# SLAC Traveler for LCLS-II Undulator Quad Measurement Results

This traveler is intended to cover the evaluation of the magnetic measurements of an Undulator Quadrupole magnet. It contains items to be checked off against tolerances as well as documentary information both in graphical and textual representation.

| | |
|---|---|
| SLAC Barcode Number: | 4267 |
| Vendor Serial Number: | 70 |

## Measurement Procedure:

The measurements have been carried out according to the current version of the "LCLS Undulator Quad Traveler".

## Measurement Results are stored:

## At V-Drive:

☒ V:\MET\MagServe\MagData\LCLS-II-HE\Quad\

☐ _____

## In Folder

☒ 4267\Final Results\

☐ _____

## Confirmation of File Locations:

The following table lists all required data files documenting the tuning results. An existence check was done and the result is indicated next to each filename as "exists" or "missing".

| | |
|---|---|
| strplt.ru1 | exists |
| hardat.ru1 | exists |
| ctrdat.ru2 | exists |
| ctrdat.ru3 | exists |
| ctrdat.ru4 | exists |
| index.dat | exists |
| Quad 4267 Wire Fiducial Tooling Ball Data.txt | exists |

## Summary of all Quadrupole Measurements: Data Listings A—E

| | | | | |
|---|---|---|---|---|
| | MATLAB function "evaluate Measurements" executed on | 8/29/2024 16:41 | | |
| A. | SCAN PARAMETERS | | | |
| | Vendor Serial Number | 70 | | |
| | Barcode | 4267 | | |
| | Type | SXRQUAD | | |
| B. | STRENGTH EVALUATION | | | |
| | Scanning Date & Time | 6/7/2024 13:38 | | |
| | IQF (up) | +4.1575928±0.0000041 | A | |
| | IQD (up) | −4.0953768±0.0000041 | A | |
| C. | HARMONICS EVALUATION | | | |
| | Scanning Date & Time | 6/7/2024 13:38 | | |
| | $B\rho \times\ K1L/IQ$ (tolerance >0.7 T/A) | +0.727011±0.000018 | T/A | (ok) |
| | $B\rho \times\ K2L/IQ$ (tolerance abs <1.5 $\mathrm{Tm}^{-1}$/A) | −0.0629±0.0016 | $\mathrm{Tm}^{-1}$/A | (ok) |
| D. | WIRE FIDUCIALIZATION RESULTS | | | |
| | X pos (TB4) | -167.261 | mm | |
| | Y pos (TB1,2,3,5) | +173.135 | mm | |
| | Z pos (TB1,2,3,5) | -9.540 | mm | |
| E. | CORRECTOR COEFFICIENTS | | | |
| | XCU Coefficient | +165.428 | A/kGm | |
| | YCU Coefficient | +166.778 | A/kGm | |

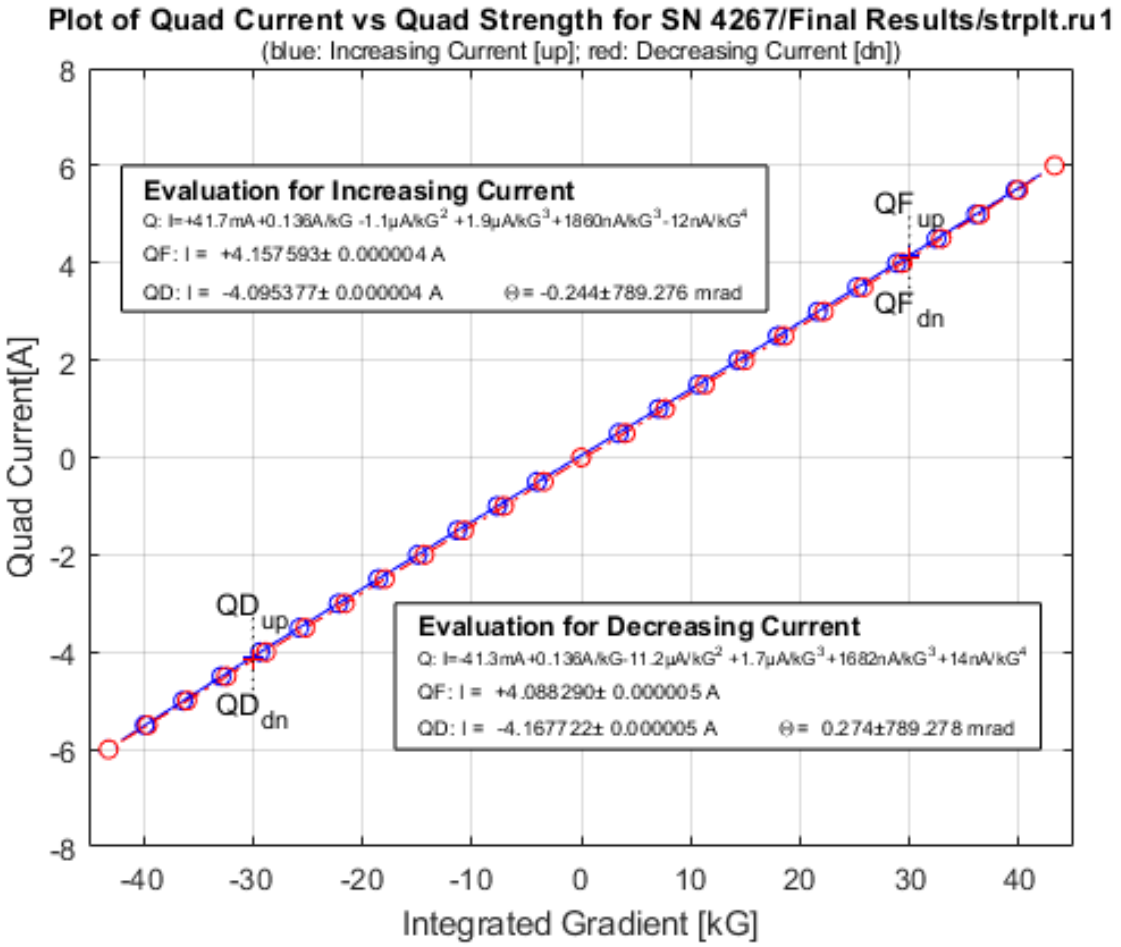
## Summary of QF Quadrupole Measurements: Data Listing F

| | | | |
|---|---|---|---|
| MATLAB function "evaluate Measurements" executed on | 8/29/2024 16:41 | | |
| F. QF CENTER EVALUATION | | | |
| Scanning Date & Time | 6/7/2024 10:47 | | |
| MODULATION | | | |
| Start Current | +4.49870±0.00010 | A | |
| Max Current | +5.50060±0.00010 | A | |
| Min Current | +3.49950±0.00010 | A | |
| Max $\Delta x$ | +1.14±0.54 | $\mu$m | |
| Max $\Delta y$ | +1.7±1.2 | $\mu$m | |
| Deviation | +1.9±2.2 | $\mu$m | |
| Center Motion Mid x | +0.25±0.12 | $\mu$m | |
| Center Motion Mid y | −1.7±1.2 | $\mu$m | |
| Center Motion Radius (tolerance <3 $\mu$m) | +1.8±1.2 | $\mu$m | (ok) |
| XCOR/YCOR 0.5 A max | | | |
| $\langle \Delta I_V \rangle$ | +1.00140±0.00010 | A | |
| $\langle \Delta I_H \rangle$ | +0.99940±0.00010 | A | |
| $\Delta C_x / \Delta I_H$ | +183.38±0.74 | $\mu$m/A | |
| $\Delta \Theta_x / \Delta I_H$ @ 8.00 GeV | +22.303±0.089 | $\mu$rad/A | |
| $\Delta C_y / \Delta I_V$ | +183.54±0.74 | $\mu$m/A | |
| $\Delta \Theta_y / \Delta I_V$ @ 8.00 GeV | +22.322±0.089 | $\mu$rad/A | |
| $x_C$ (tolerance abs <3 $\mu$m) | −1.2±1.0 | $\mu$m | (ok) |
| $y_C$ (tolerance abs <3 $\mu$m) | −0.6±1.1 | $\mu$m | (ok) |
| XCOR/YCOR 1.0 A max | | | |
| $\langle \Delta I_V \rangle$ | +2.003550±0.000071 | A | |
| $\langle \Delta I_H \rangle$ | +2.00180±0.00010 | A | |
| $\Delta C_x / \Delta I_H$ | +185.16±0.82 | $\mu$m/A | |
| $\Delta \Theta_x / \Delta I_H$ @ 8.00 GeV | +22.52±0.20 | $\mu$rad/A | |
| $\Delta C_y / \Delta I_V$ | +183.66±0.82 | $\mu$m/A | |
| $\Delta \Theta_y / \Delta I_V$ @ 8.00 GeV | +22.34±0.20 | $\mu$rad/A | |
| $x_C$ (tolerance abs <3 $\mu$m) | −1.9±1.1 | $\mu$m | (ok) |
| $y_C$ (tolerance abs <3 $\mu$m) | +0.7±1.9 | $\mu$m | (ok) |

## Summary of QD Quadrupole Measurements: Data Listing G

| | | | |
|---|---|---|---|
| MATLAB function "evaluate Measurements" executed on | 8/29/2024 16:41 | | |
| G. QD CENTER EVALUATION | | | |
| Scanning Date & Time | 6/7/2024 10:47 | | |
| MODULATION | | | |
| Start Current | $-4.50020 \pm 0.00010$ | A | |
| Max Current | $-3.50110 \pm 0.00010$ | A | |
| Min Current | $-5.50220 \pm 0.00010$ | A | |
| Max $\Delta x$ | $+0.6 \pm 1.2$ | $\mu$m | |
| Max $\Delta y$ | $+2.23 \pm 0.55$ | $\mu$m | |
| Deviation | $+1.7 \pm 2.1$ | $\mu$m | |
| Center Motion Mid x | $+0.5 \pm 1.0$ | $\mu$m | |
| Center Motion Mid y | $-1.26 \pm 0.31$ | $\mu$m | |
| Center Motion Radius (tolerance <3 $\mu$m) | $+2.2 \pm 1.1$ | $\mu$m | (ok) |
| XCOR/YCOR 0.5 A max | | | |
| $\langle \Delta I_V \rangle$ | $+1.00140 \pm 0.00010$ | A | |
| $\langle \Delta I_H \rangle$ | $+0.99940 \pm 0.00010$ | A | |
| $\Delta C_x / \Delta I_H >$ | $+183.38 \pm 0.74$ | $\mu$m/A | |
| $\Delta \Theta_x / \Delta I_H >$ @ 8.00 GeV | $+22.568 \pm 0.090$ | $\mu$rad/A | |
| $\Delta C_y / \Delta I_V >$ | $+183.54 \pm 0.74$ | $\mu$m/A | |
| $\Delta \Theta_y / \Delta I_V >$ @ 8.00 GeV | $+22.587 \pm 0.090$ | $\mu$rad/A | |
| $x_C$ (tolerance abs <3 $\mu$m) | $+1.2 \pm 1.0$ | $\mu$m | (ok) |
| $y_C$ (tolerance abs <3 $\mu$m) | $+0.6 \pm 1.1$ | $\mu$m | (ok) |
| XCOR/YCOR 1.0 A max | | | |
| $\langle \Delta I_V \rangle$ | $+2.003550 \pm 0.000071$ | A | |
| $\langle \Delta I_H \rangle$ | $+2.00180 \pm 0.00010$ | A | |
| $\Delta C_x / \Delta I_H >$ | $+185.16 \pm 0.82$ | $\mu$m/A | |
| $\Delta \Theta_x / \Delta I_H >$ @ 8.00 GeV | $+22.79 \pm 0.20$ | $\mu$rad/A | |
| $\Delta C_y / \Delta I_V >$ | $+183.66 \pm 0.82$ | $\mu$m/A | |
| $\Delta \Theta_y / \Delta I_V >$ @ 8.00 GeV | $+22.60 \pm 0.20$ | $\mu$rad/A | |
| $x_C$ (tolerance abs <3 $\mu$m) | $+1.9 \pm 1.1$ | $\mu$m | (ok) |
| $y_C$ (tolerance abs <3 $\mu$m) | $-0.7 \pm 1.9$ | $\mu$m | (ok) |

## Evaluation of Strength Data: Fit of Current vs. Integrated Quad Gradient




The figure shows the quadrupole current vs. the integrated quadrupole gradient over the full range of quadrupole currents for both the up and down directions of current changes. The circles mark the data points. The nominal working points for the QD and QF functions are marked by crosses. The corresponding currents and the polynomial coefficients are listed in the boxes. $\Delta\Theta$ is the rms of the quadrupole skew angle along the current range. The quadrupole magnet has been standardized with the corrector currents set to zero. The standardization cycle ended at the -6 A. The corrector currents were kept at zero during the procedure.

## Evaluation of Strength Data: Fit Coefficients

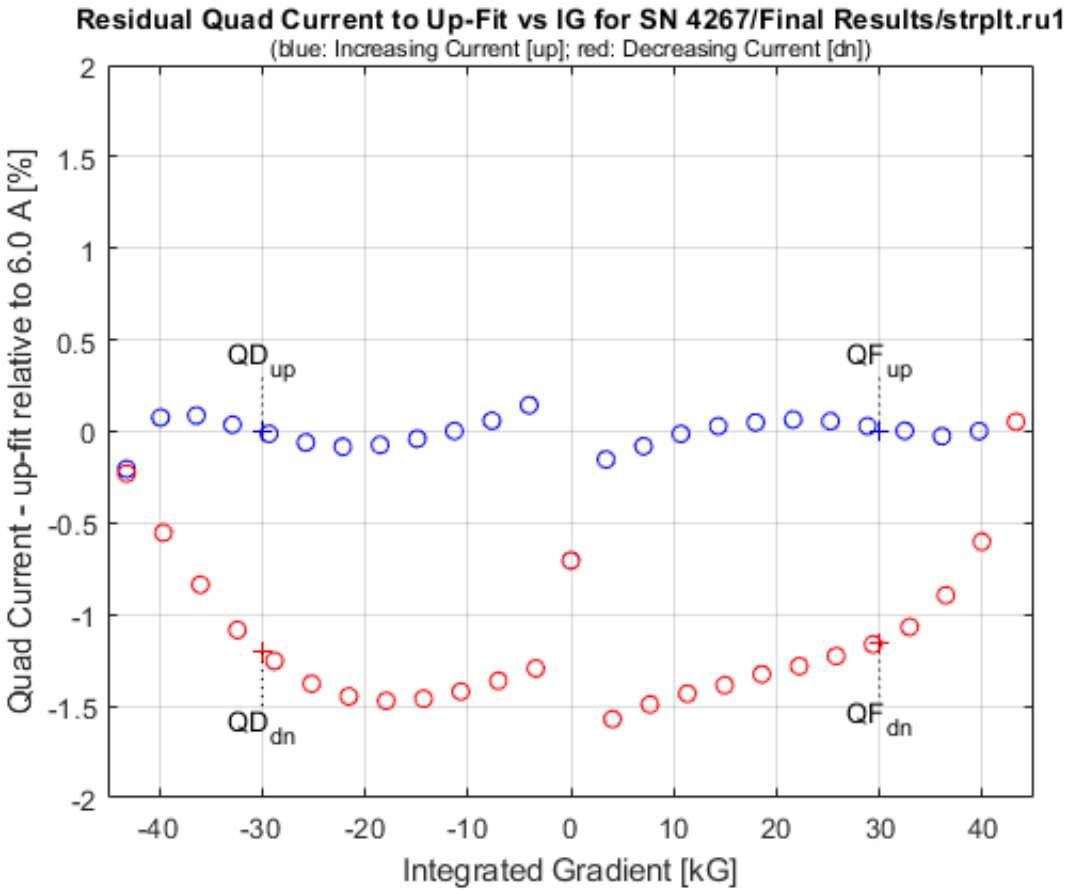
Measured values of the integrated quadrupole gradient $\Gamma = \int \frac{dB_x}{dy} dz = \int \frac{dB_y}{dx} dz$ in the 'up' direction (current settings from -6.0 A to +6.0 A in 0.5-A steps). These 'up-direction' polynomial coefficients will be used by operations

$$I_{up}(\Gamma) = \sum_{n=0}^{5} c_n \Gamma^n \qquad \Longrightarrow$$

| | | | |
|---|---|---|---|
| +0.4166517 | ±0.0000382 | $\times 10^{-1}$ | A |
| +1.3608643 | ±0.0000038 | $\times 10^{-1}$ | A/kG |
| -1.1304346 | ±0.0137912 | $\times 10^{-6}$ | A/kG$^2$ |
| +1.8600485 | ±0.0007615 | $\times 10^{-6}$ | A/kG$^3$ |
| -0.1177750 | ±0.0000892 | $\times 10^{-7}$ | A/kG$^4$ |
| -0.2604641 | ±0.0003664 | $\times 10^{-9}$ | A/kG$^5$ |

☒ Coefficients checked for completeness and correctness.

## Evaluation of Strength Data: Current vs. Integrated Quad Gradient (rel)

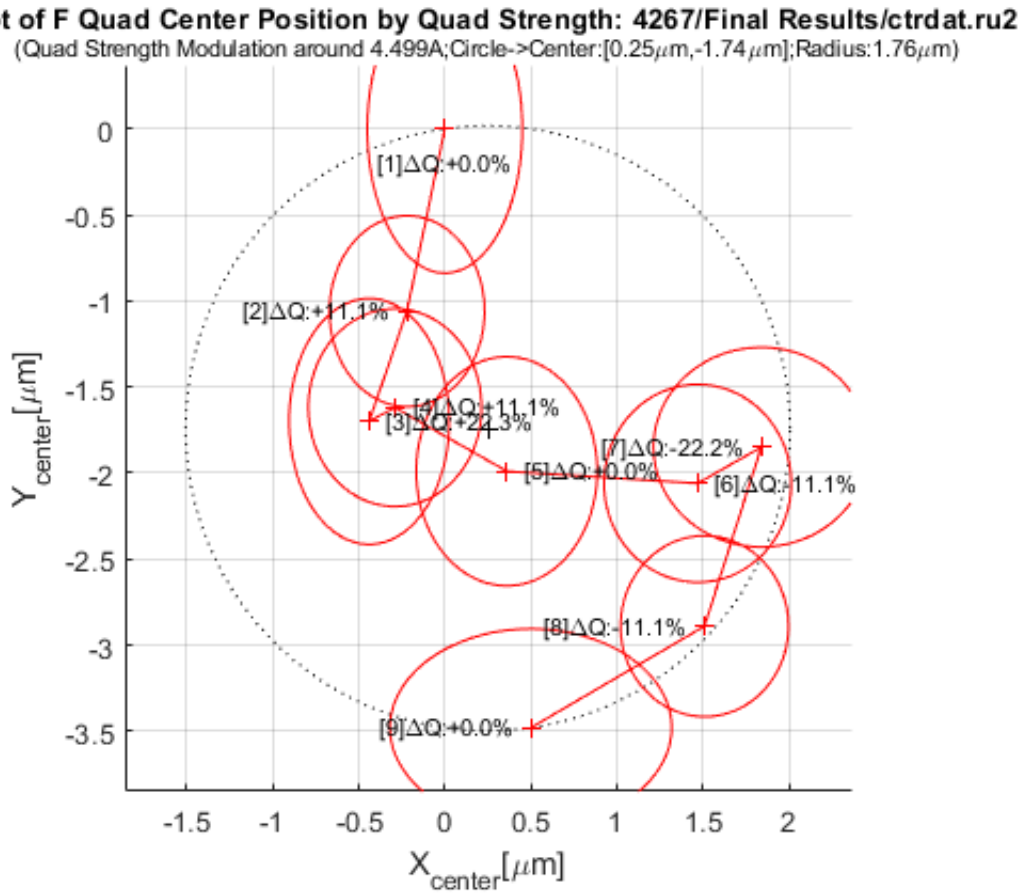



The figure shows residuals of integrated quadrupole gradient vs. quadrupole current relative to the maximum quadrupole current of +6.0 A over the full range of quadrupole currents for both the up and down directions. The residuals are calculated with respect to the up-fit polynomial. The circles mark the data points. The nominal working points for the QD and QF functions ($QD_{up}$, $QF_{up}$) as well as the corresponding points for the down directions ($QD_{dn}$, $QF_{dn}$) are marked by crosses.
The relative residual Quad Currents, ("Quad Current-up-fit relative to 6.0 A [%]"), $\Delta I_{res,up}$, are calculated using.

$$\Delta I_{res,up} = \left(I_{meas} - I_{fit,up}\right) / I_{max}$$

where the $I_{meas}$ are the quadrupole current readings, the $I_{fit,up}$ are the corresponding quadruole current values calculated from a fit to the up-data, and $I_{max}$ is the maximum quadurpole current, use (+6 A).

## Magnetic Center Movement under QF Gradient Scans

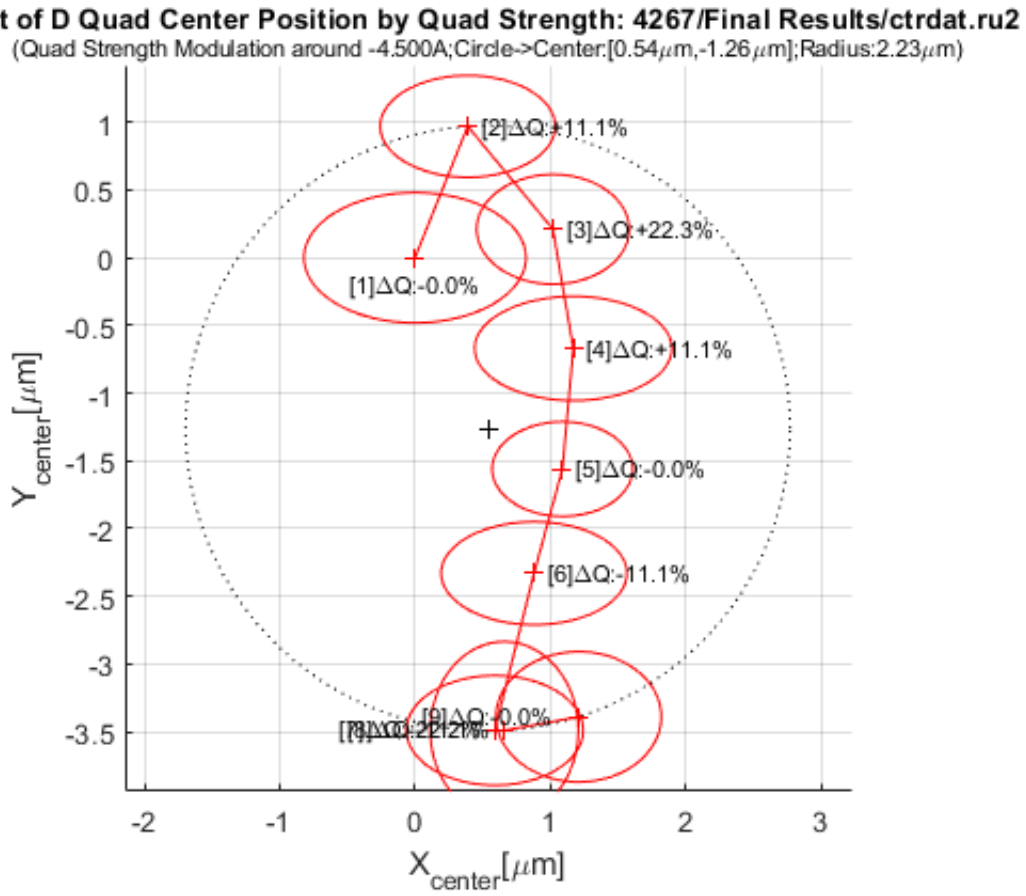



The figure shows the change in position of the magnetic center of the quadrupole (relative to the starting position) under scans of the quadrupole gradient. For this measurement, the dipole correctors have been turned off and the quadrupole has been standardized using the main quadrupole current to a final value of -6 A. From there, the main quadrupole current was raised to the starting point of the procedure at about +4.3 A (see the exact starting current underneath the title line), the nominal operating point for LCLS Undulator QF quadrupoles. The scanning procedure went to the following current settings

| n | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| $\Delta I$ | [A] | +0.0 | +0.5 | +1.0 | +0.5 | +0.0 | -0.5 | -1.0 | -0.5 | +0.0 |
| $I$ | [A] | +4.5 | +5.0 | +5.5 | +5.0 | +4.5 | +4.0 | +3.5 | +4.0 | +4.5 |
| $\Delta I_{rel}$ | [%] | +0.0 | +11.1 | +22.3 | +11.1 | +0.0 | -11.1 | -22.2 | -11.1 | +0.0 |

The dotted circle marks the range of center movement. The circle's center and radius values are listed underneath the figure title. The red error ellipses are based on the error data included in the '**ctrdat** file.

## Magnetic Center Movement under QD Gradient Scans




The figure shows the change in position of the magnetic center of the quadrupole (relative to the starting position) under scans of the quadrupole gradient. For this measurement, the dipole correctors have been turned off and the quadrupole has been standardized using the main quadrupole current to a final value of -6 A. From there, the main quadrupole current was raised to the starting point of the procedure at about +4.3 A (see the exact starting current underneath the title line), the nominal operating point for LCLS Undulator QD quadrupoles. The scanning procedure went to the following current settings

| n | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| $\Delta I$ | [A] | +0.0 | -0.5 | -1.0 | -0.5 | +0.0 | +0.5 | +1.0 | +0.5 | +0.0 |
| $I$ | [A] | -4.5 | -5.0 | -5.5 | -5.0 | -4.5 | -4.0 | -3.5 | -4.0 | -4.5 |
| $\Delta I_{rel}$ | [%] | -0.0 | +11.1 | +22.3 | +11.1 | -0.0 | -11.1 | -22.2 | -11.1 | -0.0 |

The dotted circle marks the range of center movement. The circle's center and radius values are listed underneath the figure title. The red error ellipses are based on the error data included in the **ctrdat** file.

## Quadrupole Harmonics Analysis

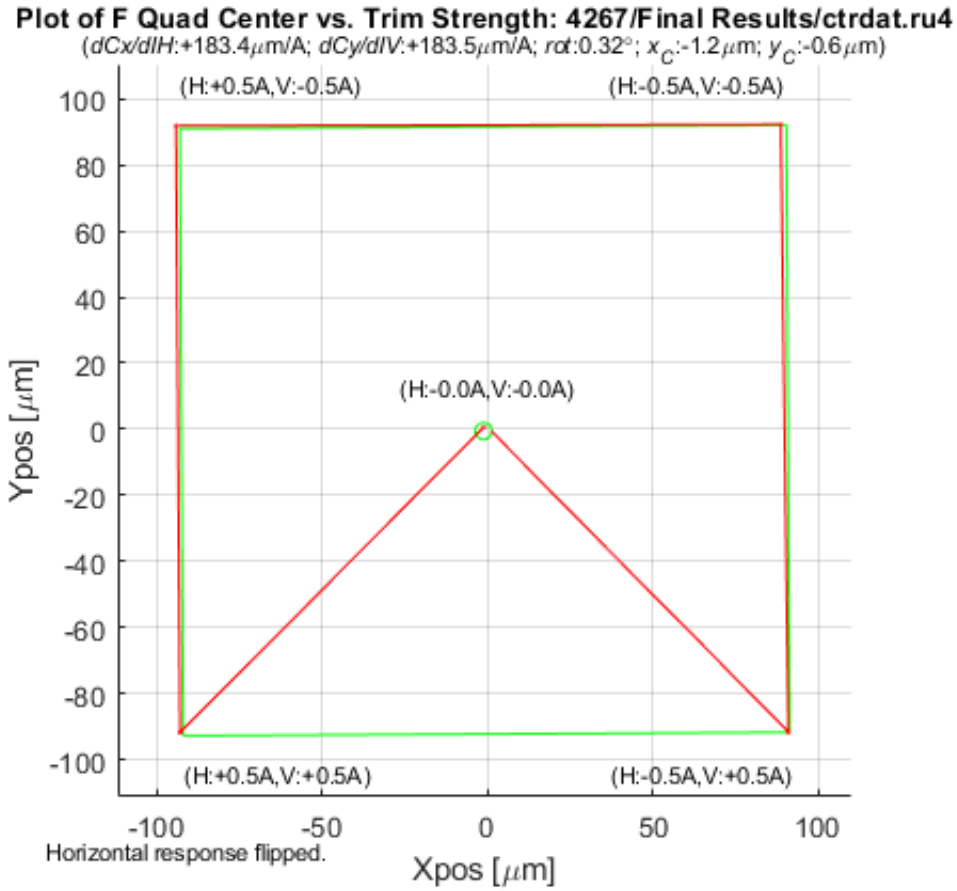
The next table lists the amplitudes and angles of first 5 field harmonics (h1: quadrupole, h2: sextupole, h3: octupole, h4: dekapole, h5: dodekapole). The amplitudes are expressed as the integrated field strength per unit excitation current for the individual harmonics component on a circle of the specified radius with respect to the magnetic center of the quadrupole magnet. The angles are the deviations of the orientation of each harmonic from its non-skew orientation.
The harmonics analysis is listed at two different quadrupole excitation currents corresponding to the nominal QF (3 Tm) and QD (-3 Tm) functions of the magnet. See "B. STRENGTH EVALUATION" in the Summary Tables, above, for the corresponding current values. The quadrupole magnet was standardized with the corrector currents set to zero before the harmonics analysis was started. The standardization cycle ended at the -6 A. The corrector currents were kept at zero during the measurement.

| QF harmonics for barcode 4267 at radius +2.997 mm | | | | | | | |
|---|---|---|---|---|---|---|---|
| $h_1$ | +0.00217724±0.00000021 | Tm/A | | | $\Theta_1$ | -0.170000 | ° |
| $h_2$ | -0.000000628±0.000000069 | Tm/A | $h_2/h_1$ | -0.000288±0.000032 | $\Theta_2$ | -21.0±3.2 | ° |
| $h_3$ | -0.00000201±0.00000010 | Tm/A | $h_3/h_1$ | -0.000922±0.000047 | $\Theta_3$ | -3.9±1.2 | ° |
| $h_4$ | -0.00000039±0.00000021 | Tm/A | $h_4/h_1$ | -0.000177±0.000098 | $\Theta_4$ | +4.6±7.8 | ° |
| $h_5$ | +0.000000050±0.000000100 | Tm/A | $h_5/h_1$ | +0.000023±0.000046 | $\Theta_5$ | +4± 29 | ° |
| | | | | | | | |
| QD harmonics for barcode 4267 at radius +2.997 mm | | | | | | | |
| $h_1$ | +0.00217369±0.00000025 | Tm/A | | | $\Theta_1$ | -0.170000 | ° |
| $h_2$ | -0.000000500±0.000000060 | Tm/A | $h_2/h_1$ | -0.000230±0.000027 | $\Theta_2$ | -23.8±1.4 | ° |
| $h_3$ | -0.00000167±0.00000017 | Tm/A | $h_3/h_1$ | -0.000770±0.000077 | $\Theta_3$ | -6.5±1.3 | ° |
| $h_4$ | -0.00000022±0.00000021 | Tm/A | $h_4/h_1$ | -0.000102±0.000095 | $\Theta_4$ | -0.2±4.3 | ° |
| $h_5$ | -0.00000005±0.00000010 | Tm/A | $h_5/h_1$ | -0.000022±0.000048 | $\Theta_5$ | +0.3±8.6 | ° |

The next table lists the harmonics integrated KL parameters according to the definitions used in the MAD code for 5 field harmonics (h1: quadrupole, h2: sextupole, h3: octupole, h4: dekapole, h5: dodekapole). The values are derived from the table above.

| QF KL values for barcode 4267 at 8.00 GeV | | | |
|---|---|---|---|
| K1L | +0.112422±0.000011 | | $m^{-1}$ |
| K2L | -0.0108±0.0012 | | $m^{-2}$ |
| K3L | -1.153±0.059 | ×10 | $m^{-3}$ |
| K4L | -0.74±0.41 | $\times 10^3$ | $m^{-4}$ |
| K5L | +0.032±0.064 | $\times 10^6$ | $m^{-5}$ |
| | | | |
| QD KL values for barcode 4267 at 8.00 GeV | | | |
| K1L | +0.112422±0.000013 | | $m^{-1}$ |
| K2L | -0.0086±0.0010 | | $m^{-2}$ |
| K3L | -0.964±0.096 | ×10 | $m^{-3}$ |
| K4L | -0.43±0.40 | $\times 10^3$ | $m^{-4}$ |
| K5L | -0.031±0.066 | $\times 10^6$ | $m^{-5}$ |

## Evaluation of XCOR/YCOR Action (±0.5 A) on QF: Magnetic Center Change

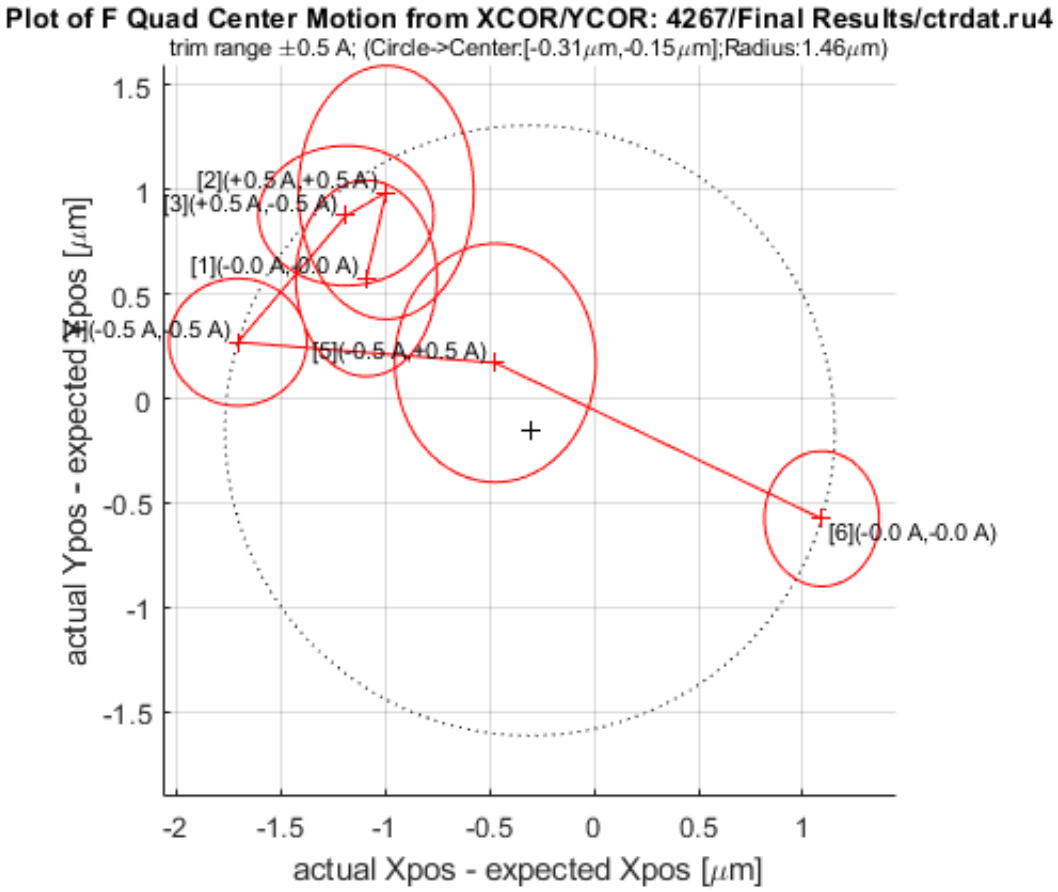



The figure shows the change in position of the magnetic center of the quadrupole (relative to the starting position) under changes of the dipole corrector currents over half of their ranges. For this measurement, the dipole correctors have initially been turned off and the quadrupole has been standardized using the main quadrupole current to a final value of -6 A. From there, the main quadrupole current was raised to the starting point of the procedure at about +4.3 A, the nominal operating point for LCLS Undulator QF quadrupoles. The scanning procedure went to the following current settings of the dipole correctors currents ($I_H$, $I_V$):

| n | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| $I_H$ | [A] | +0.0 | +0.5 | +0.5 | -0.5 | -0.5 | +0.0 |
| $I_V$ | [A] | +0.0 | +0.5 | -0.5 | -0.5 | +0.5 | +0.0 |

In the figure, the measured center positions are connected with red lines. Green lines indicate a rectangle, fitted to the measured positions. The parameters of the fitted rectangle are listed underneath the figure title: "$dCx/dIH$" is the XCOR gain. "$dCy/dIV$" is the YCOR gain. "$rot$" is the quadrupole roll error during the measurement, which is different and generally much larger than the roll of the installed quadrupole."$x_c$" and "$y_c$" are the center coordinates of the fit-rectangle with respect to the starting position. The average and rms deviation, $\Delta r$, of the measured quadrupole center positions from the corresponding corners of the fit-rectangle are listed at the lower right corner of the figure.

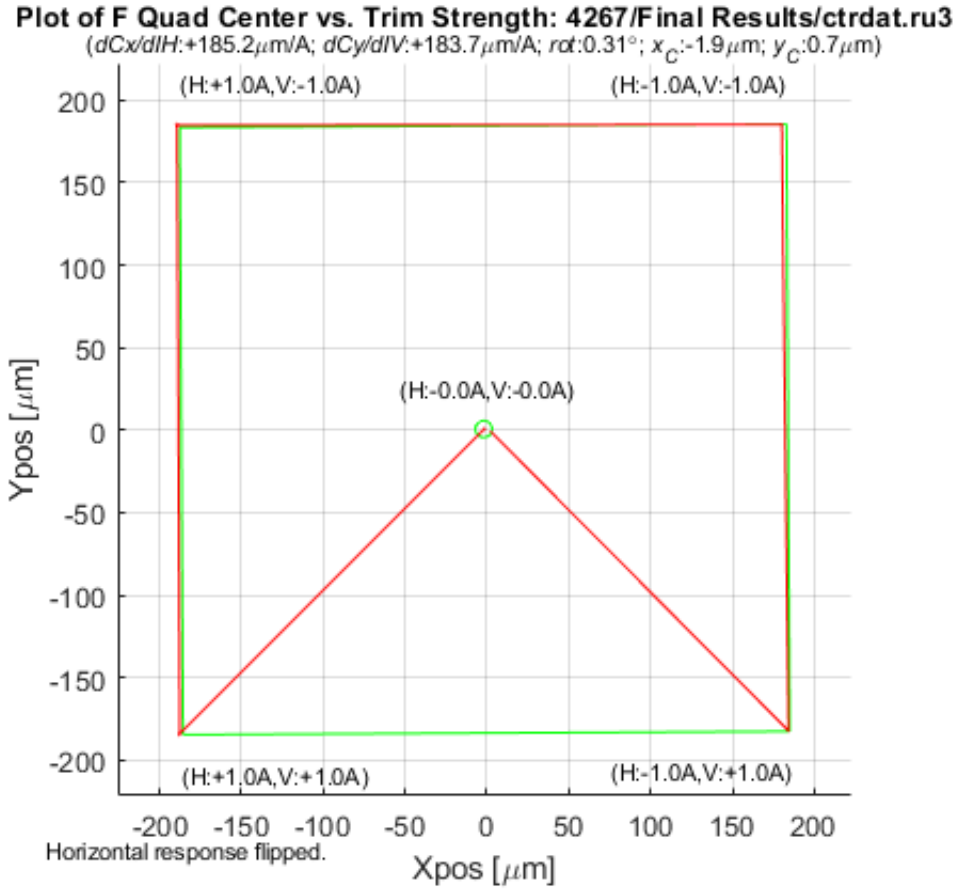
## Details of XCOR/YCOR Action (±0.5 A) on QF: Magnetic Center Miss




This figure is based on the same data as the figure on page 11. It shows, in the form of red crosses, the differences between the data points (the corners and the center point of the red curve in the figure on page 11) and the corners and the center of the green rectangle in that figure.

The red crosses are connected with red lines that follow the measurement sequence indicated by the first number in the associated point comment, which also shows the trim exitation currents associated with that data point. The red error ellipses, which are also present in the figure on page 11, but too small to recognize there, are based on the error values for the individual data points listed in the corresponding **ctrdat** file. The dotted line represents the smallest circle that captures the data points. The radius and the center cooridinates of that circle are printed underneath the figure title.

## Evaluation of XCOR/YCOR Action (±1.0 A) on QF: Magnetic Center Change

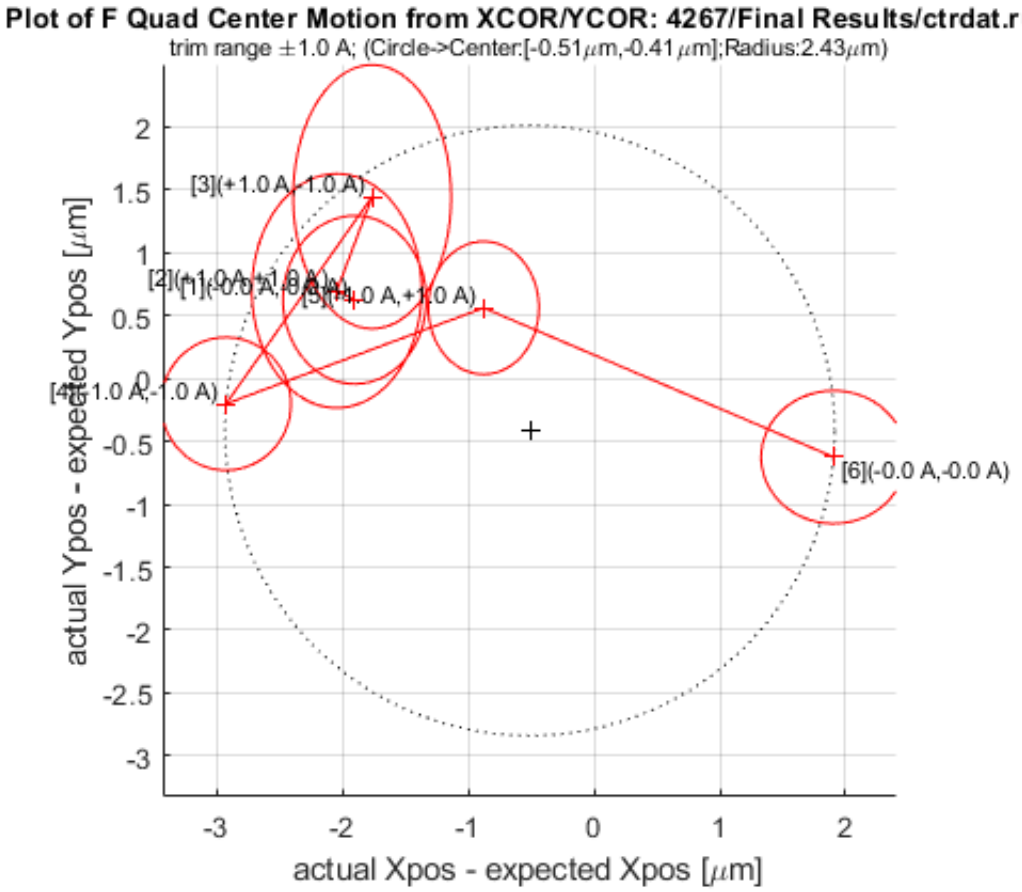



The figure shows the change in position of the magnetic center of the quadrupole (relative to the starting position) under changes of the dipole corrector currents over their full ranges. For this measurement, the dipole correctors have initially been turned off and the quadrupole has been standardized using the main quadrupole current to a final value of -6 A. From there, the main quadrupole current was raised to the starting point of the procedure at about +4.3 A, the nominal operating point for LCLS Undulator QF quadrupoles. The scanning procedure went to the following current settings of the dipole correctors currents ($I_H$, $I_V$):

| n | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| $I_H$ | [A] | +0.0 | +1.0 | +1.0 | -1.0 | -1.0 | +0.0 |
| $I_V$ | [A] | +0.0 | +1.0 | -1.0 | -1.0 | +1.0 | +0.0 |

In the figure, the measured center positions are connected with red lines. Green lines indicate a rectangle, fitted to the measured positions. The parameters of the fitted rectangle are listed underneath the figure title: "$dCx/dIH$" is the XCOR gain. "$dCy/dIV$" is the YCOR gain. "$rot$" is the quadrupole roll error during the measurement, which is different and generally much larger than the roll of the installed quadrupole."$x_c$" and "$y_c$" are the center coordinates of the fit-rectangle with respect to the starting position. The average and rms deviation, $\Delta r$, of the measured quadrupole center positions from the corresponding corners of the fit-rectangle are listed at the lower right corner of the figure.

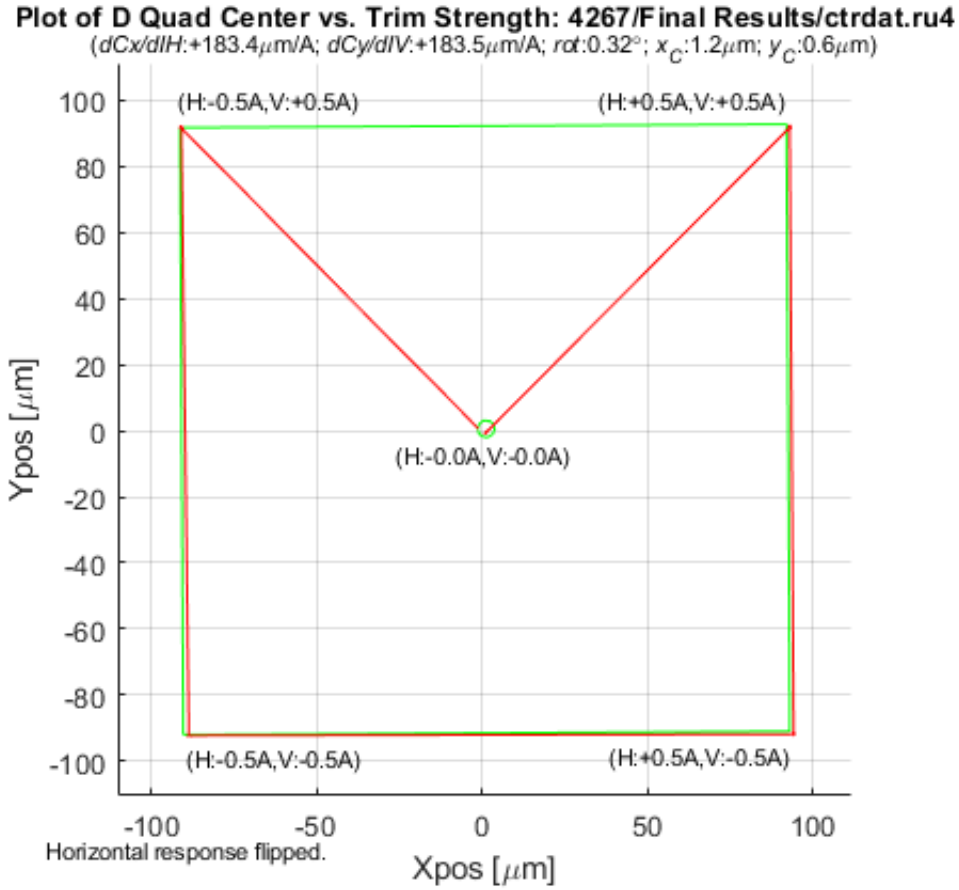
## Details of XCOR/YCOR Action (±1.0 A) on QF: Magnetic Center Miss




This figure is based on the same data as the figure on page 13. It shows, in the form of red crosses, the differences between the data points (the corners and the center point of the red curve in the figure on page 13) and the corners and the center of the green rectangle in that figure.

The red crosses are connected with red lines that follow the measurement sequence indicated by the first number in the associated point comment, which also shows the trim exitation currents associated with that data point. The red error ellipses, which are also present in the figure on page 13, but too small to recognize there, are based on the error values for the individual data points listed in the corresponding **ctrdat** file. The dotted line represents the smallest circle that captures the data points. The radius and the center cooridinates of that circle are printed underneath the figure title.

## Evaluation of XCOR/YCOR Action (±0.5 A) on QD: Magnetic Center Change

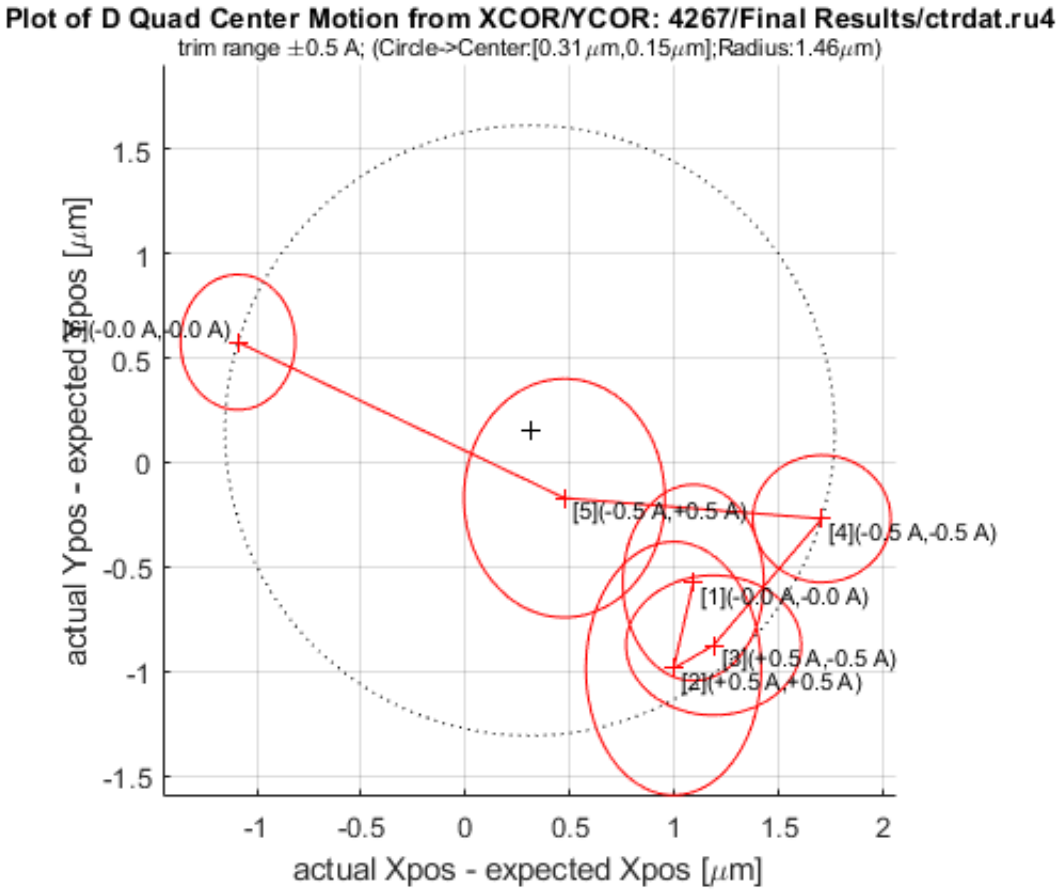



The figure shows the change in position of the magnetic center of the quadrupole (relative to the starting position) under changes of the dipole corrector currents over half of their ranges. For this measurement, the dipole correctors have initially been turned off and the quadrupole has been standardized using the main quadrupole current to a final value of -6 A. From there, the main quadrupole current was raised to the starting point of the procedure at about -4.3 A, the nominal operating point for LCLS Undulator QD quadrupoles. The scanning procedure went to the following current settings of the dipole correctors currents ($I_H$, $I_V$):

| n | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| $I_H$ | [A] | +0.0 | +0.5 | +0.5 | -0.5 | -0.5 | +0.0 |
| $I_V$ | [A] | +0.0 | +0.5 | -0.5 | -0.5 | +0.5 | +0.0 |

In the figure, the measured center positions are connected with red lines. Green lines indicate a rectangle, fitted to the measured positions. The parameters of the fitted rectangle are listed underneath the figure title: "$dCx/dIH$" is the XCOR gain. "$dCy/dIV$" is the YCOR gain. "$rot$" is the quadrupole roll error during the measurement, which is different and generally much larger than the roll of the installed quadrupole. "$xc$" and "$yc$" are the center coordinates of the fit-rectangle with respect to the starting position. The average and rms deviation, $\Delta r$ , of the measured quadrupole center positions from the corresponding corners of the fit-rectangle are listed at the lower right corner of the figure.

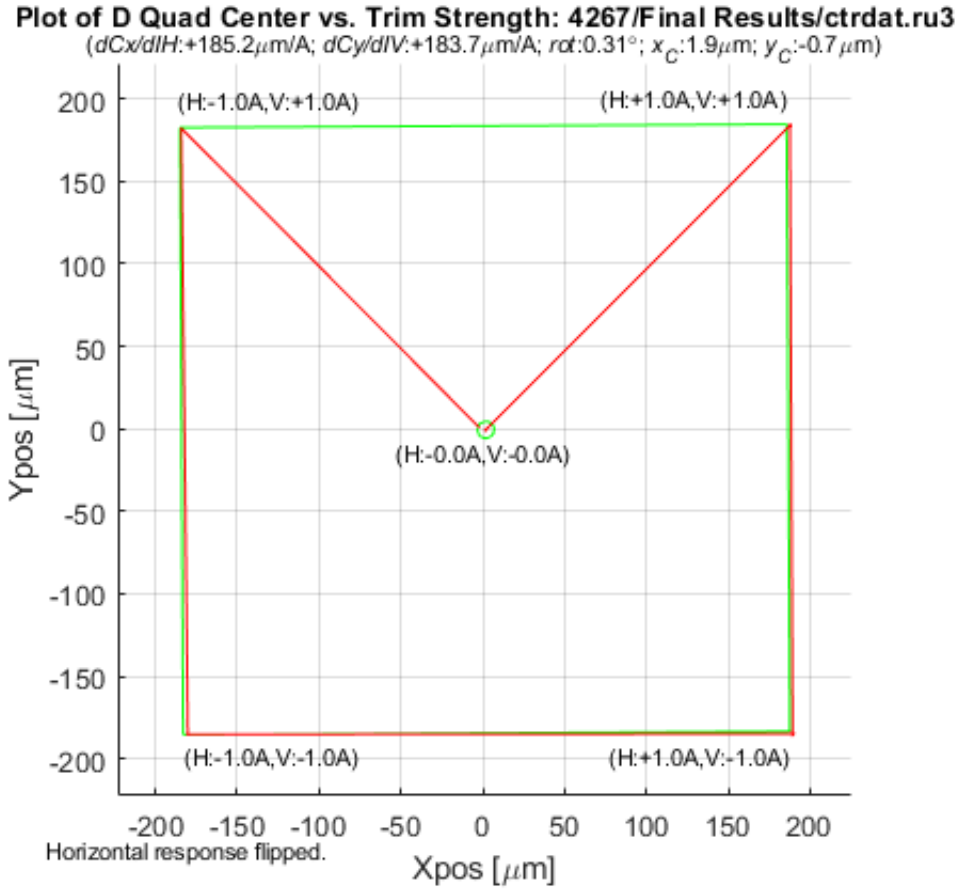
## Details of XCOR/YCOR Action (±0.5 A) on QD: Magnetic Center Miss




This figure is based on the same data as the figure on page 15. It shows, in the form of red crosses, the differences between the data points (the corners and the center point of the red curve in the figure on page 15) and the corners and the center of the green rectangle in that figure.

The red crosses are connected with red lines that follow the measurement sequence indicated by the first number in the associated point comment, which also shows the trim exitation currents associated with that data point. The red error ellipses, which are also present in the figure on page 15, but too small to recognize there, are based on the error values for the individual data points listed in the corresponding **ctrdat** file. The dotted line represents the smallest circle that captures the data points. The radius and the center cooridinates of that circle are printed underneath the figure title.

## Evaluation of XCOR/YCOR Action (±1.0 A) on QD: Magnetic Center Change

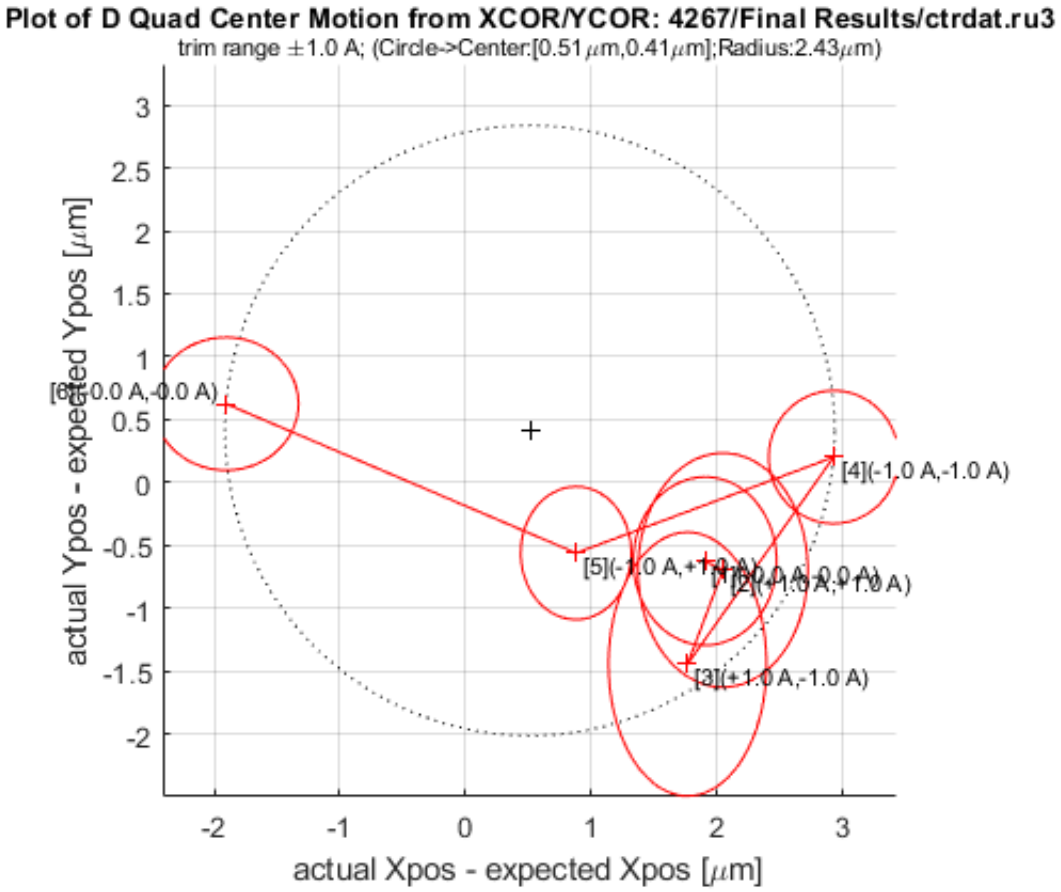



The figure shows the change in position of the magnetic center of the quadrupole (relative to the starting position) under changes of the dipole corrector currents over their full ranges. For this measurement, the dipole correctors have initially been turned off and the quadrupole has been standardized using the main quadrupole current to a final value of -6 A. From there, the main quadrupole current was raised to the starting point of the procedure at about -4.3 A, the nominal operating point for LCLS Undulator QD quadrupoles. The scanning procedure went to the following current settings of the dipole correctors currents ($I_H$, $I_V$):

| n | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| $I_H$ | [A] | +0.0 | +1.0 | +1.0 | -1.0 | -1.0 | +0.0 |
| $I_V$ | [A] | +0.0 | +1.0 | -1.0 | -1.0 | +1.0 | +0.0 |

In the figure, the measured center positions are connected with red lines. Green lines indicate a rectangle, fitted to the measured positions. The parameters of the fitted rectangle are listed underneath the figure title: "$dCx/dIH$" is the XCOR gain. "$dCy/dIV$" is the YCOR gain. "$rot$" is the quadrupole roll error during the measurement, which is different and generally much larger than the roll of the installed quadrupole. "$xc$" and "$yc$" are the center coordinates of the fit-rectangle with respect to the starting position. The average and rms deviation, $\Delta r$ , of the measured quadrupole center positions from the corresponding corners of the fit-rectangle are listed at the lower right corner of the figure.

## Details of XCOR/YCOR Action (±1.0 A) on QD: Magnetic Center Miss




This figure is based on the same data as the figure on page 17. It shows, in the form of red crosses, the differences between the data points (the corners and the center point of the red curve in the figure on page 17) and the corners and the center of the green rectangle in that figure.

The red crosses are connected with red lines that follow the measurement sequence indicated by the first number in the associated point comment, which also shows the trim exitation currents associated with that data point. The red error ellipses, which are also present in the figure on page 17, but too small to recognize there, are based on the error values for the individual data points listed in the corresponding **ctrdat** file. The dotted line represents the smallest circle that captures the data points. The radius and the center cooridinates of that circle are printed underneath the figure title.

## Quadrupole Fiducialization Data

| Final Combined Tooling Ball values for barcode 4267 | | | | | | |
|---|---|---|---|---|---|---|
| n | X | | Y | | Z | |
| 1 | +85.771 | mm | +173.083 | mm | -38.212 | mm |
| 2 | -85.632 | mm | +173.135 | mm | -38.048 | mm |
| 3 | -85.573 | mm | +173.185 | mm | +38.141 | mm |
| 4 | -167.261 | mm | +2.829 | mm | +0.097 | mm |
| 5 | +0.102 | mm | +173.137 | mm | -0.039 | mm |

Fiducialized Magnetic Center Location for barcode 4267

| | | |
|---|---|---|
| dX | -167.261 | mm |
| dY | +173.135 | mm |
| dZ | -9.540 | mm |

| **Finding** | **Solution** |
|---|---|
| | |
| | |

Approval and Assignment by Heinz-Dieter Nuhn

| | | |
|---|---|---|
| Data Storage Checked: | Y | |
| Magnet Accepted: | Y | |
| Bar Code: | 4267 | |
| Quadrupole Type: | SXRQUAD | |

| | | |
|---|---|---|
| | Heinz-Dieter Nuhn | August 29, 2024 |
| (Signature) | (Name) | (Date) |