

Long Coil Measurement Anomalies of the SSRL BL5 EPU

S. Anderson, L. Griffin, Y. Levashov, H-D Nuhn, E. Reese and Z. Wolf

SLAC

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Abstract¹

During verification measurements of the SSRL Beam Line 5 EPU, the field integral long coil measurements consistently gave anomalously large B_x 1st integral values in comparison to single wire, pulsed wire and Danfysik's measurements, all of which gave B_x 1st integral measurements near zero. This note details the tests performed in order to understand the long coil B_x 1st integral measurement errors on the Beam Line 5 EPU. As part of checking the long coil integral measurements, single moving wire and pulsed wire measurements were made and these measurements agree with Danfysik's measurements of the integrals. This agreement gives confidence that the single moving wire method or the pulsed wire method can be used to measure the integrals of an EPU.

1 Introduction

SSRL purchased an EPU, to be installed in Beam Line 5, which was designed, manufactured and measured by Danfysik. Danfysik made hall probe and flip coil measurements to determine the local fields and field integrals respectively. SLAC Magnetic Measurements group was tasked to verify the measurements made by Danfysik and this was done using the Dover test bench hall probe system and a long coil previously built for another SSRL undulator (Figure 1). The trajectory field measurements and field integrals calculated from the hall probe measurements agreed with Danfysik's measurements. All of the long coil B_y 1st integral measurements and the HP mode B_x 1st integral measurements match Danfysik's measurements as well (Figures 2-6), but the long coil B_x 1st integral measurements for the CP+, CP- and VP+ modes did not (Figures 7-9)². The long coil measurements had large B_x 1st integral values away from the center x axis while the single wire, pulsed wire and Danfysik's measurements show the B_x 1st integrals to be near zero across the x axis. These measurement anomalies manifest when the EPU is in either CP+ (circular polarized), CP- , VP+ (vertically polarized) or VP- modes, but not when the EPU is in HP (horizontally polarized) mode. Interestingly, the long coil B_x 1st integrals vs. X change sign between the - and + settings of the CP and VP modes, though the B_y integrals vs. x do not, which makes B_y field crosstalk into the B_x integrals measurements unlikely. To try and understand the long coil B_x 1st integral measurement errors a series of tests were performed, each of which tested a possible error source. All measurements were done with the EPU set at a 13 mm gap.

2 Long Coil Diagnostic Tests

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² Danfysik did not supply integral measurements for the VP- mode.

To diagnose the long coil Bx 1st integral anomalies a series of tests were performed to understand why the long coil does not properly measure the CP and VP Bx 1st integrals.

The tests performed were:

1. Measure the Bx and By 1st integrals in CP+ and CP- modes with the EPU control power off to see if control system electronic noise was effecting the measurements.
2. Measure the Bx and By 1st integrals in CP+, CP- and HP modes with the addition of a vertical calibration magnet and then of a horizontal calibration magnet. When the vertical calibration magnet is used only the By 1st integral should change while the Bx integral should not and when the horizontal calibration magnet is used only the Bx 1st integral should change while the By integral should not. Also the Bx integral measurement should correctly measure the horizontal calibration magnet integral field and the By integral measurement should correctly measure the vertical calibration magnet integral field.
3. Straighten the long coil vertically along its length using measurements from a CMM. After alignment, install the long coil and measure the 1st integrals. The long coil G-10 slot, where the coil wires are located, can be adjusted vertically along its length every 13 cm. There are no horizontal adjustments. Straightening the coil vertically tests the sensitivity of Bx integrals to the local vertical coil alignment.
4. Measure the Bx 1st integrals using a single wire with the long coil software and stages. This tests the long coil software and stages independent of the coil.
5. Use a laser tracker to make sure that the long coil moves correctly during a Bx measurement. For a Bx measurement the long coil is moved vertically by 0.5 mm and the stages should move only vertically and not horizontally.

To test if the EPU control power effected the long coil Bx integral measurements, the EPU was set to CP+ mode and the long coil was used to measurement the Bx 1st integral with the EPU control power on and then with it off. Figure 10 shows no difference between the Bx integrals with the power on or off.

Next, horizontal and vertical field calibration magnets were setup next to the EPU so they could be measured while the EPU was set to CP+ mode. Figures 11 and 12 show that the long coil properly measured the calibration magnet field integrals. The delta change between having a calibration magnet powered and having it off and removed is equal to the 1st integral values of the calibration magnets. The horizontal calibration magnet gives a ~500 G-cm 1st integral and the vertical calibration magnet a ~2800 G-cm 1st integral and these are the differences seen between having each of the calibrations magnet on and off (and removed to eliminate residual fields). The calibration magnet measurements also show that the Bx 1st integrals are only slightly effected by the By field of the vertical calibration magnet. The size of the effect of the calibration magnet By field (2800 G-cm) on the Bx integral should be large if the EPU By integral (which has a maximum value of ~1000 G-cm) is effecting the Bx 1st integrals for the CP+ mode, but the vertical calibration magnet effect on the Bx 1st integral is ~30 G-cm which is small compared to the nearly 900 G-cm one would expect if there was crosstalk. This small effect is probably due to a slight roll (only 0.6 deg is needed) of the vertical calibration magnet, which was only aligned with a level. Though these calibration magnet tests seem to suggest that the long coil Bx 1st integral measurements are unaffected by By fields, the calibration magnets are short compared to

the EPU so it is possible that the long coil is relatively straight at the locations of the calibration magnets but is misaligned somewhere inside the EPU itself and this misalignment causes the errors in the Bx 1st integrals.

The long coil was next straightened using CMM measurements of the G-10 surface above the coil wire bundles. While the long coil was being straightened, a single wire was used in place of the long coil to make measurements using the long coil software, stages and electronics. The single wire measurements used the same software, stages and electronics with only the addition of a SRS amplifier and filter unit. The SRS amplifier was set to a gain of 500 to boost the wire signal to be comparable to that of the long coil (which has 350 turns) and the amplifiers' low pass filter was set to filter 60 Hz noise. Figures 13 and 14 are the plots of these single wire measurements compared to the long coil, Danfysik and moving wire measurements that were previously made for the CP- and CP+ modes at 13 mm gap. The single wire measurements using the long coil system measurements are noisy, but they agree with the Danfysik and moving wire measurements which points to the coil being the source of the Bx 1st integral measurement anomalies.

Once the long coil was aligned using the CMM data, it was setup again to measure the EPU. CP+ and CP- mode Bx 1st integral measurements were made using the aligned coil. These measurements are nearly identical to the before alignment long coil measurements (Figures 15 and 16), so the vertical alignment using the CMM did not correct the Bx 1st integral anomalies. The long coil straightness was additionally checked using optical metrology alignment scopes before and after the alignment using the CMM. The optical measurements, which look at the long coil wire bundle itself, and the CMM measurements, which measure the G-10 above the long coil wire bundle, don't match each other (Figure 17). The CMM measurements show the G-10 is straight to +/- 100 microns (the large offset in the center is a glued seam at the center of the coil), while the optical measurements show a 600 micron sag and a few adjustment points with 200-400 microns differences from before to after alignment. Sag in the moving wire causes a shift in the offset of the Bx 1st integral measurements, so in theory the coil sag should do the same. Individual adjustment point misalignments of the long coil might cause the anomalies seen in the long coil Bx 1st integral measurements, yet the change of several of the adjustment points by 200-400 microns from before to after alignment caused little change in the long coil Bx 1st integral measurements. Since there was little affect seen for the Bx 1st integral for the CP+ and CP- modes after the CMM alignment, the coil was deliberately misadjusted at two points along the coil using the adjustment screws. Adjustment screws 18 (in the middle of the magnet) and 24 (near the exit of the magnet) were moved by 355 and 533 microns respectively and figure 16 shows that even with these misalignments of the adjustment screws, there is no change to the CP+ mode Bx 1st integral measurements. From these tests it would seem that the long coil measurements are insensitive to the vertical straightness of the long coil.

Finally, a laser tracker was used to verify that the long coil was moving properly when its vertical stages were moved by 500 microns, which is the amount moved during a Bx integral measurement. These measurements were made at several x positions across the EPU gap to see if there was a systematic movement error as the measurements were taken across the EPU gap. Figures 18 and 19 show that the coil moves on average 500 microns vertically and less than 10 microns in horizontally when a vertical scan is made. Position 6 and 27 refer to where the laser tracker sensors were located and they refer to the numbered adjustment screws which are upstream and downstream of the EPU respectively. The average delta vertical movement was 501 +/- 7 microns for position 6 and 497 +/- 13 microns for position 27 which is within the expected 500 micron value. The X vs. delta horizontal movement plot

shows that there is up to 12 microns of movement in x, but the delta horizontal movement errors are random across the gap and are not of sufficient size to cause the long coil Bx 1st integral anomalies.

3 Conclusion

In conclusion, the EPU power system does not cause errors in the long coil measurement system and no flaws were found in the software or stage movement of the long coil system. The long coil Bx 1st integrals seem unaffected by the local vertical alignment of the long coil along its length as defined by the adjustment screws, though it could be possible that misalignments between adjustment points are the cause of the Bx 1st integral errors. It might be possible to use the calibration magnets to test each segment of the long coil in between adjustment points. The horizontal alignment of the wires along the length of the coil are set and cannot be adjusted, so it is possible that the wire deviations in x are causing the measurement anomalies for the Bx 1st integral measurements but there is no way to test this theory directly on this long coil, though it may be possible to test horizontal and vertical deviations using a stranded wire system support by a G-10 form. Since the Bx 1st integral errors for CP+, CP-, VP+ and VP- measurements are not understood, this long coil should not be used in the future to make measurements on an EPU type device, instead a stretched wire or pulsed wire should be used. The measurements do show that a coil can be used on a horizontally polarized device, such as an LCLS undulator.



Figure 1: Long Coil Setup

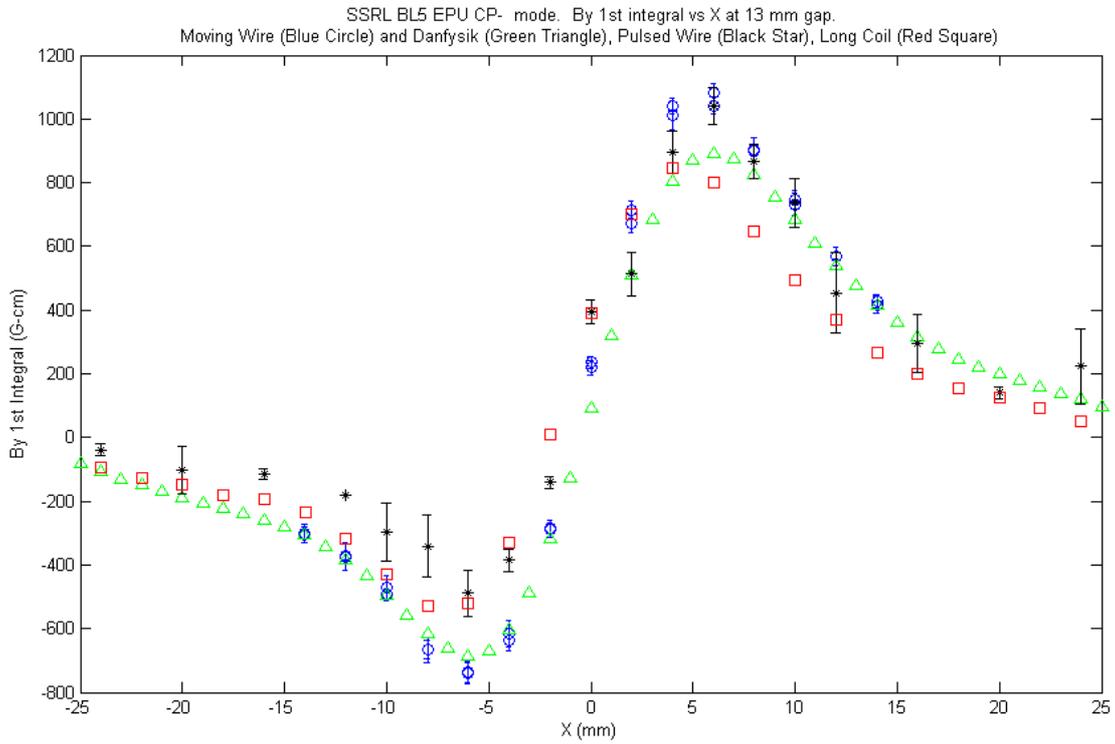


Figure 2: CP- mode By 1st Integral vs X measurements.

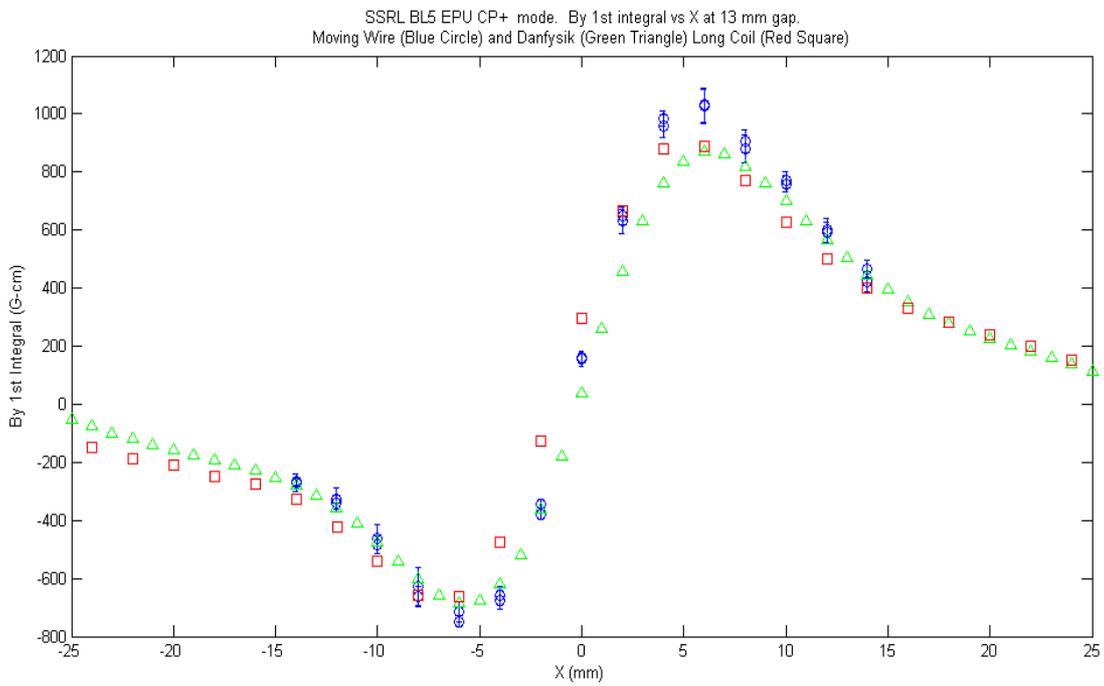


Figure 3: CP+ mode By 1st integral vs X measurements.

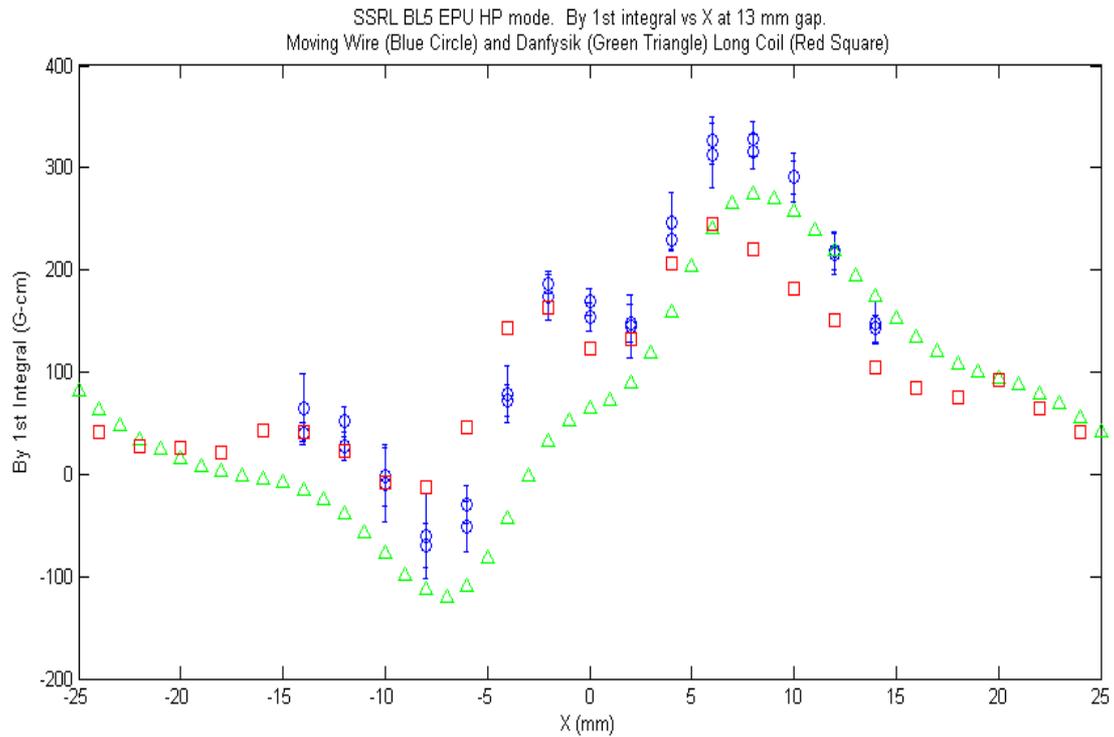


Figure 4: HP mode By 1st integral vs X measurements.

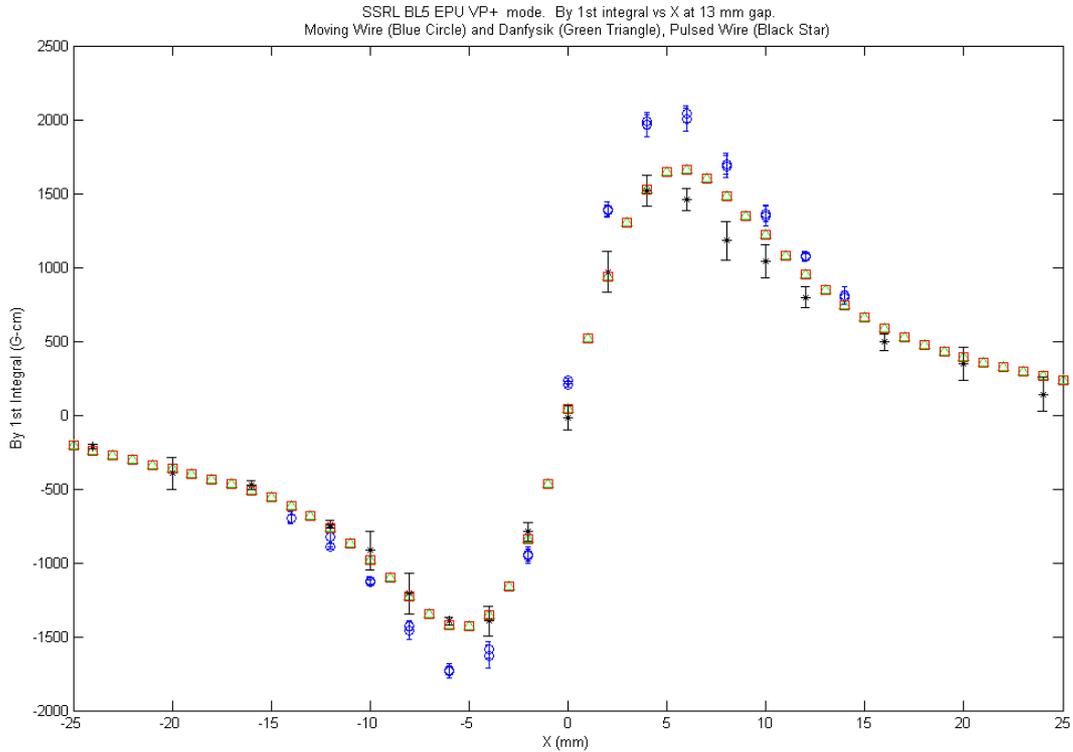


Figure 5: VP+ mode By 1st integral vs X measurements.

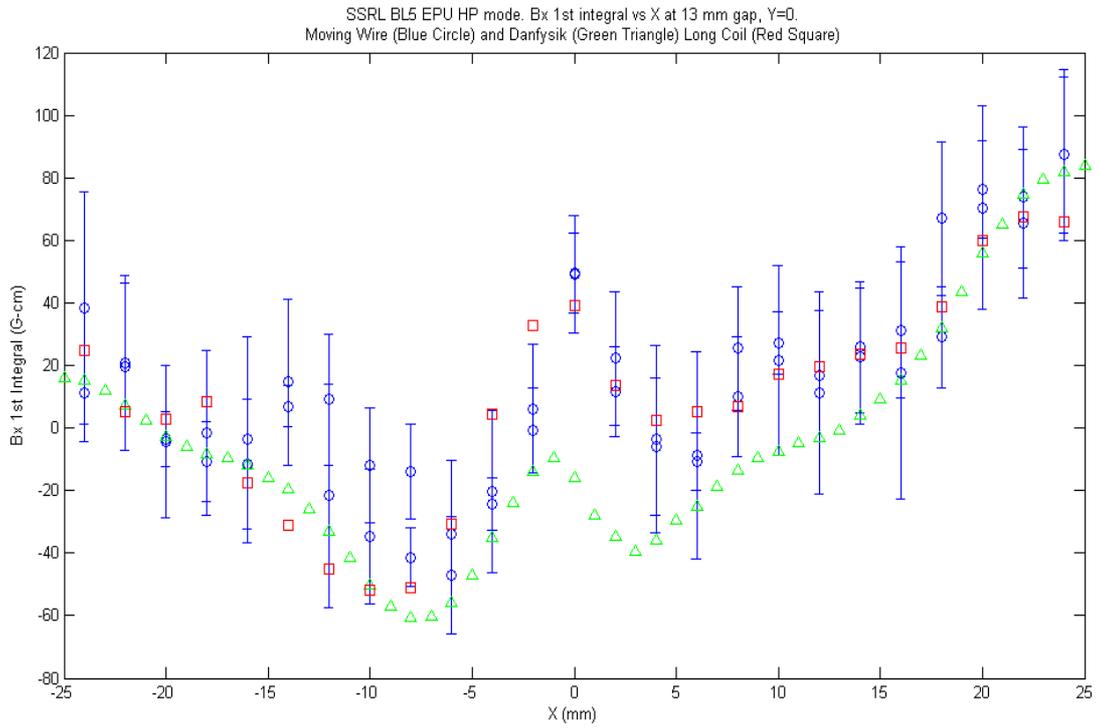


Figure 6: HP mode Bx 1st integral vs X measurements.

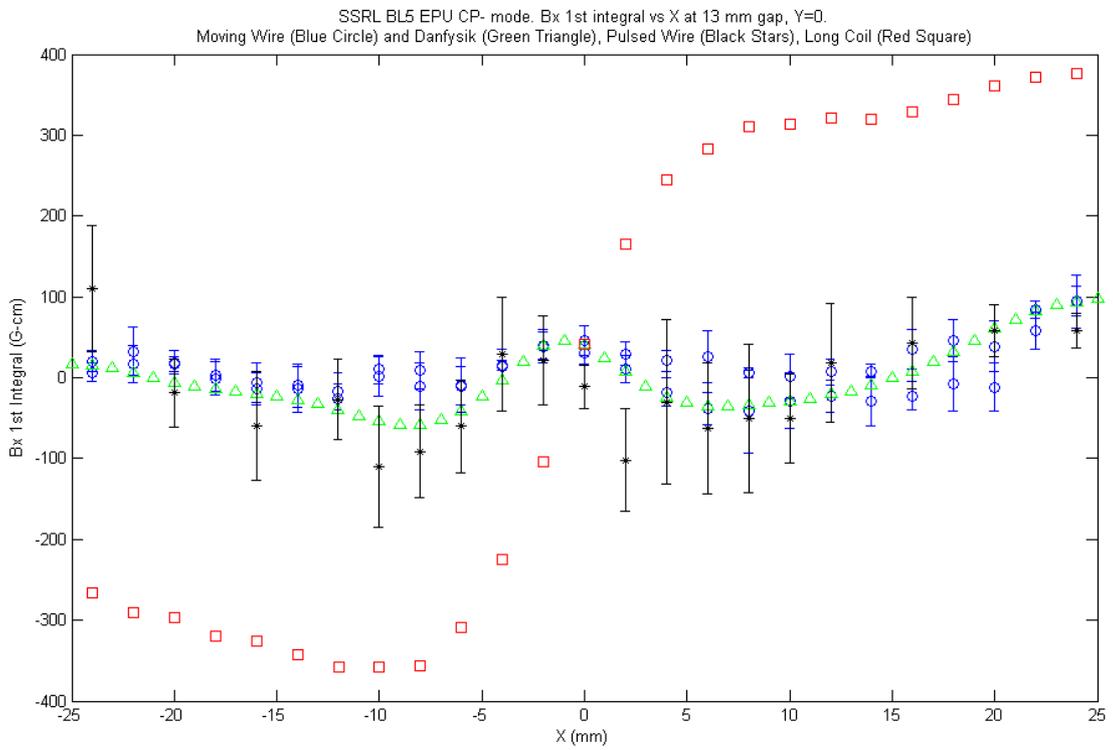


Figure 7: CP- mode Bx 1st integral vs X measurements.

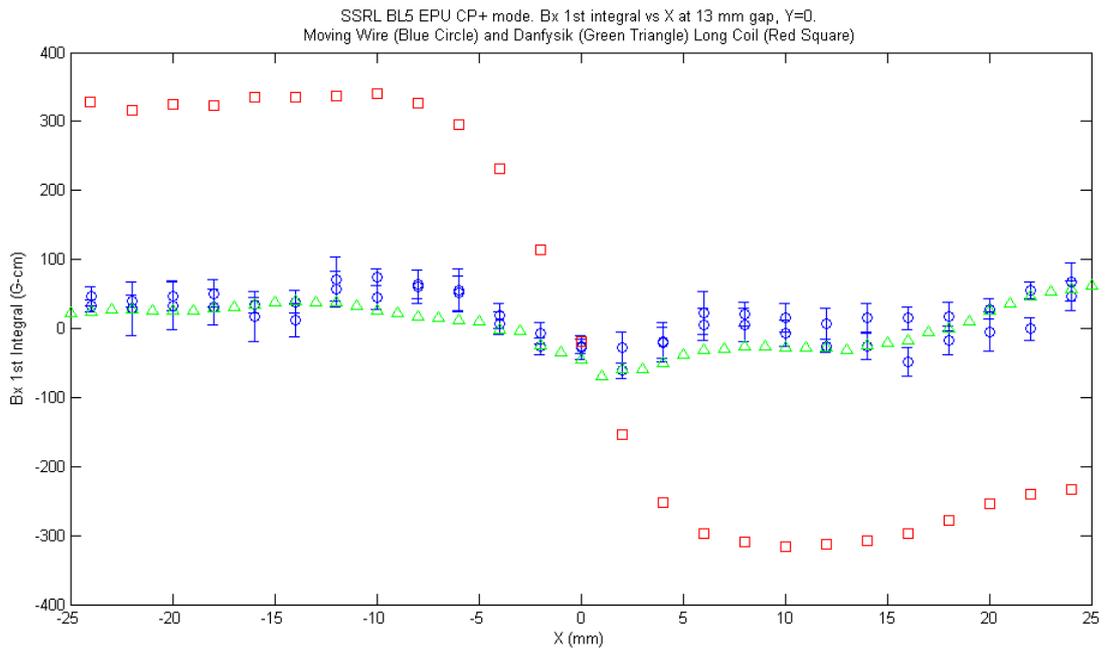


Figure 8: CP+ mode Bx 1st integral vs X measurements.

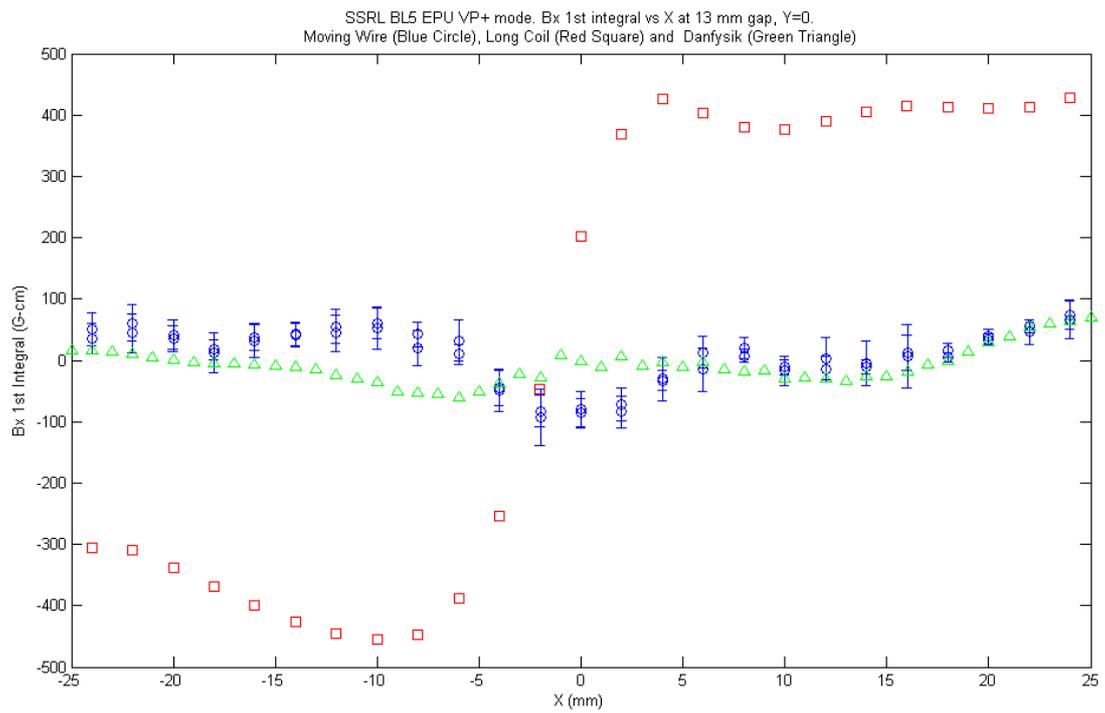


Figure 9: VP+ mode Bx 1st integral vs X measurements.

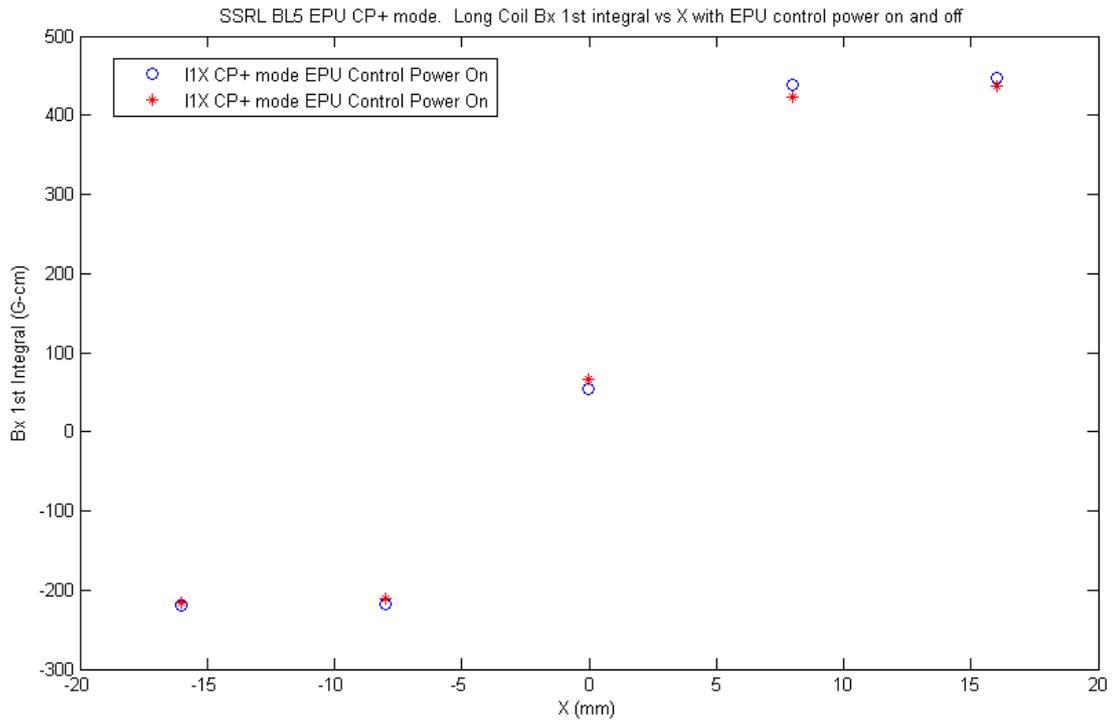


Figure 10: CP+ mode Bx 1st integral vs X measurements with EPU control power on and off

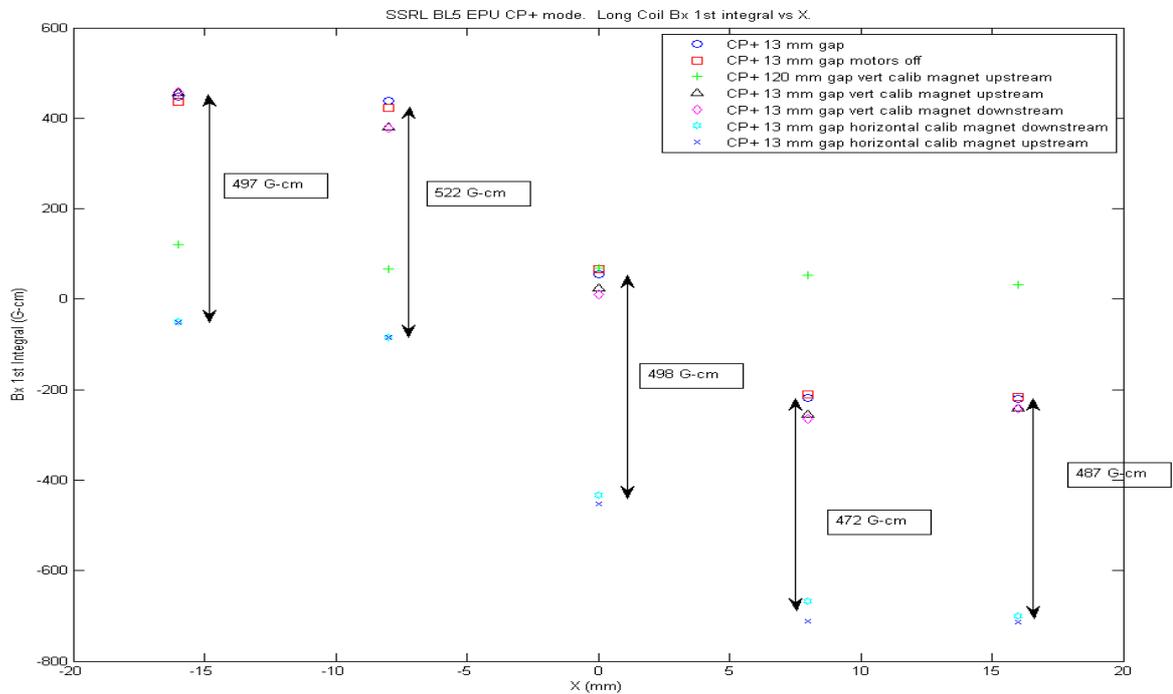


Figure 11: CP+ mode Bx 1st integral vs. X measurements with calibration magnets

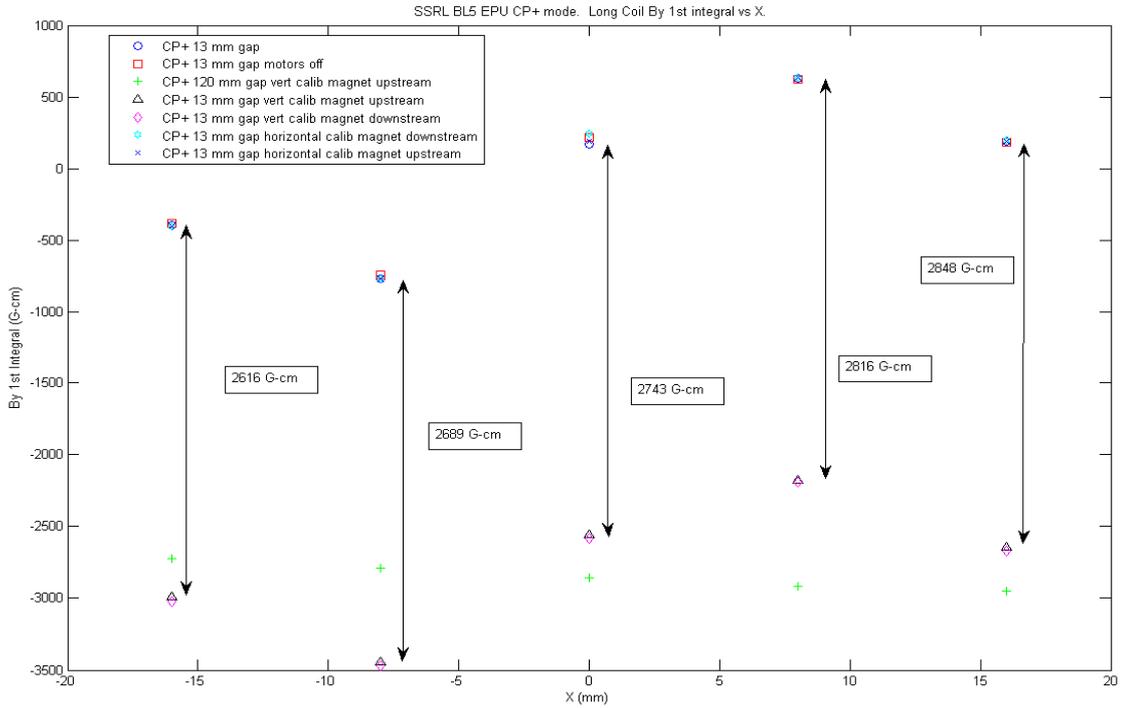


Figure 12: CP+ mode By 1st integral vs. X measurements with calibration magnets

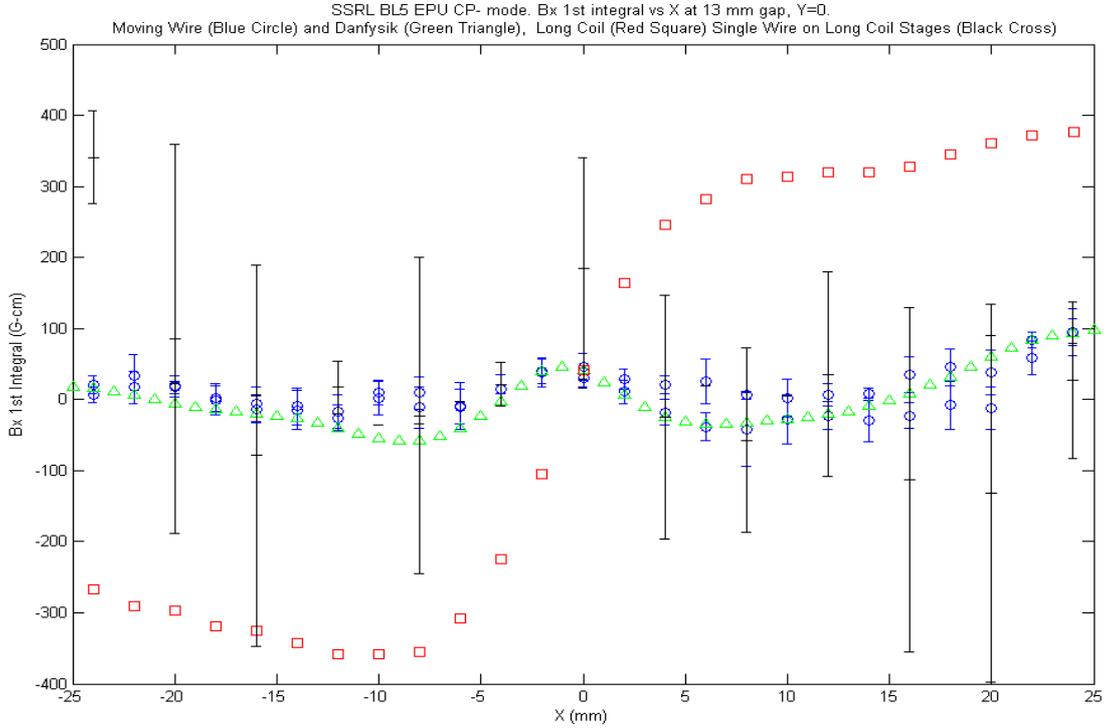


Figure 13: CP- mode Bx 1st integral vs. X measurements with Single Wire on long coil System

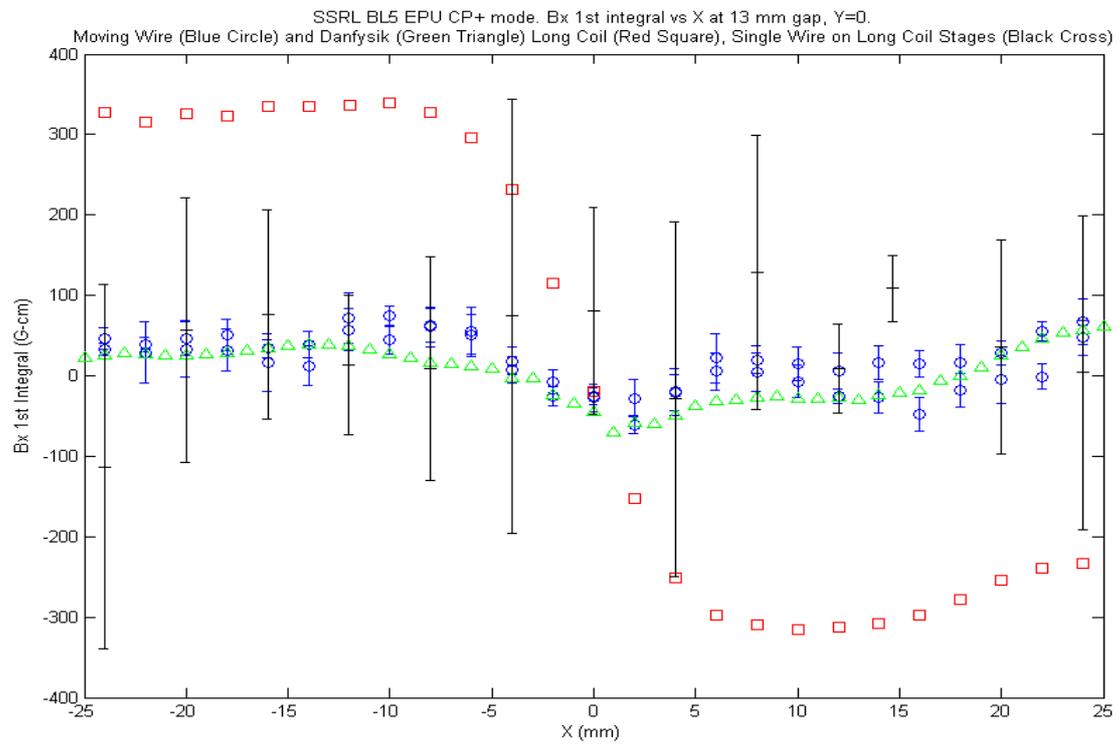


Figure 14: CP+ mode Bx 1st integral vs. X measurements with Single Wire on long coil System

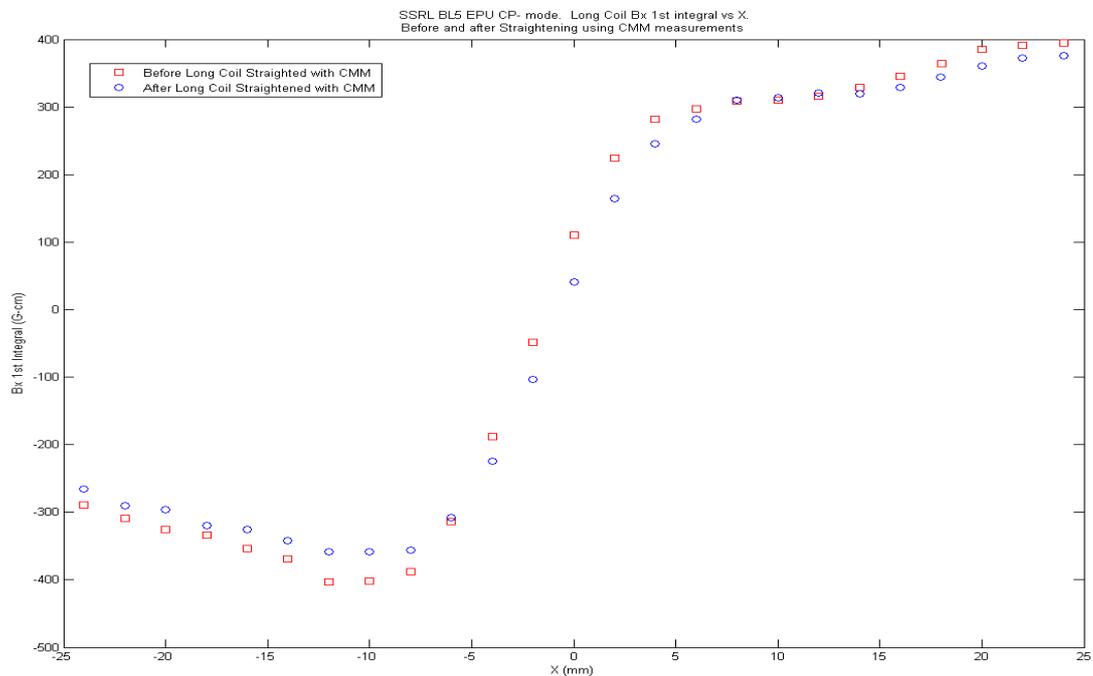


Figure 15: CP- mode Bx 1st integral vs. X measurements before and after long coil straightening.

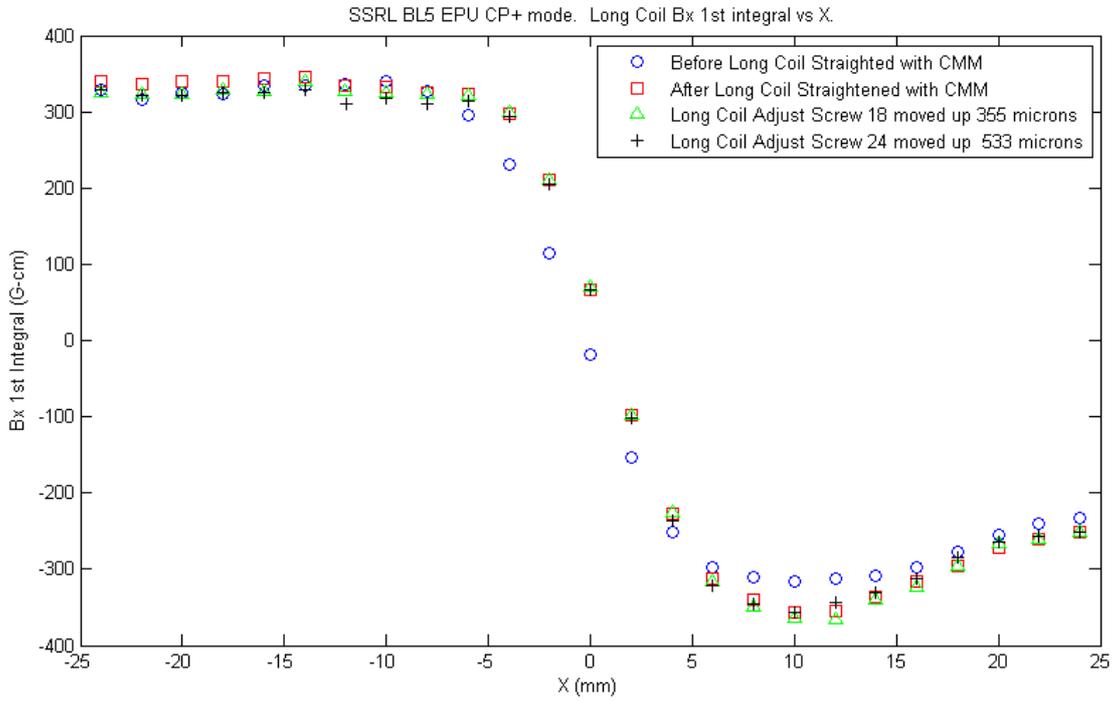


Figure 16: CP+ mode Bx 1st integral vs. X measurements before and after straightening. Adjustment screws 18 and 24 deliberately misaligned.

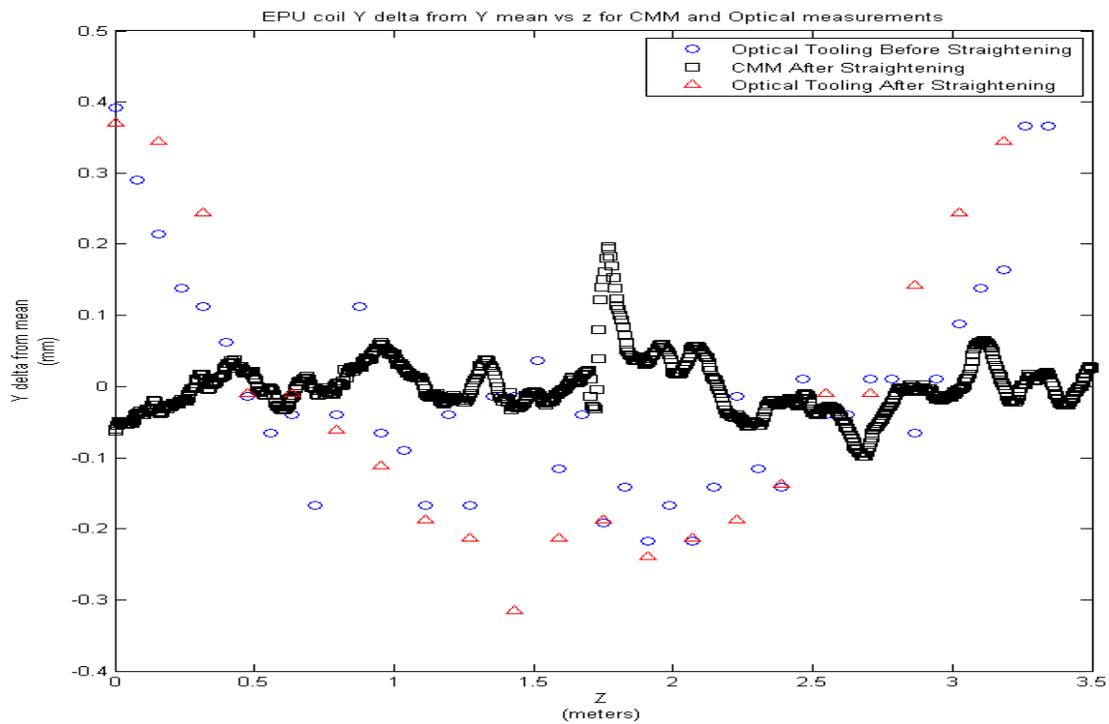


Figure 17: CMM and optical long coil alignment data

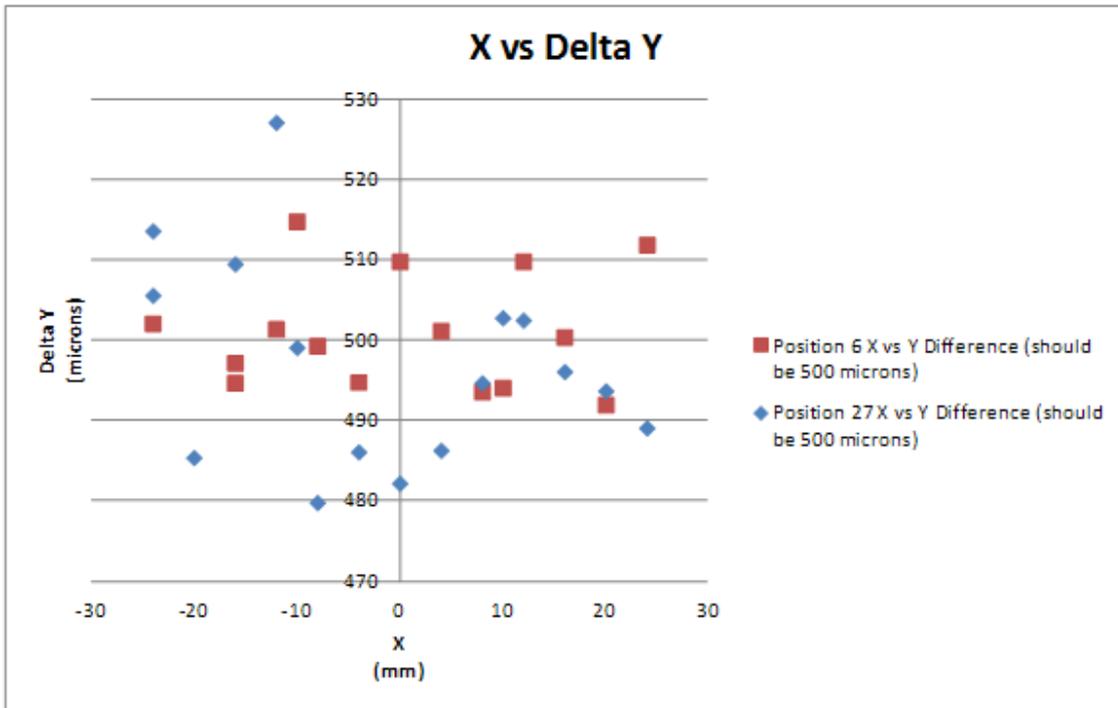


Figure 18: Long Coil laser tracker delta Y data

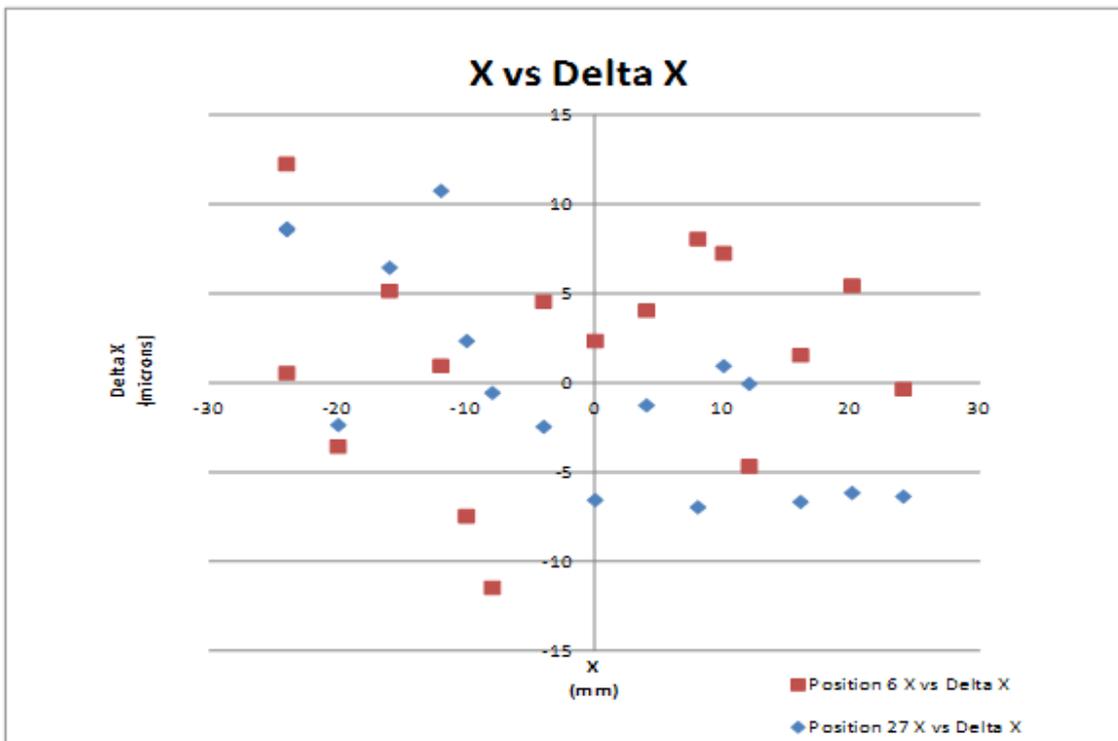


Figure 19: Long Coil laser tracker delta X data