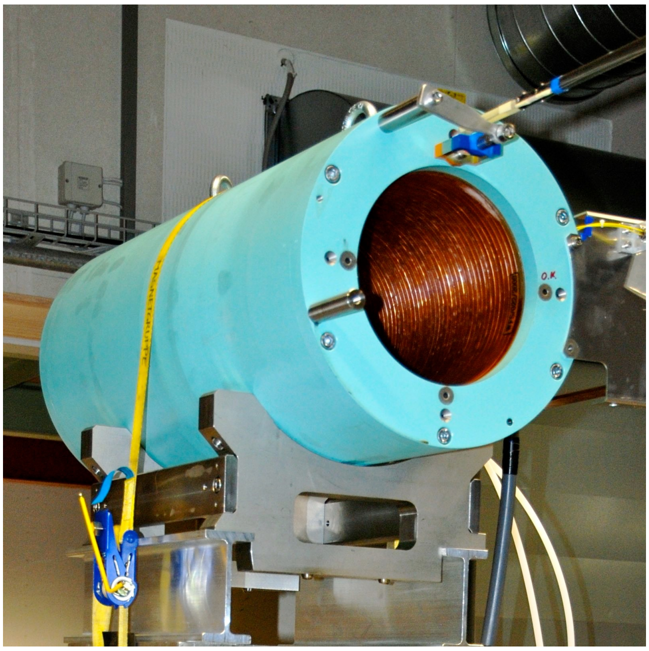
WFS Solenoids (SwissFEL 250 MeV Injector)



WFS solenoid (#10 of 17)

$2R_{IN}$ = 220 mm
$2R_{OUT}$ = 345 mm
L = 750 mm

2 coils
38x4 (actual 150 turns/coil)
I_{MAX} = 200 A

MEASUREMENT DATE:
2.Oct.2009–28.Apr.2010

MEASUREMENT ARM:
brass cylinder interface Ø 40 mm
aluminum pipe Ø 28 mm, 1 m
titan pipe Ø 12.8 mm, 1 m
[carbon pipe Ø 12.1 mm, 1.5 m]

MEASURING SPEED:
4.5 mm/sec (X-axis)
1.25 mm/sec (Y-axis)
40 mm/sec (Z-axis)

INTEGRATION TIME:
20 msec

DVM-1 (1 V RANGE):
Hall axial probe sbv35 (150 mA)
[Hall axial probe sbv397 (150 mA)]

DVM-2 (10 V RANGE):
50 V / 200 A (MSG-2.1), 5 A/s

AIR CONDITIONING:
ON (T_{SET} = 24°)

OPERATORS:
Roland Deckardt
Vjeran Vranković (report)

DATA DIRECTORY:
afs: sys/alpha_dux51/swdir/
magnet/meas/wfs

Alignment and positioning

The magnets were laid on the provided support that is placed on adjustable base plate. The base plate can be leveled by adjusting its feet heights.

In the measurements coordinate system the solenoid axis is the Z-axis, vertical axis is the Y-axis. The solenoid center is at the origin of the coordinate system.

The probe was leveled with a spirit level.

The aligning and positioning of the solenoids was done magnetically by measuring vertical field maps of the double reference pin, a permanently magnetized conically shaped iron piece, that was horizontally inserted and measured in each of 4 designated holes in the magnet plate on the -Z side. The holes lie on a circle with the center on the solenoid axis. A two-dimensional quadratic polynomial is fitted to the measured data. Because the strongest magnetic field is at the tip of the pin, the position of the fit maximum corresponds to the pin tip and therefore to the hole position.

First, the horizontal (rotation around Y-axis) and vertical inclination (rotation around X-axis) of the solenoid were adjusted until all the magnetic field fit maxima from the reference pin measurements yielded the same value, meaning that the Z coordinates of the 4 points (+X, -X, +Y, -Y) on the solenoid plate were equal and thus the magnet geometrical axis aligned with the measurement axis. Because of the strong field gradient at the tip of the reference pin, this is a very sensitive method for aligning the axes. The maximal error is in the order of a few hundreds of mm in Z, which corresponds to an angle error of less than 0.1 mrad.

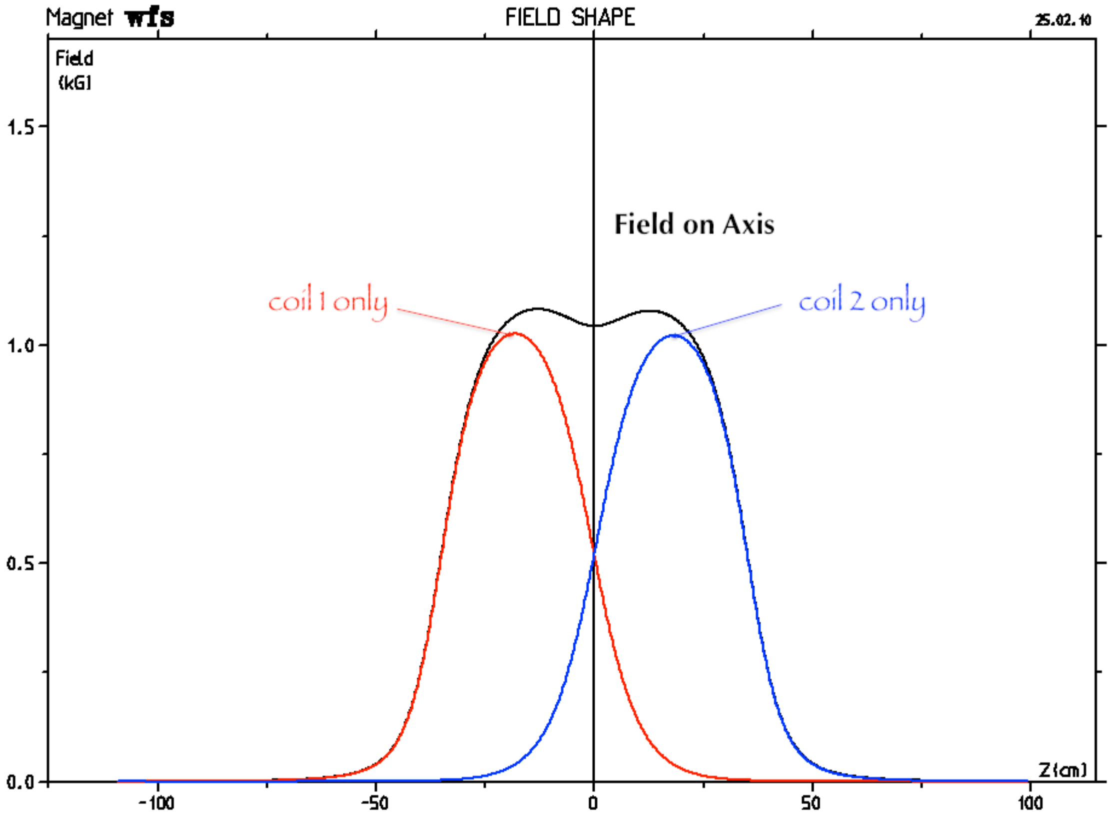
The X and Y coordinates of the solenoid axis were determined by fitting a circle to positions of 4 reference holes in the magnet plate. The accuracy of finding location of the reference pin is a few hundreds of mm, so the X and Y positions of the solenoid center were determined within that error.

The Z coordinate was also set magnetically. Because of the strong field gradient of the reference point the accuracy of the Z positioning is 0.01 mm.

After each rotation of the probe arm (PSI=0° and PSI=180°) the position of the probe is lost and the process for finding its coordinates had to be repeated.

Number of turns in the coils

The field $B_z(z)$ on the solenoid axis is shown with each coil powered separately and with both coils connected in series. The current is 200 A.



The field integral is proportional to the excitation of the coil, it equals the Amp-turns N·I in the coil(s). We used this fact to determine the number of turns in the coils:

$$N = \frac{\int B_z(I)\,dz}{4 \cdot \pi \cdot I}$$

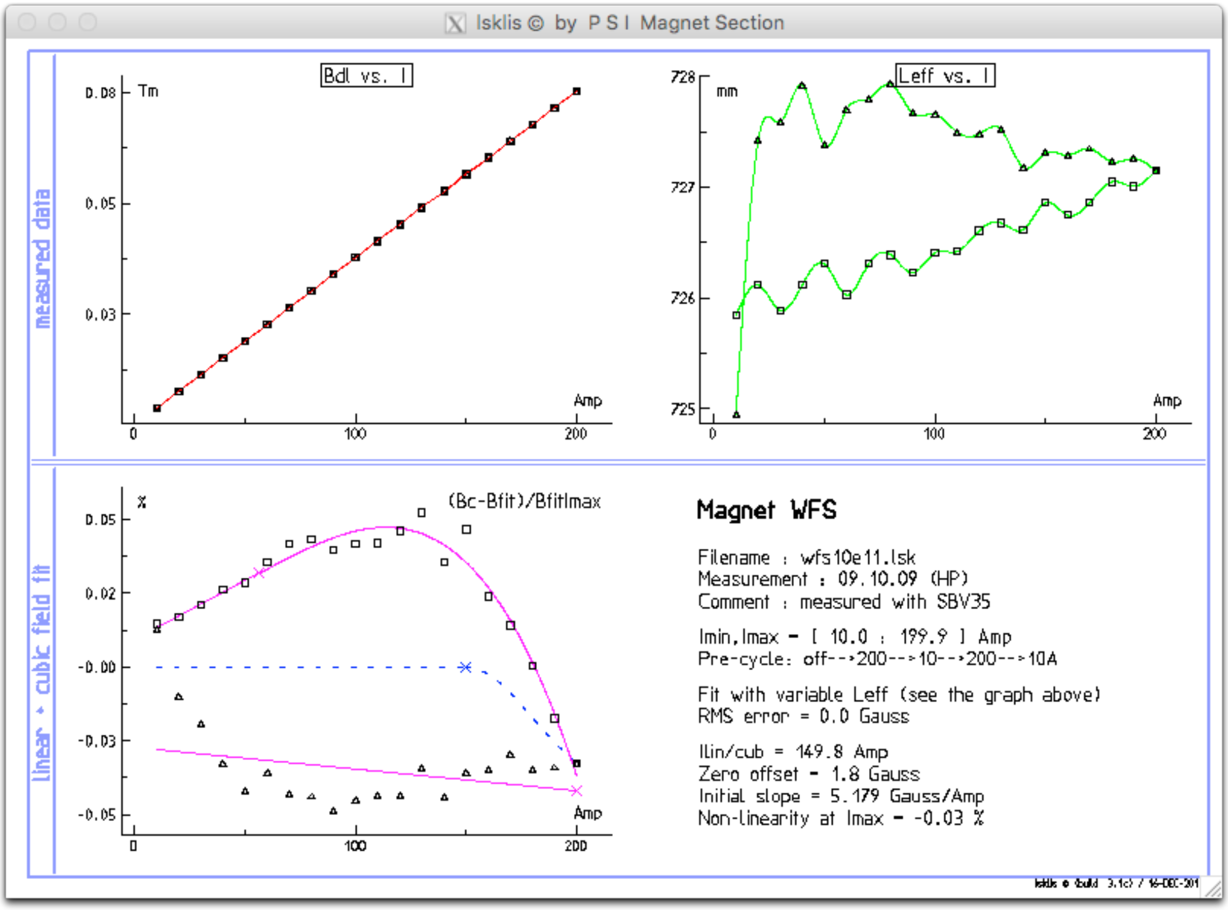
It is necessary though to remove the earth and the background fields from the measured fields:

$$\frac{measurement(+current) - measurement(-current)}{2}$$

The following table shows coil turn numbers. The first 7 solenoids were measured only with the both coils excited so we cannot say what the individual turn number for each coil in these solenoids are but only the total turn number.

Solenoid no.	Pos.	Coil 1	Coil 2	Total
1	SB-1a	150	150	300
2	SB-2a	N/A	N/A	300
3	SB-4x	150	150	300
4	SB-1d	149	149	298
5	SB-1c	150	151	301
6	SB-4x	150	150	300
7	SB-4x	N/A	N/A	301
8	SB-3b	N/A	N/A	298
9	SB-3d	N/A	N/A	297
10	SB-2b	N/A	N/A	300
11	SB-2c	N/A	N/A	299
12	SB-3c	149	150	299
13	SB-2d	N/A	N/A	299
14	SB-3a	150	150	300
15	SB-1b	150	150	300
16	reserve	150	151	301
17	SB-4x	150	150	300

Excitation curve

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linear_<1:Ilin> and cubic_<Ilin:Imax> approximation of Bc0:
Blin = b0 + b1 * Irel                       ;   Irel = I / Imax
Bcub = Blin + b2 * Irel^2 + b3 * Irel^3     ;   Irel = (I - Ilin) / (Imax - Ilin)

      Ilin_A     Imax_A       b0_G        b1_G        b2_G        b3_G      RMS_G
      ======     ======       ====        ====        ====        ====      =====
/      199.9      199.9        1.5      1035.2         0.0         0.0        0.1
\       56.3      199.9        1.9      1036.2         0.1        -1.4        0.0
-      149.8      199.9        1.8      1035.4        -0.7         0.4        0.0

/ = increasing current branch
\ = decreasing current branch
- = average
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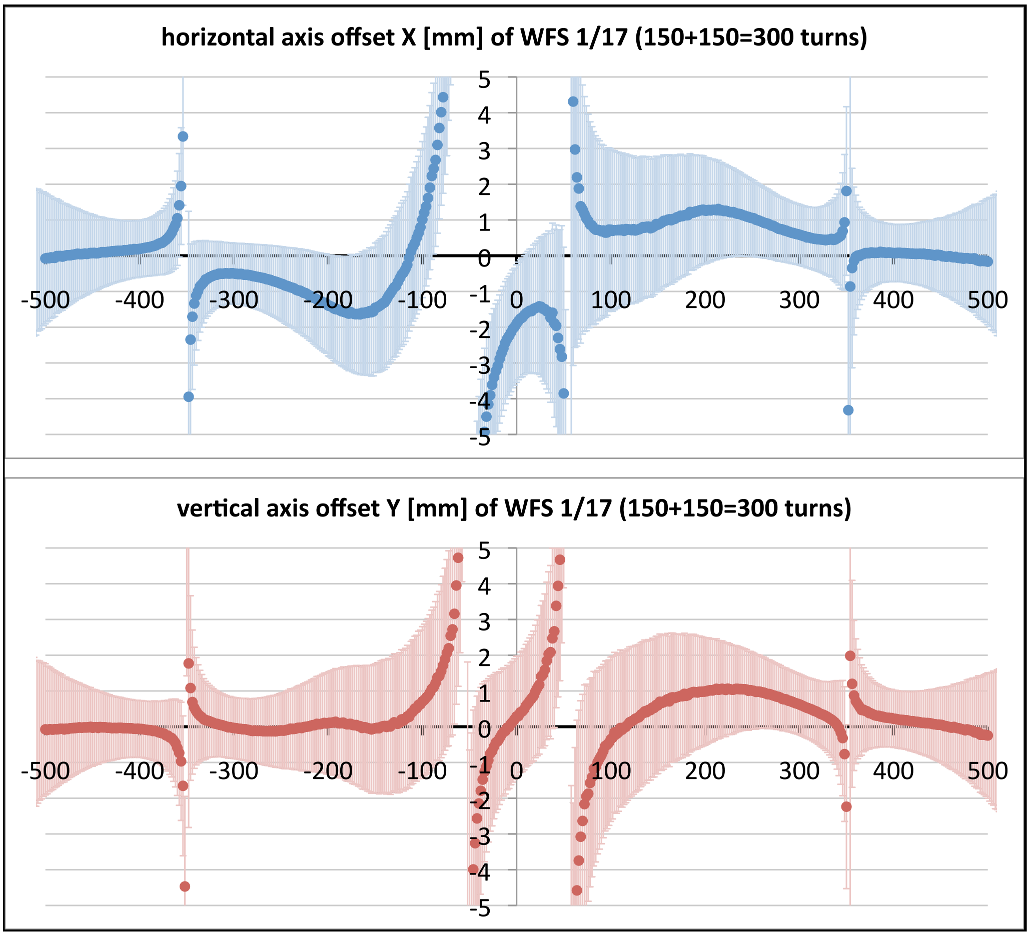
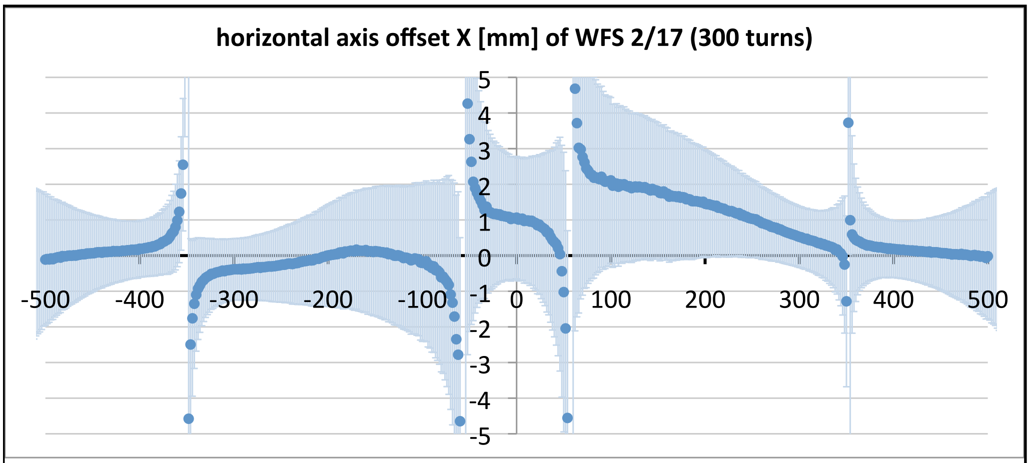
Magnetic axis

Two fieldmaps for each plane (ZX and ZY) were measured with Hall probe rotated 180° and the fields were averaged. This process cancels out all side component readings, thus in effect eliminating a possible angle error of the Hall probe.

The 2nd order one-dimensional polynomial fit is performed for each Z position and the maxima or minima indicate the location of the magnetic axis. The error bars show the space extent of ±0.01 Gauss field region.




horizontal axis offset X [mm] of WFS 2/17 (300 turns)
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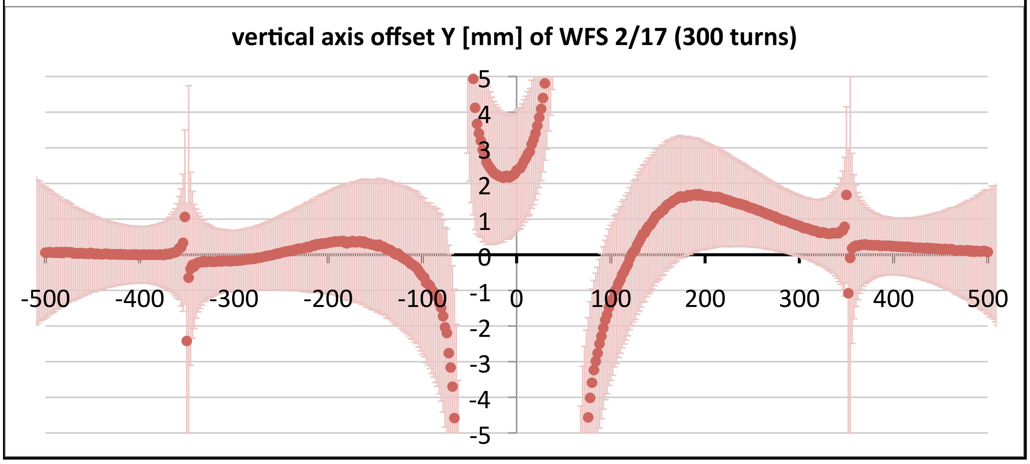
vertical axis offset Y [mm] of WFS 2/17 (300 turns)
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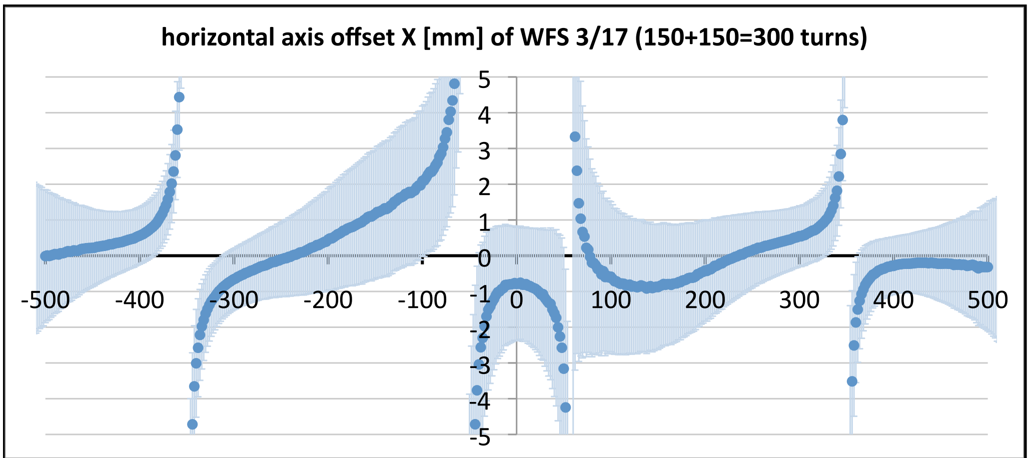
horizontal axis offset X [mm] of WFS 3/17 (150+150=300 turns)
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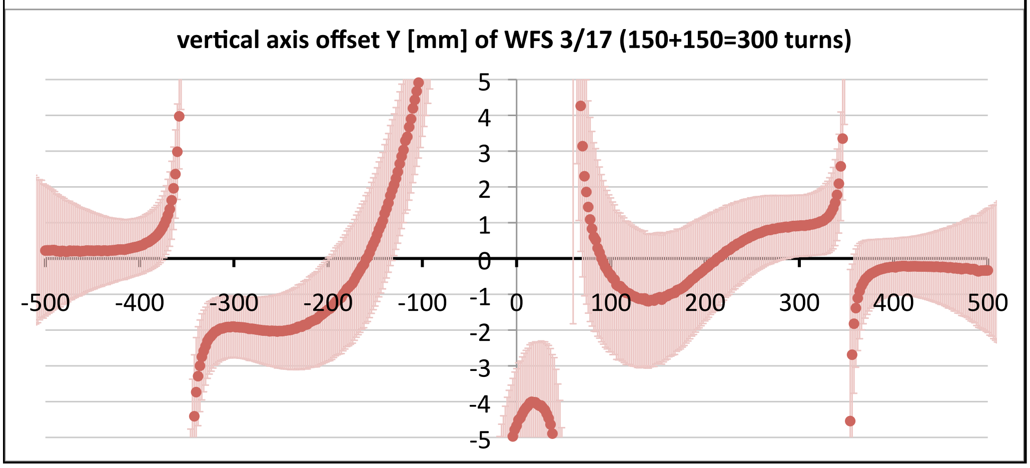
vertical axis offset Y [mm] of WFS 3/17 (150+150=300 turns)
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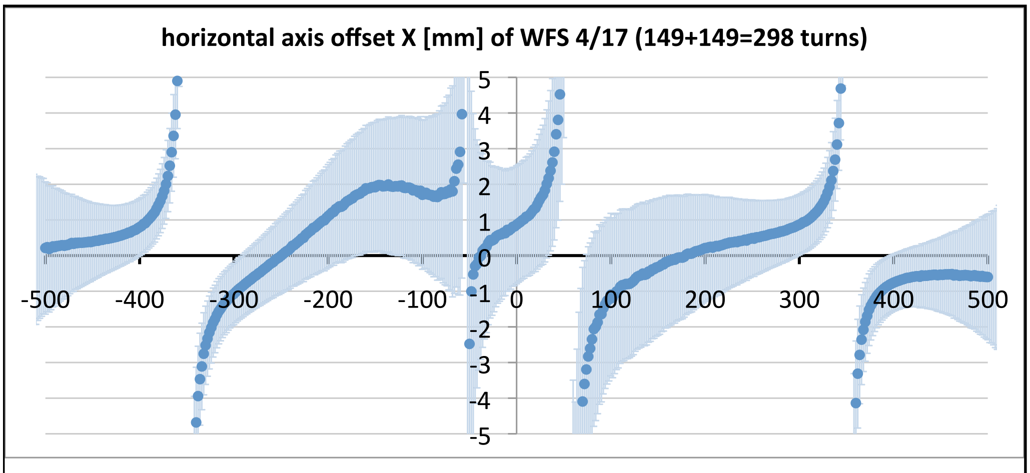
horizontal axis offset X [mm] of WFS 4/17 (149+149=298 turns)
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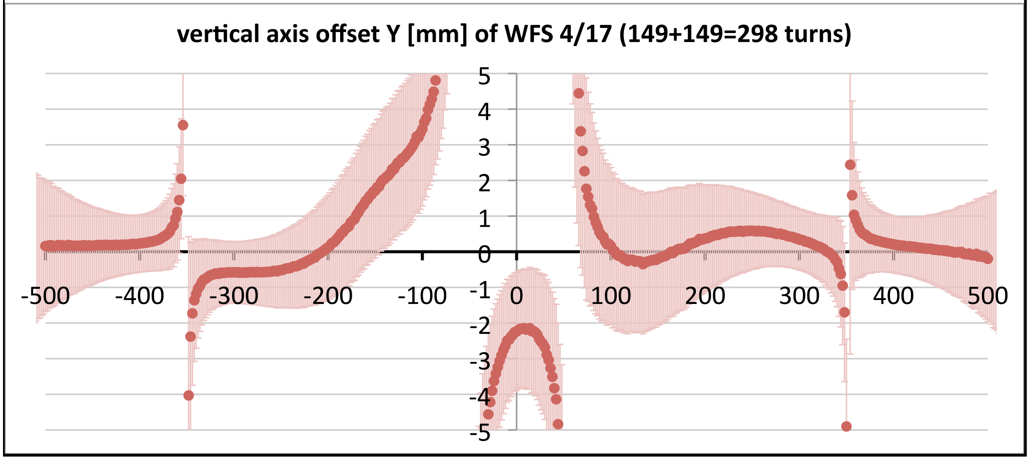
vertical axis offset Y [mm] of WFS 4/17 (149+149=298 turns)
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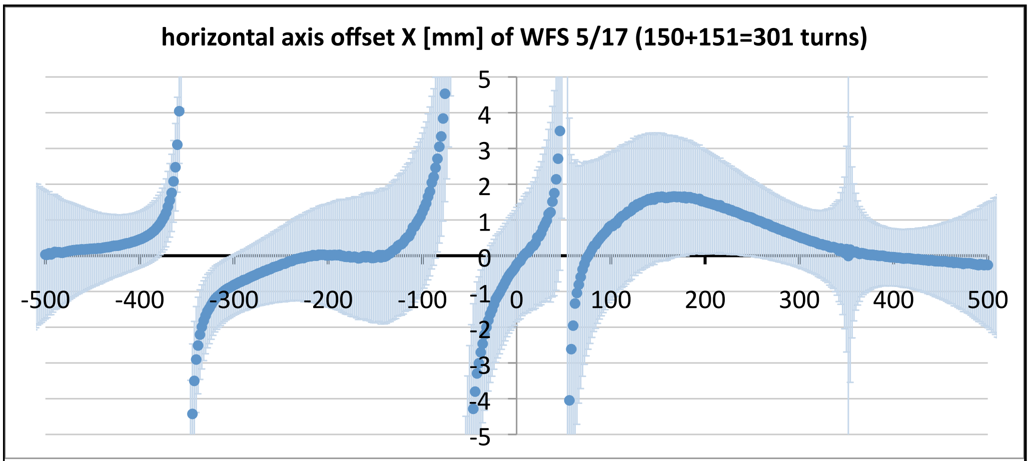
horizontal axis offset X [mm] of WFS 5/17 (150+151=301 turns)
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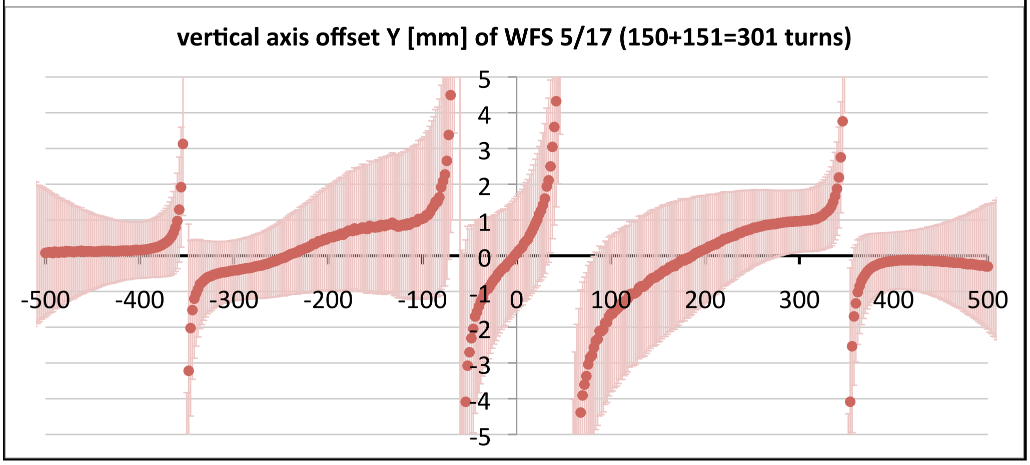
vertical axis offset Y [mm] of WFS 5/17 (150+151=301 turns)
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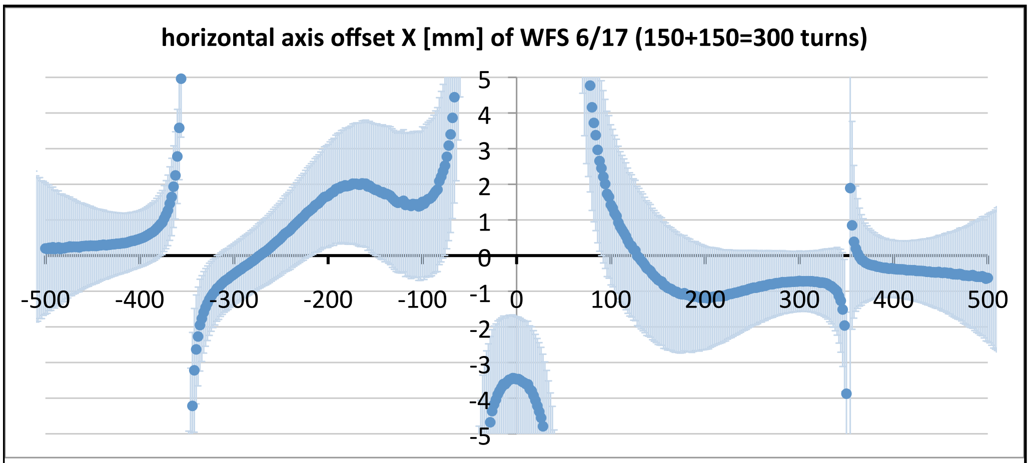
horizontal axis offset X [mm] of WFS 6/17 (150+150=300 turns)
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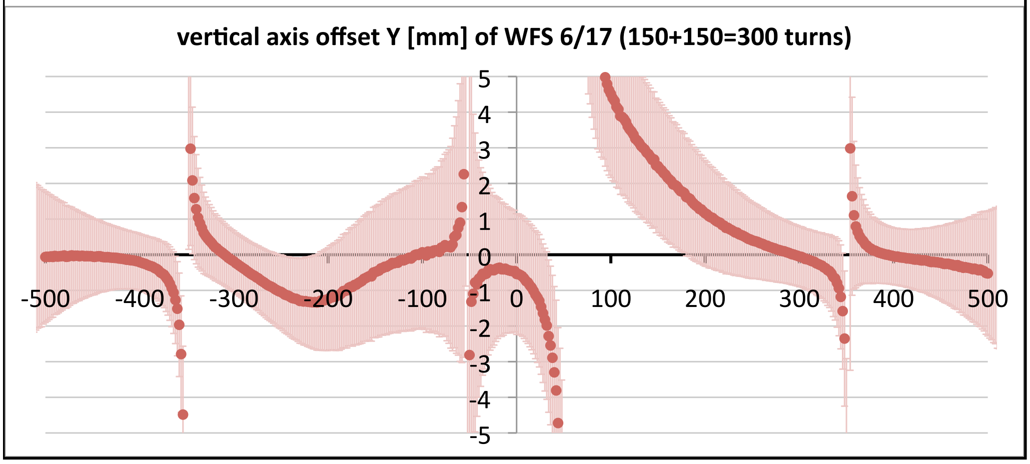
-500 -400 -300 -200 -100 0 100 200 300 400 500


vertical axis offset Y [mm] of WFS 6/17 (150+150=300 turns)
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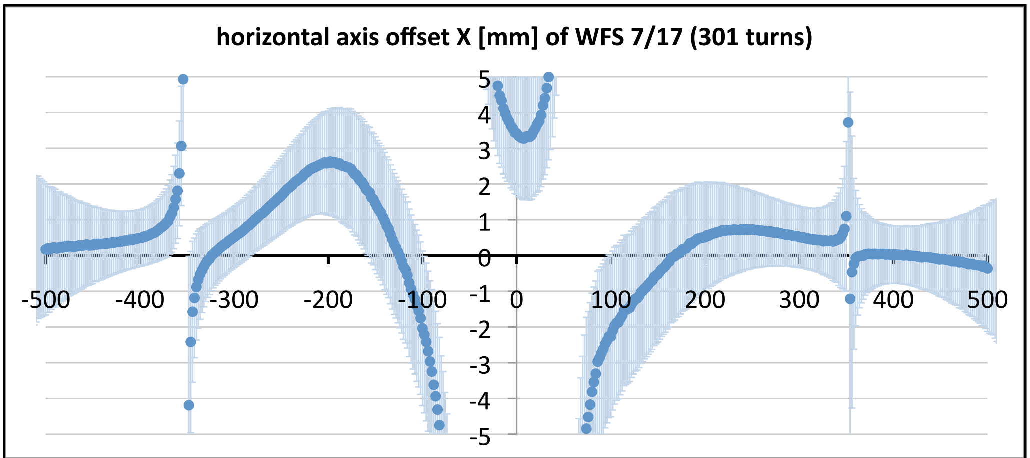
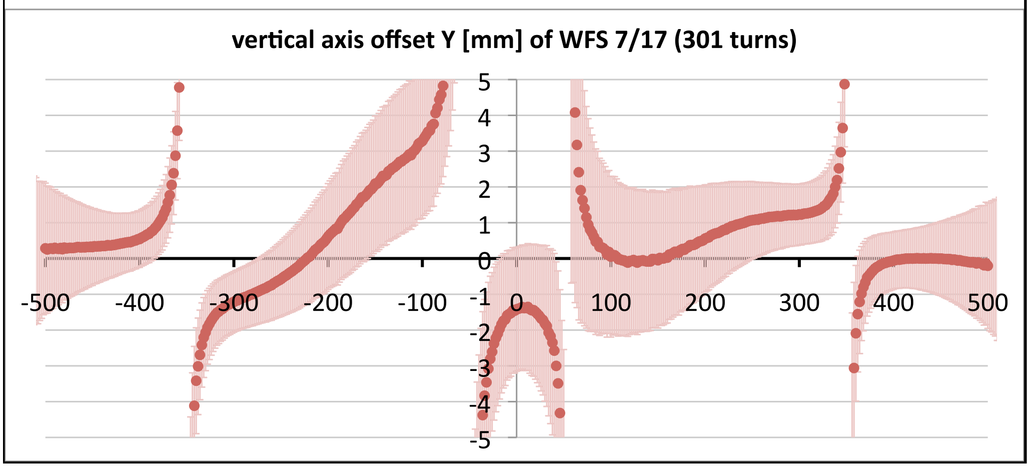
-500 -400 -300 -200 -100 0 100 200 300 400 500


horizontal axis offset X [mm] of WFS 7/17 (301 turns)
5 4 3 2 1 0 -1 -2 -3 -4 -5
-500 -400 -300 -200 -100 0 100 200 300 400 500


vertical axis offset Y [mm] of WFS 7/17 (301 turns)
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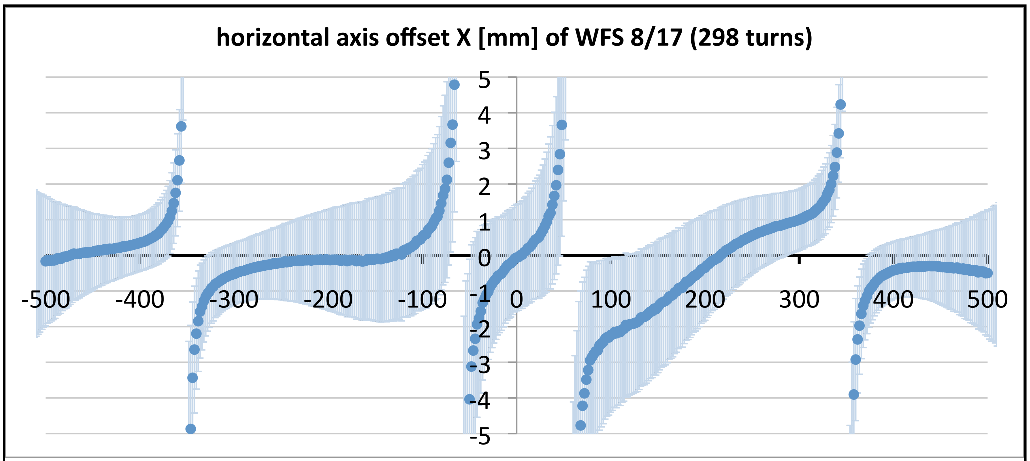
-500 -400 -300 -200 -100 0 100 200 300 400 500


horizontal axis offset X [mm] of WFS 8/17 (298 turns)
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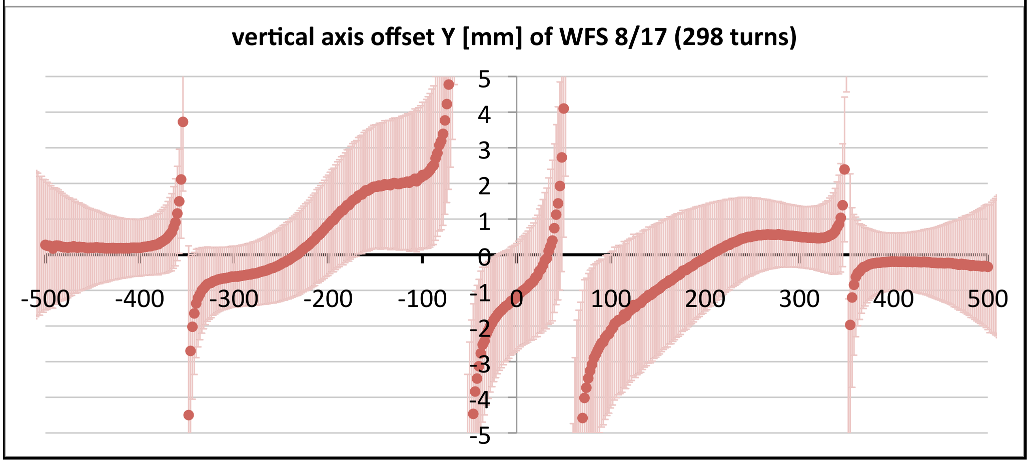
-500 -400 -300 -200 -100 0 100 200 300 400 500


vertical axis offset Y [mm] of WFS 8/17 (298 turns)
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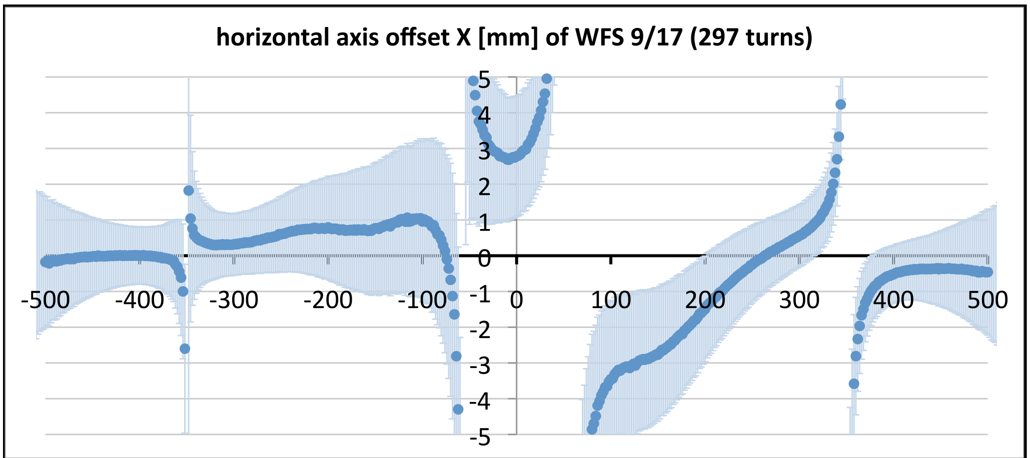
-500 -400 -300 -200 -100 0 100 200 300 400 500


horizontal axis offset X [mm] of WFS 9/17 (297 turns)
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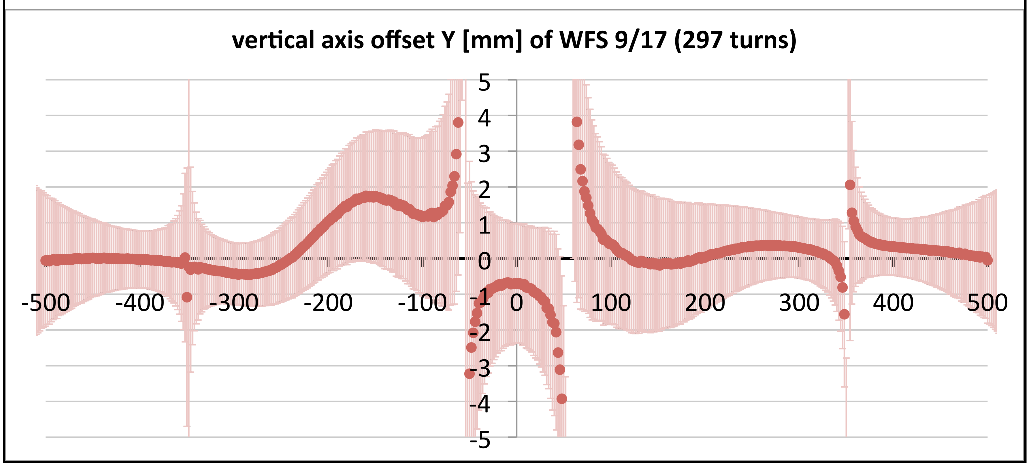
-500 -400 -300 -200 -100 0 100 200 300 400 500


vertical axis offset Y [mm] of WFS 9/17 (297 turns)
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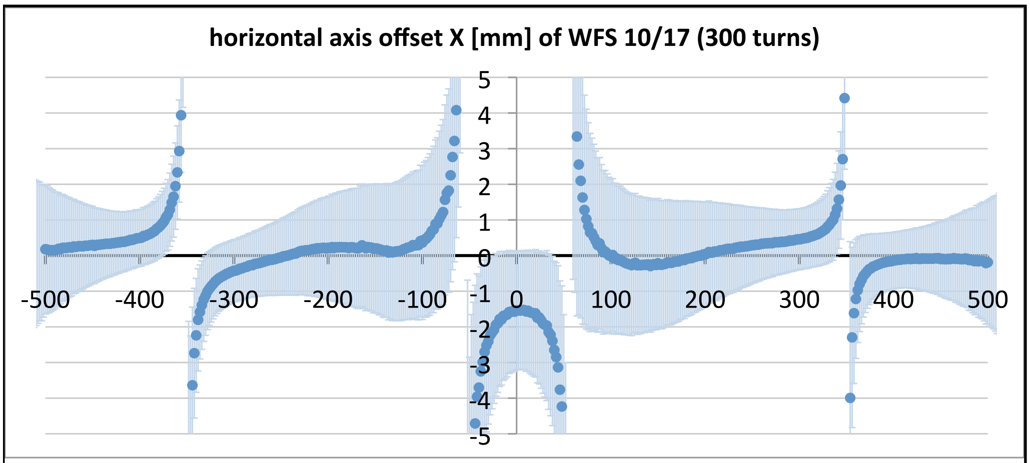
horizontal axis offset X [mm] of WFS 10/17 (300 turns)
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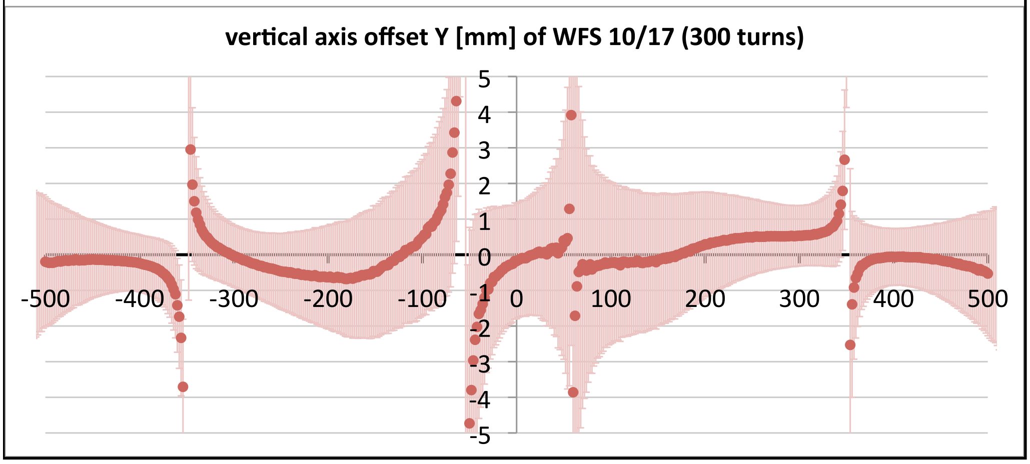
vertical axis offset Y [mm] of WFS 10/17 (300 turns)
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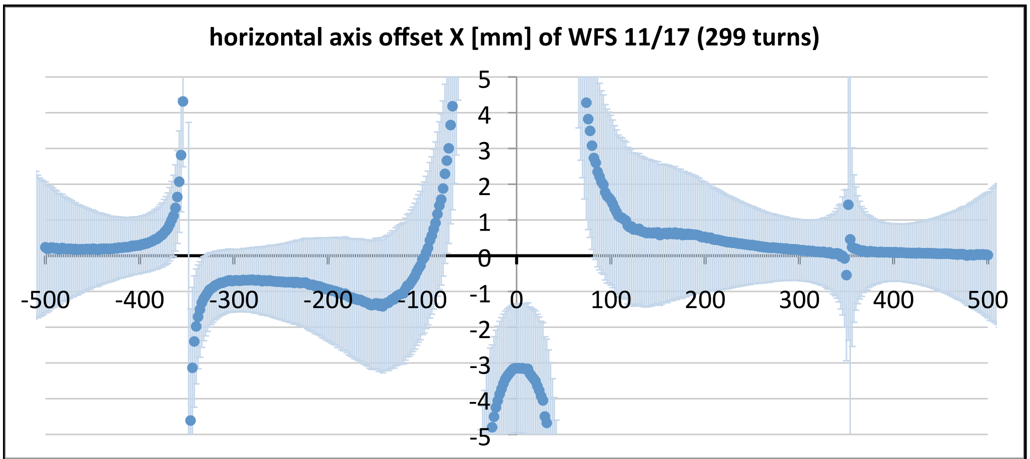
horizontal axis offset X [mm] of WFS 11/17 (299 turns)
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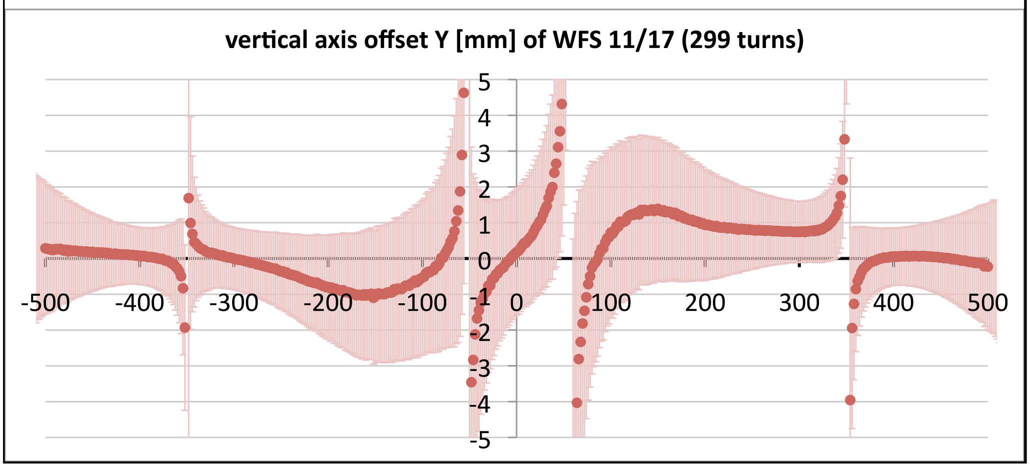
-500 -400 -300 -200 -100 0 100 200 300 400 500


vertical axis offset Y [mm] of WFS 11/17 (299 turns)
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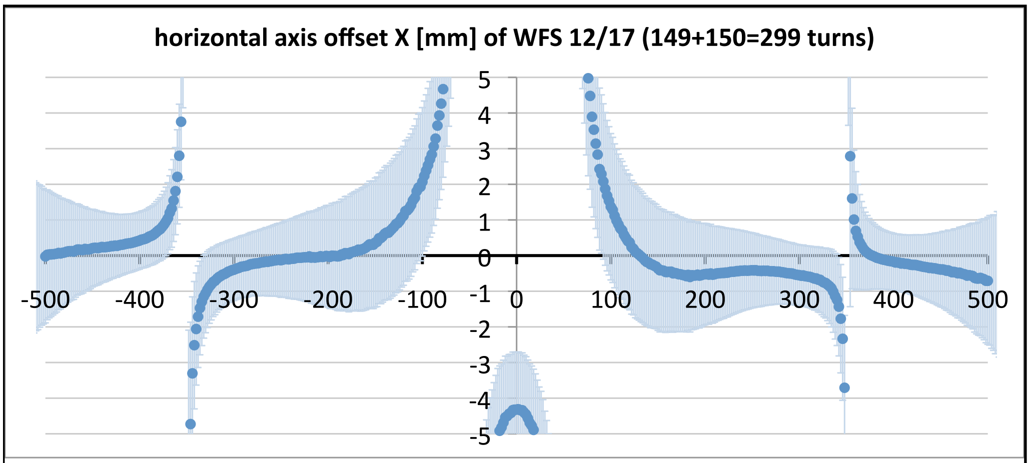
horizontal axis offset X [mm] of WFS 12/17 (149+150=299 turns)
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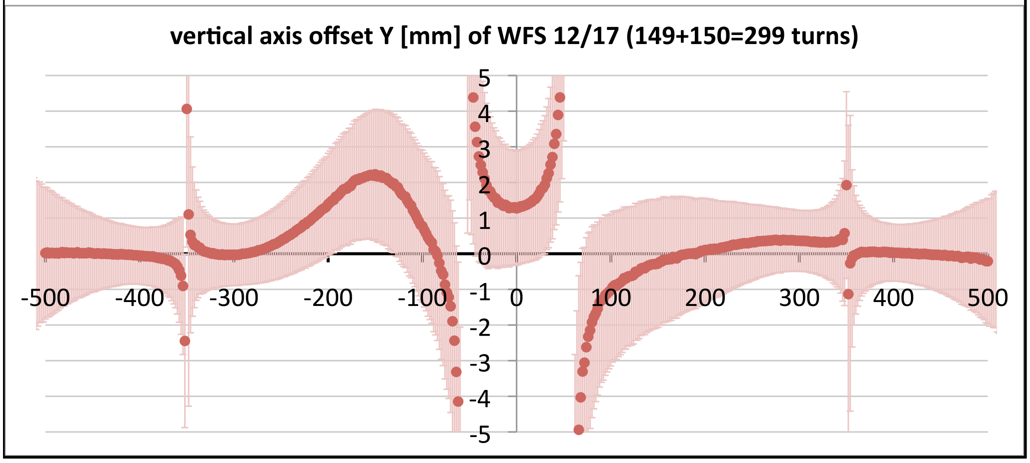
vertical axis offset Y [mm] of WFS 12/17 (149+150=299 turns)
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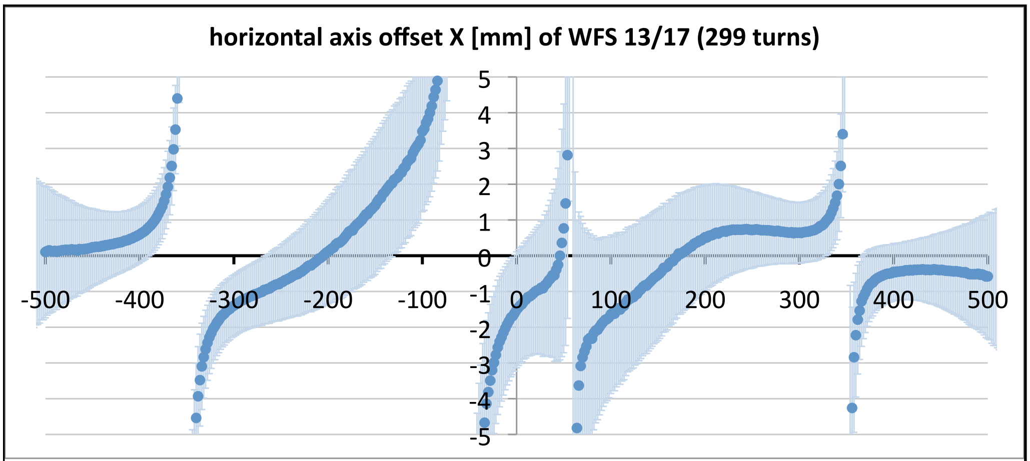
horizontal axis offset X [mm] of WFS 13/17 (299 turns)
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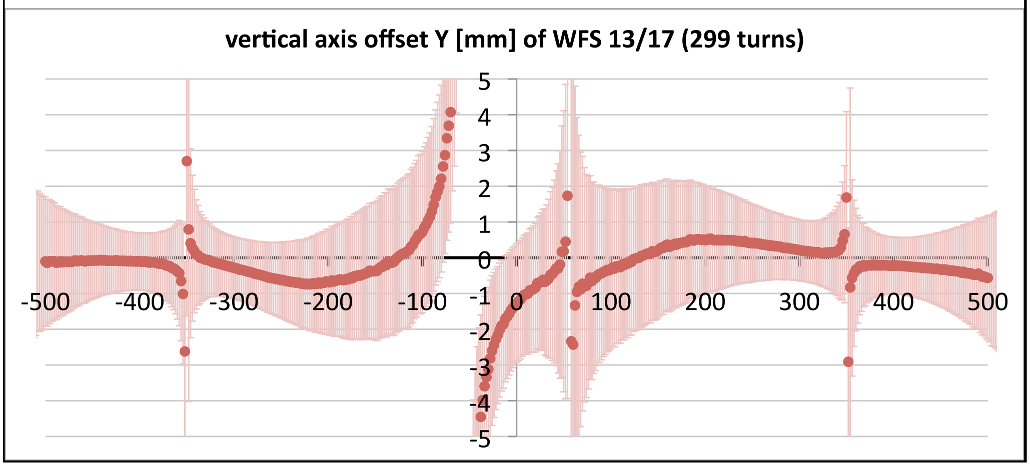
vertical axis offset Y [mm] of WFS 13/17 (299 turns)
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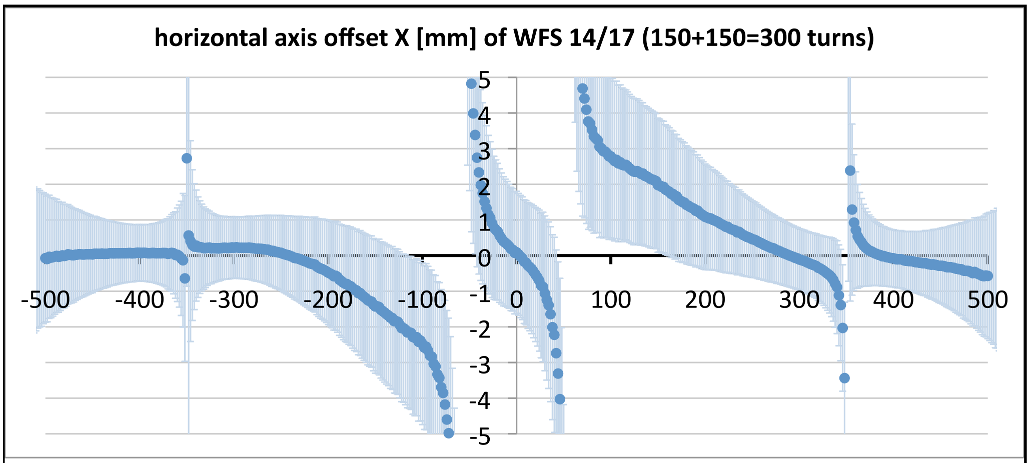
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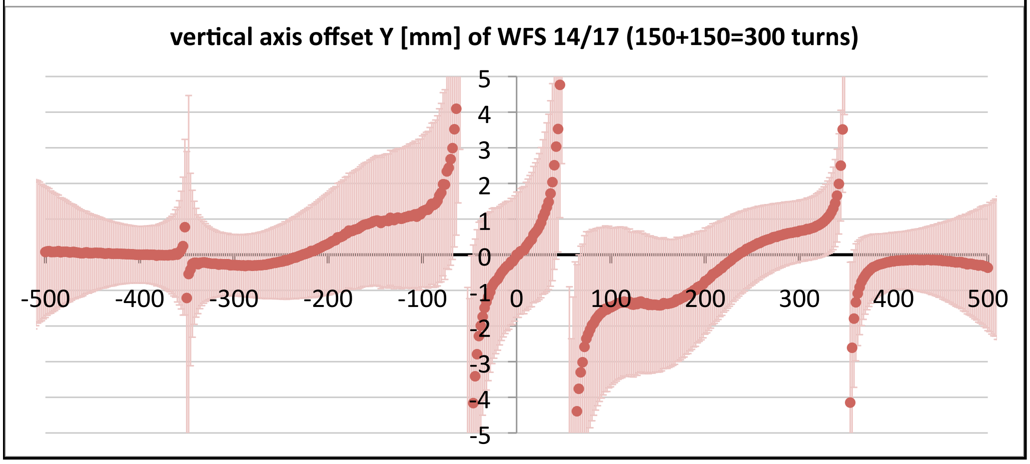
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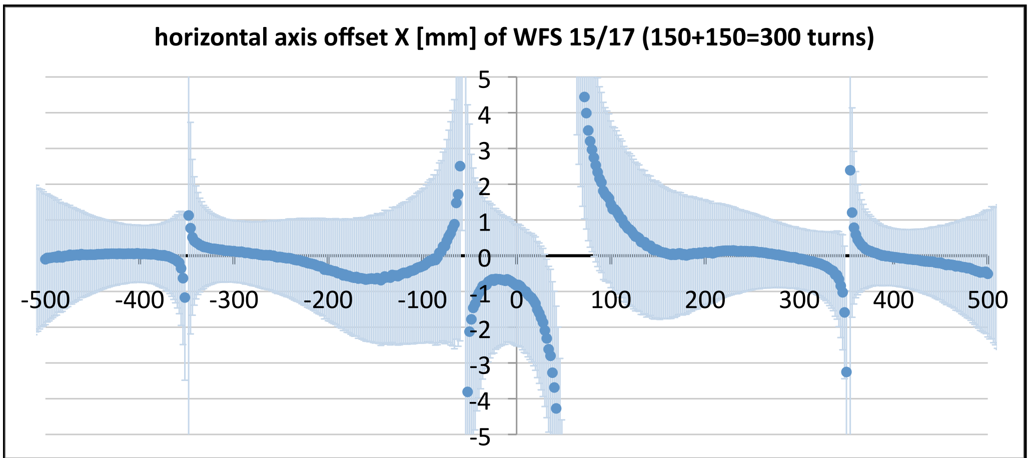
horizontal axis offset X [mm] of WFS 15/17 (150+150=300 turns)
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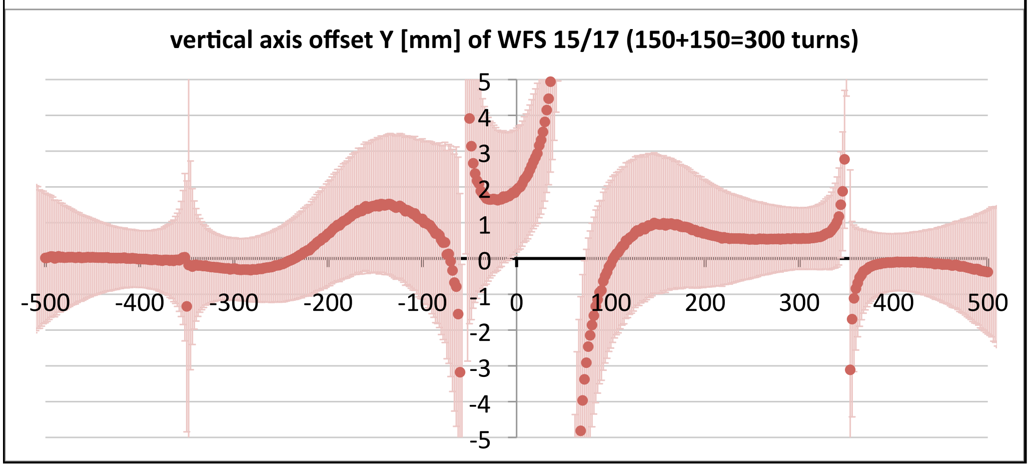
vertical axis offset Y [mm] of WFS 15/17 (150+150=300 turns)
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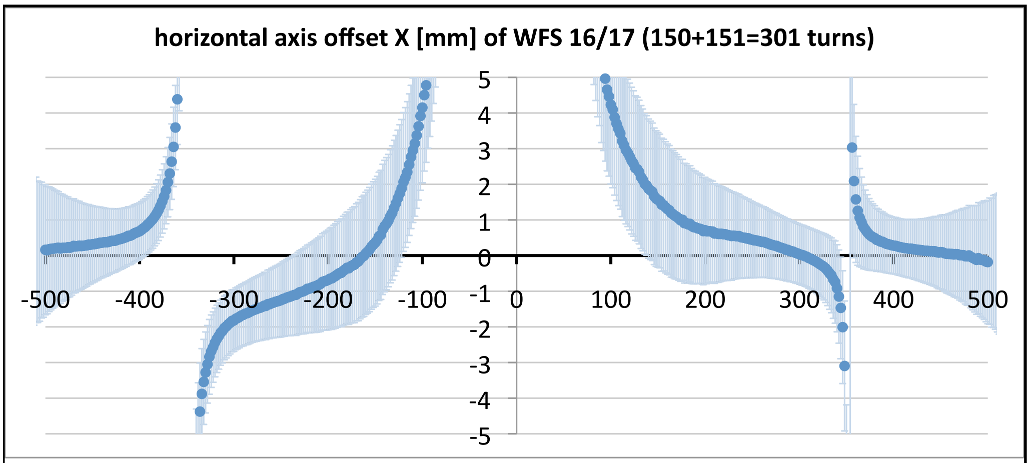
horizontal axis offset X [mm] of WFS 16/17 (150+151=301 turns)
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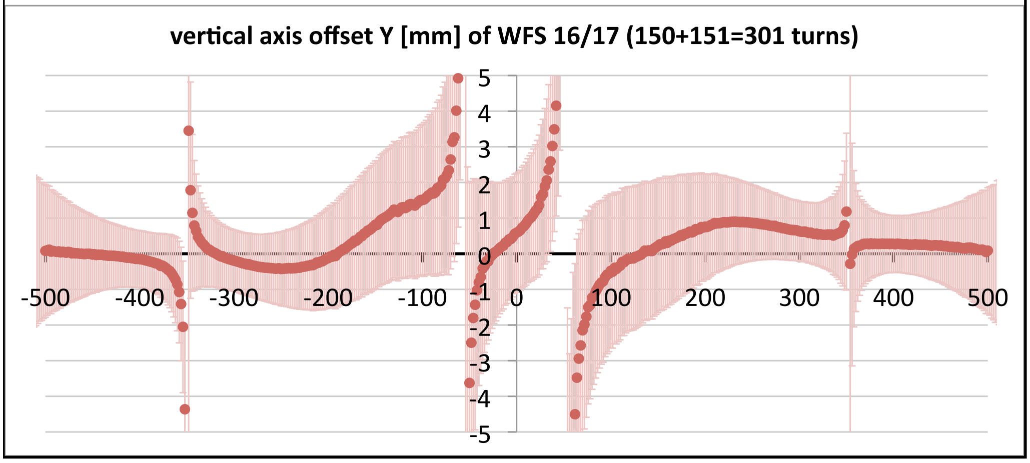
vertical axis offset Y [mm] of WFS 16/17 (150+151=301 turns)
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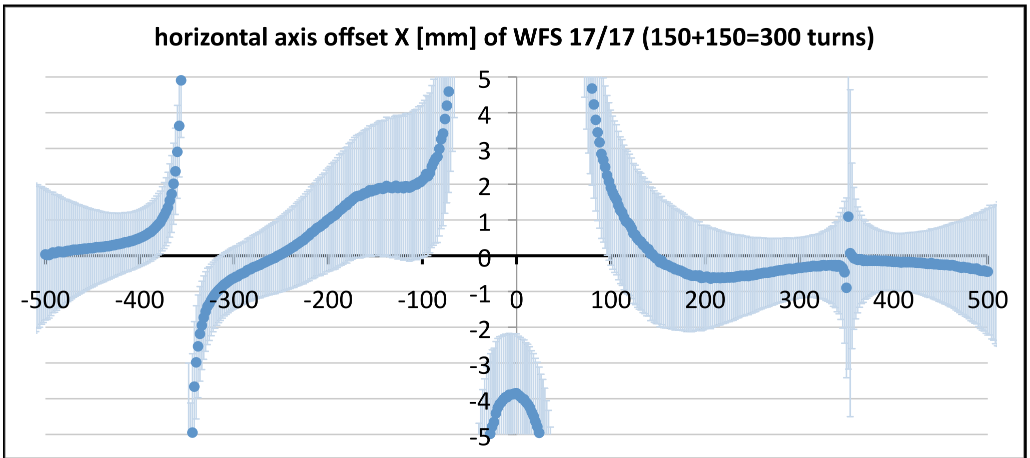
horizontal axis offset X [mm] of WFS 17/17 (150+150=300 turns)
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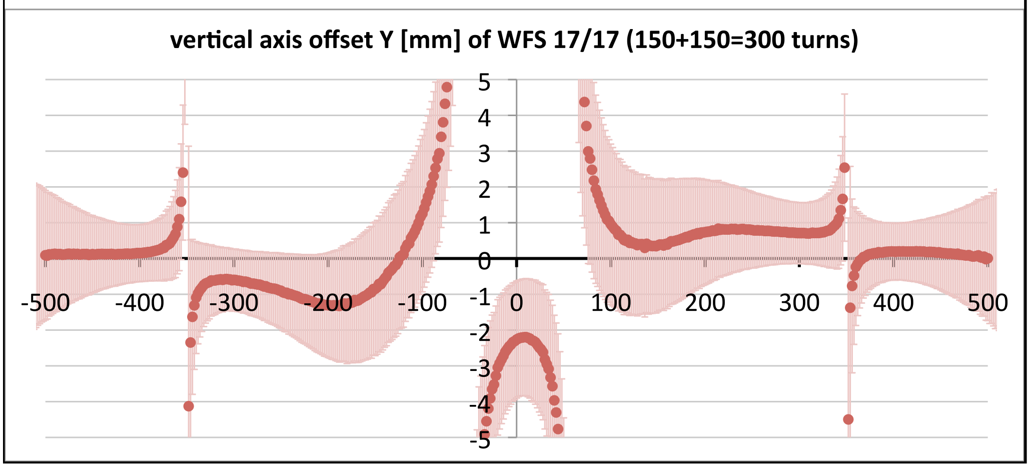
vertical axis offset Y [mm] of WFS 17/17 (150+150=300 turns)
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