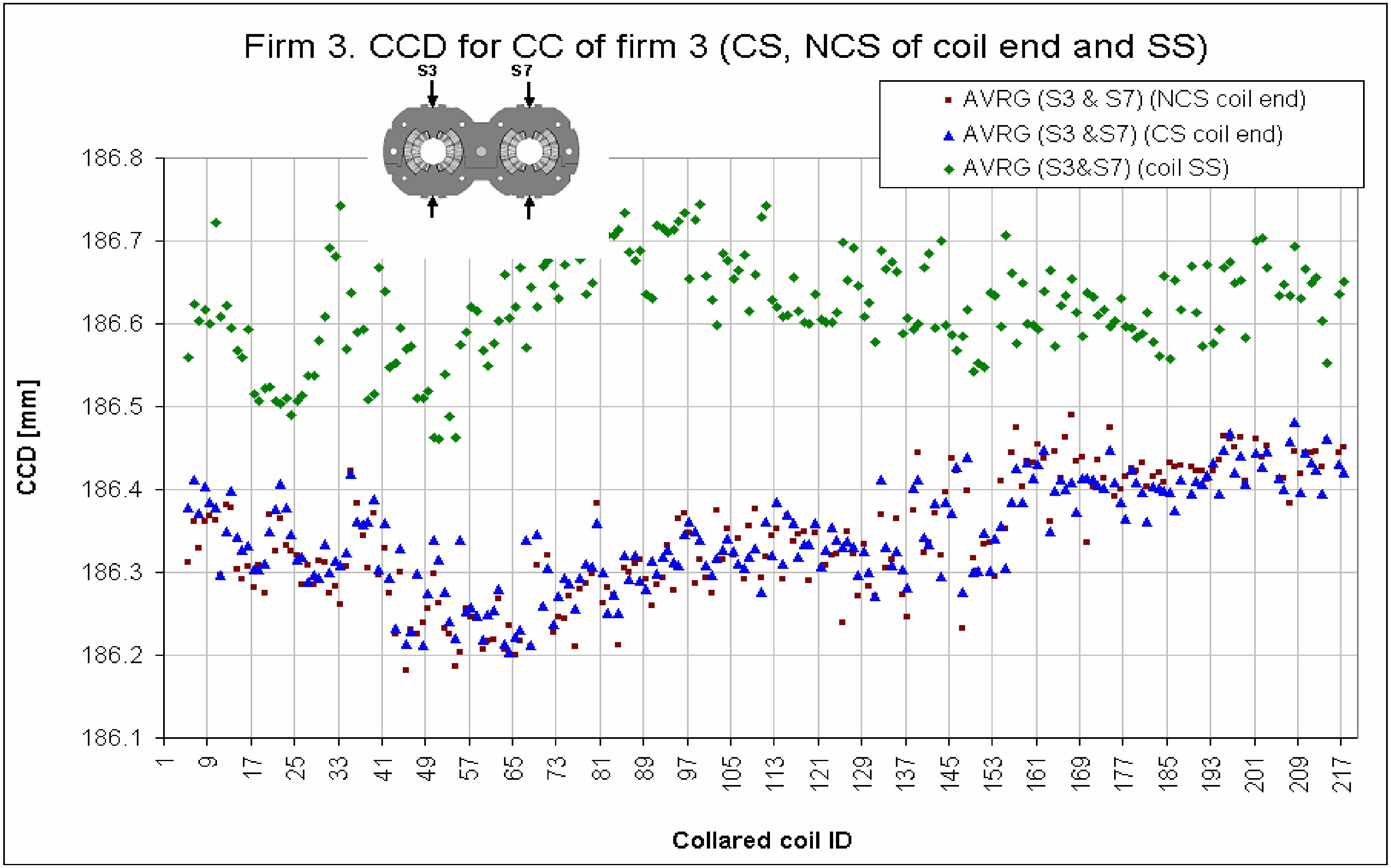

Fig. 31 Firm 3. Average of collared coil dimensions measured over coil ends and coil straight part at the points S3 and S7.

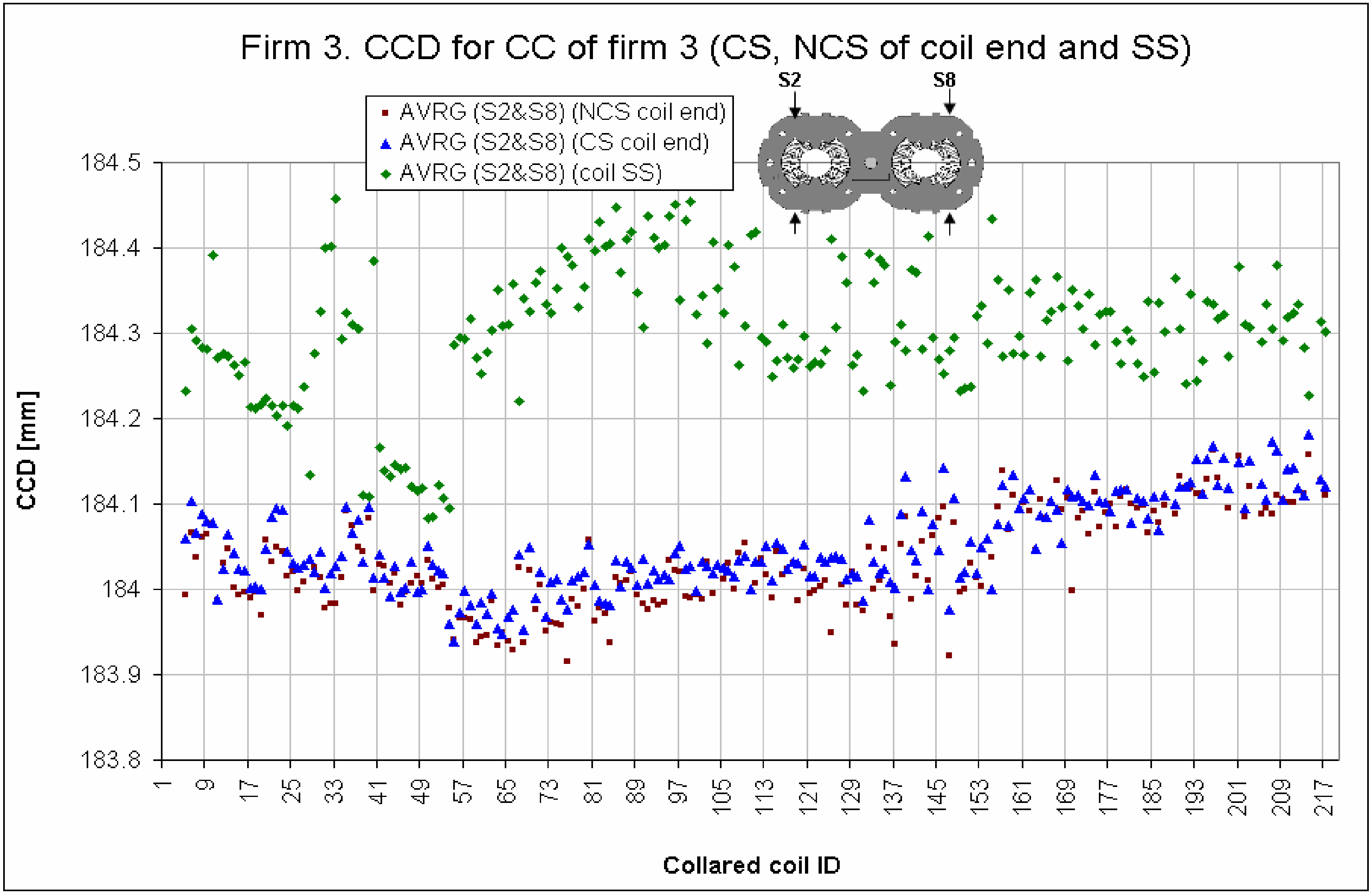

Fig. 32 Firm 3. Average of collared coil dimensions measured over coil ends and coil straight part at the points S2 and S8.

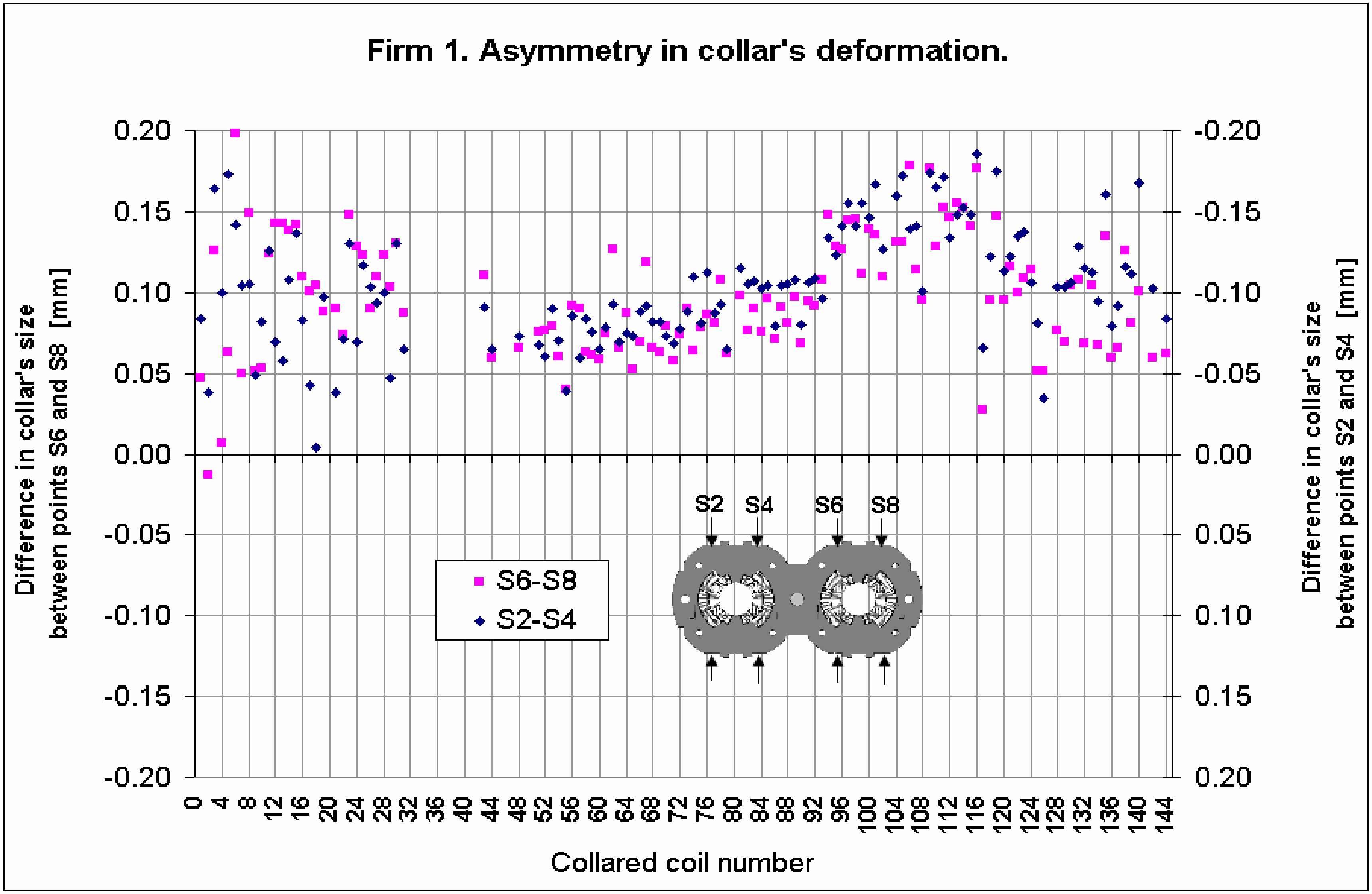

Fig. 33 Firm 1. Measured asymmetry in collared coil dimensions.

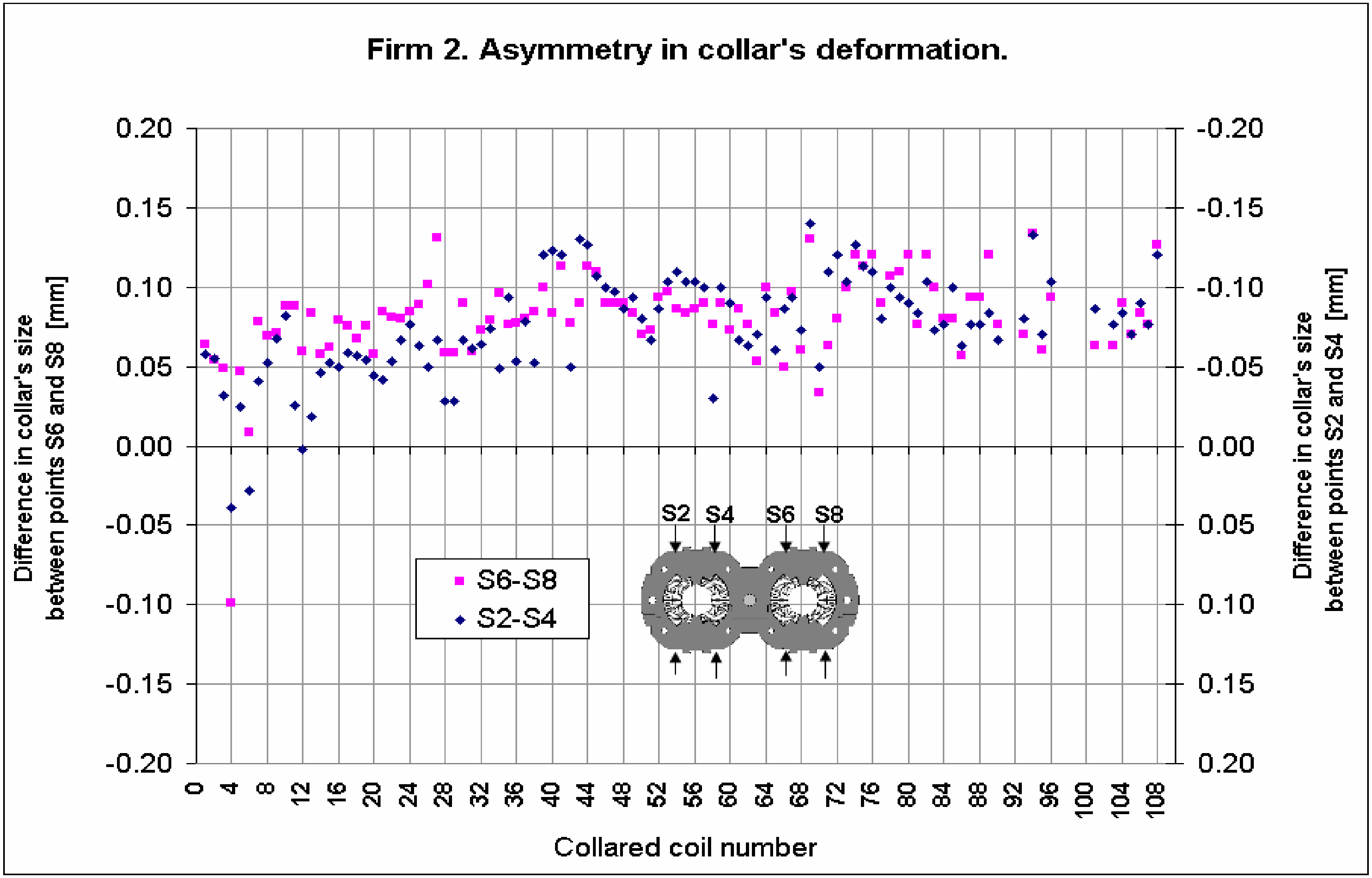

Fig. 34 Firm 2. Measured asymmetry in collared coil dimensions.

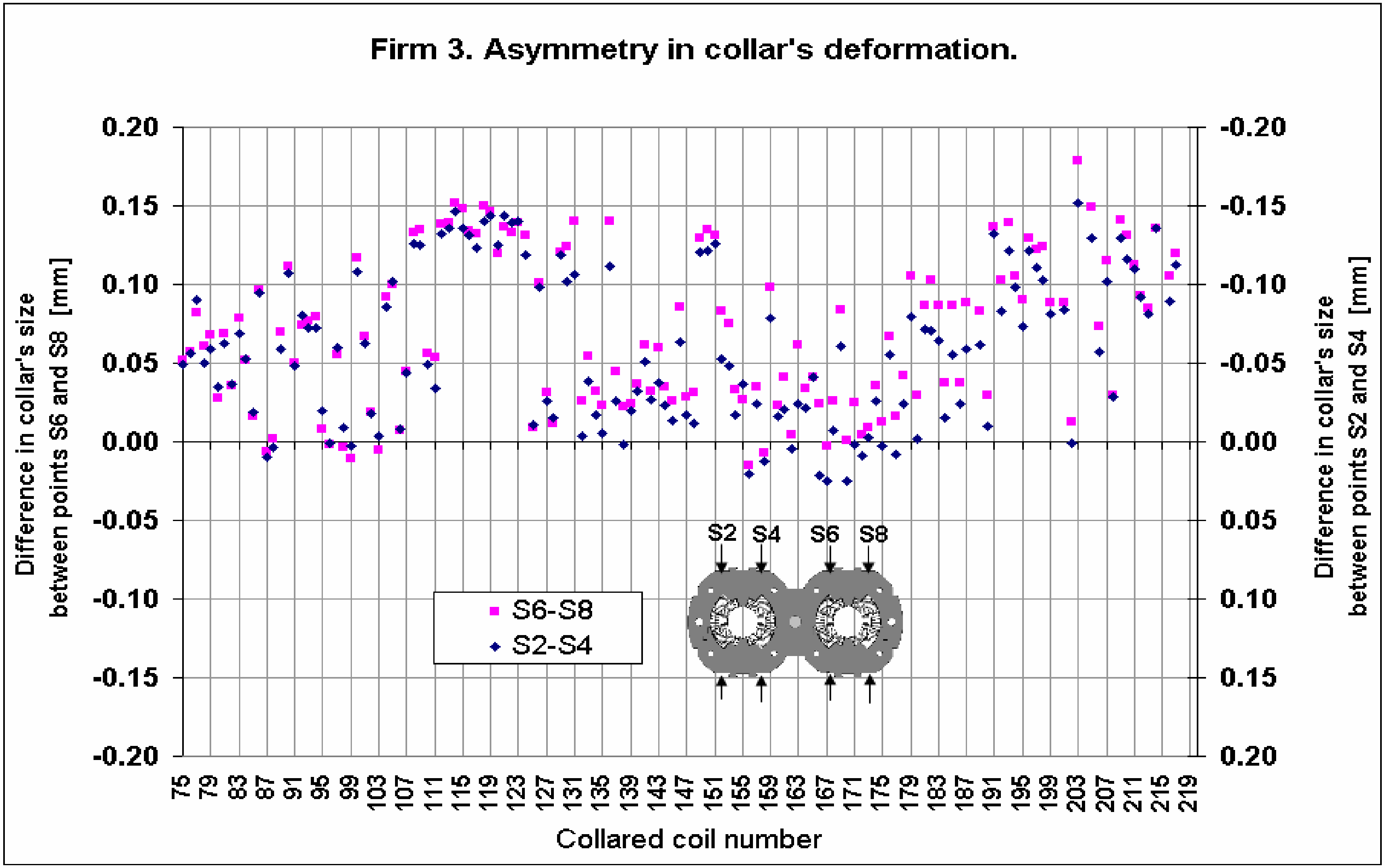

Fig. 35 Firm 3. Measured asymmetry in collared coil dimensions.