Refinements of the non-linear lattice model for the BESSY storage ring

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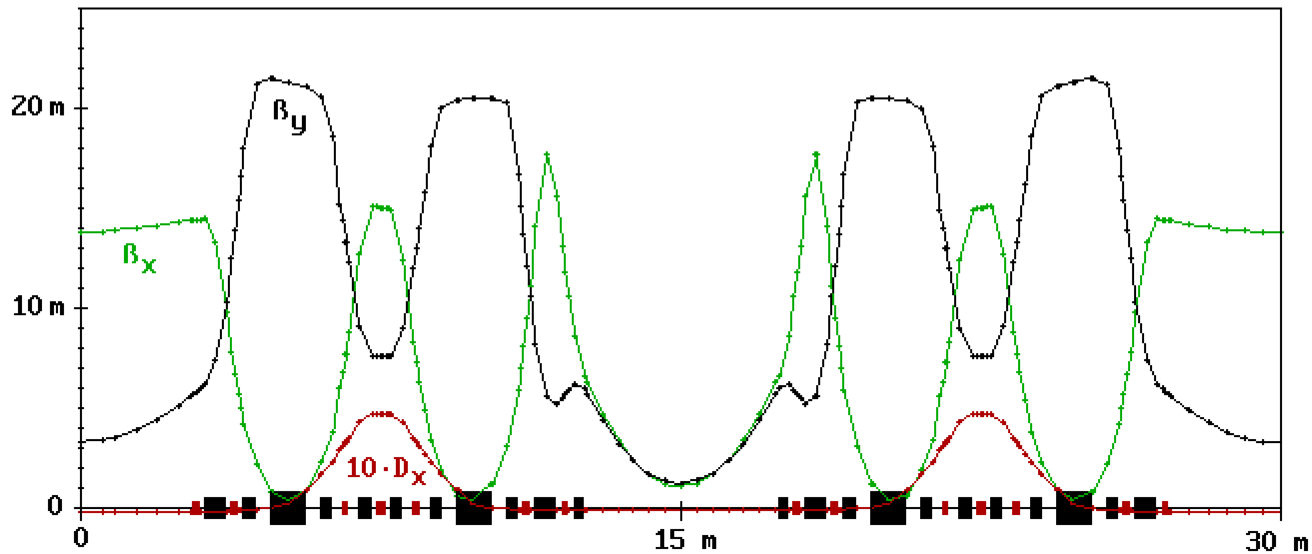
Linear Lattice
My Tracking Code
Refinements of the Model
Fringe Fields of:
- Dipoles
- Quadrupoles
- Sextupoles

Additional Functions included in the Sextupole Magnets
Small Adjustments of Harmonic Sextupoles

Conclusions

Linear Lattice

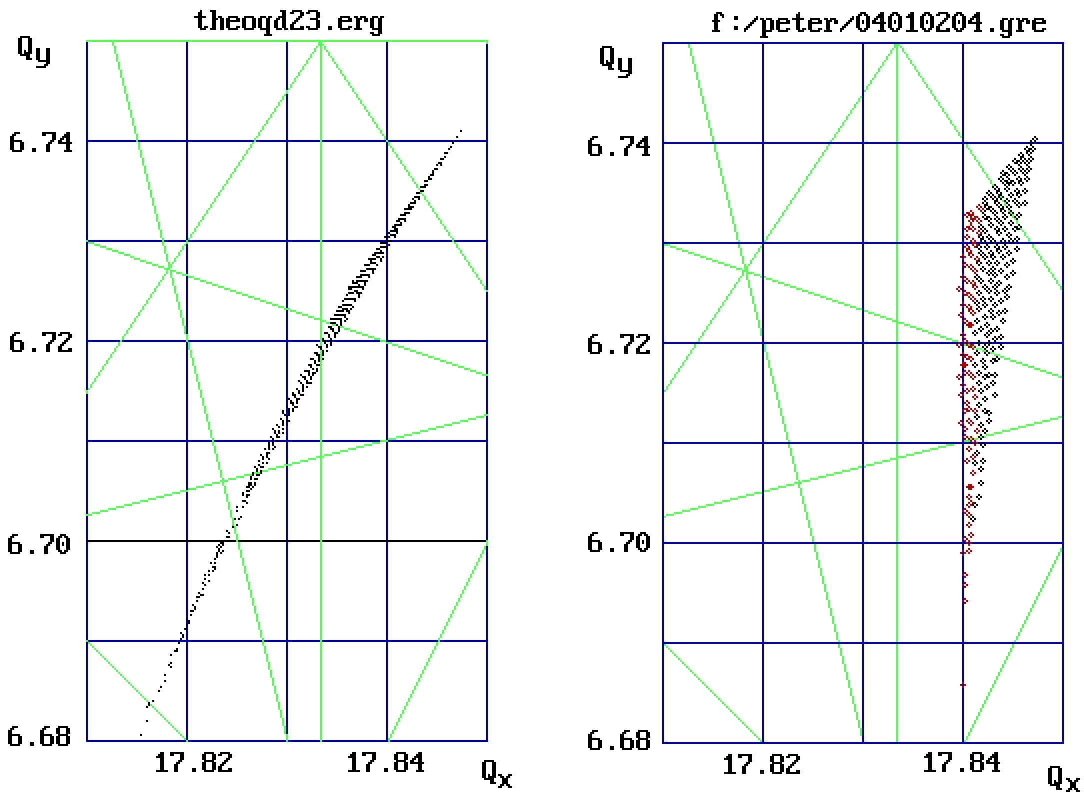
Linear (and linearly coupled) from orbit response matrix analysis



Optics functions of 1/8 of the storage ring as a result of a response matrix analysis

My Tracking Code

- Small angle approximation
- symplectic, 4th order integrator (Laskar, Robutel, thesis L. Nadolski)
- includes the known physical aperture limitations (ID-vacuum chambers)



Frequency map as calculated by the course model (left) and measured (right).

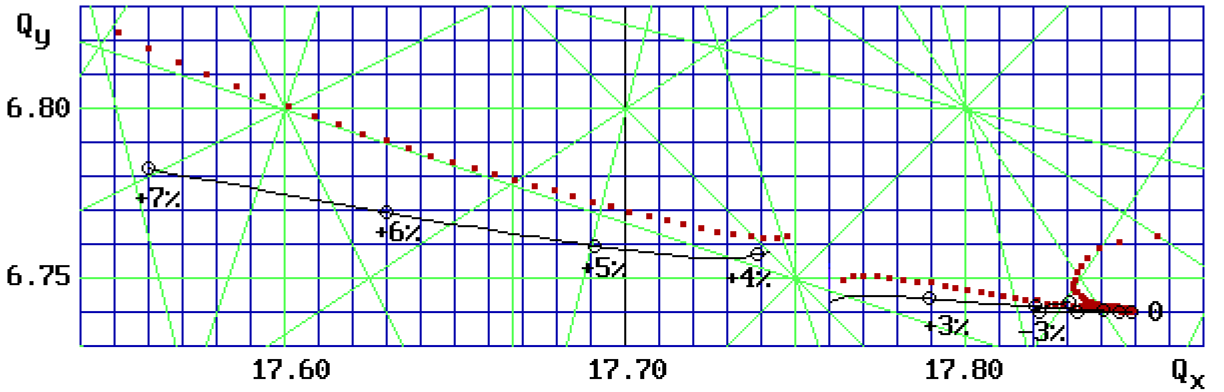
Conditions for the frequency map calculation:

- chromaticity: ξ_x=+3.31 and ξ_y=3.64
- with nominal harmonic sextupole settings
- 128 turns tracked
- fundamental frequencies determined with Hanning window

Conditions for the tune calculation as a function of momentum:

- chromaticity: ξ_x=-0.19 and ξ_y=0.00
- with nominal harmonic sextupole settings
- 256 turns tracked
- fundamental frequencies determined with Hanning window

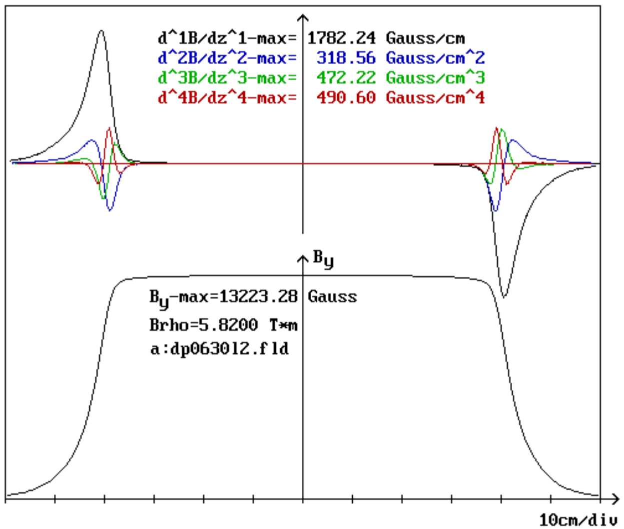
Small skew gradient errors are included, sextupoles are modeled as 13 equal kicks.

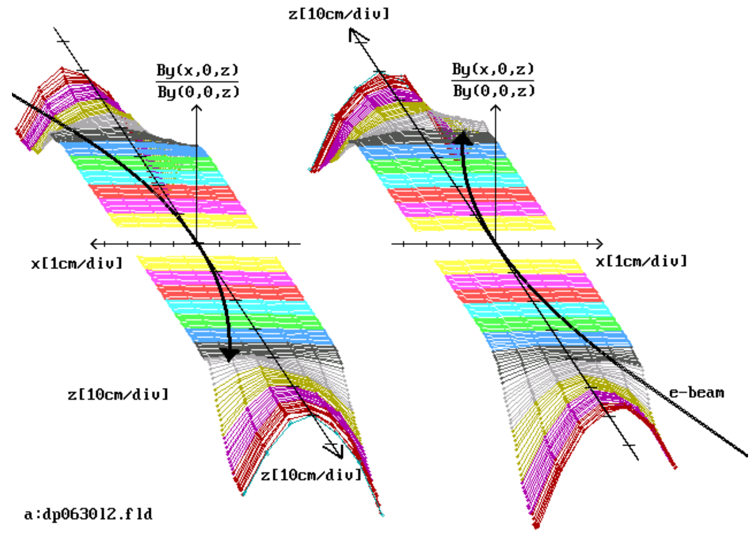


Momentum dependent tune shift. Measurement (red) and prediction with course model.

Agreement is not satisfactory

Refinements: Dipole Fringe Field

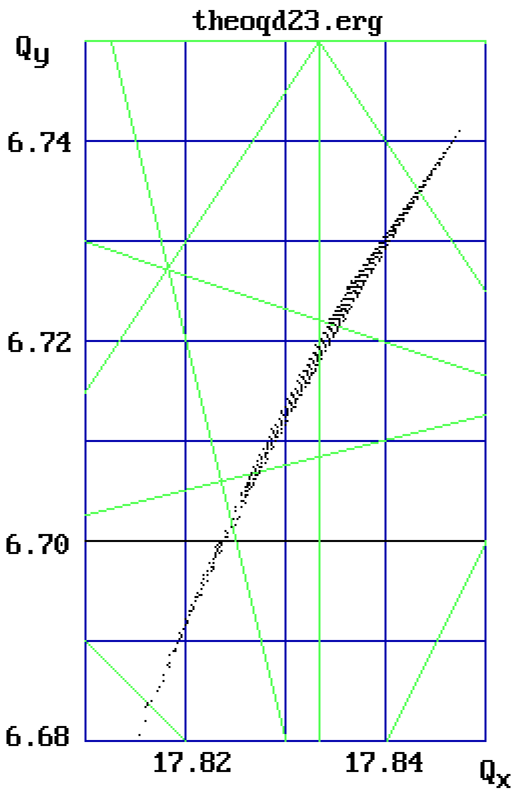


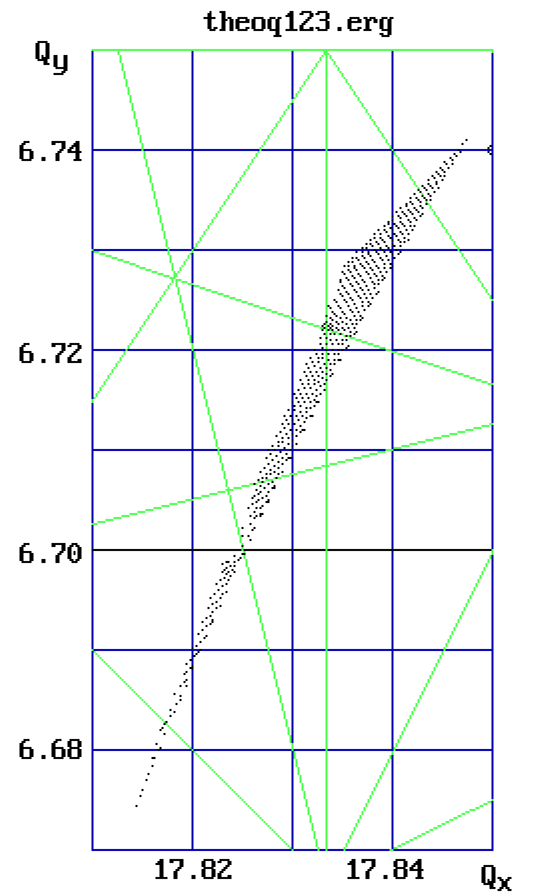


Analysis of 33 measured dipole field maps:

•12% reduction of the vertical focussing		
•integrated sextupole component	entrance	exit edge
	$+0.03 m^{-2}$	$+0.11 m^{-2}$
•integrated octupole component	entrance	exit edge
	$+5 m^{-3}$	$-13 m^{-3}$

Result: Calculated sextupole currents are in better agreement with actual settings and important as soon as amplitude dependent tune shifts are small...





Modification of the calculated frequency map if the dipole fringe field is included (right).

Refinements: Quadrupole Fringe Field

$$x^f = x \pm \frac{b_2}{12(1+\delta)}\left\{x^3 + 3y^2 x\right\}$$

$$p_x^f = p_x \pm \frac{b_2}{4(1+\delta)}\left\{2xyp_y - x^2 p_x - y^2 p_x\right\}$$

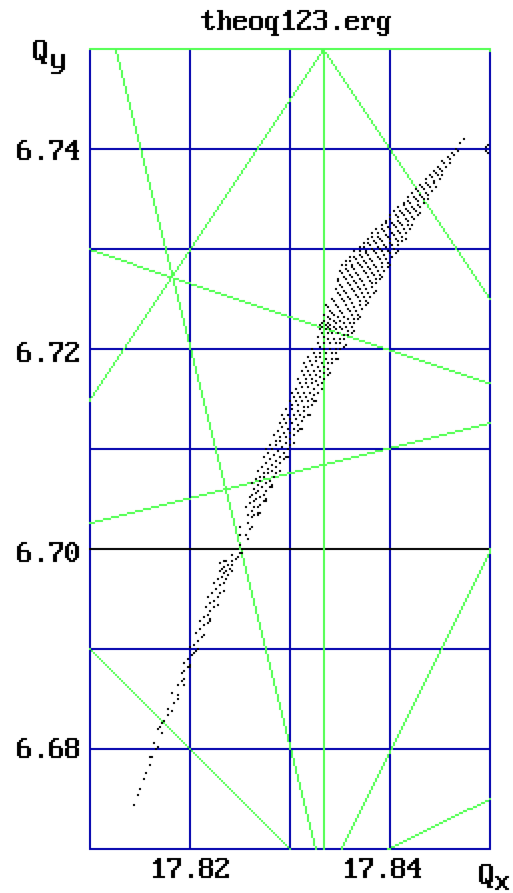
$$y^f = y \mp \frac{b_2}{12(1+\delta)}\left\{y^3 + 3x^2 y\right\}$$

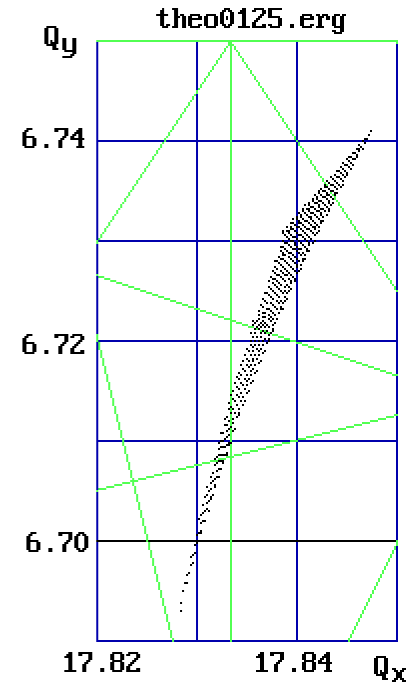
$$p_y^f = p_y \mp \frac{b_2}{4(1+\delta)}\left\{2xyp_x - y^2 p_y - x^2 p_y\right\}$$

$$\delta^f = \delta$$

$$l^f = l \pm \frac{b_2}{12(1+\delta)}\left\{y^3 p_y - x^3 p_x + 3x^2 y p_y - 3y^2 x p_x\right\}$$

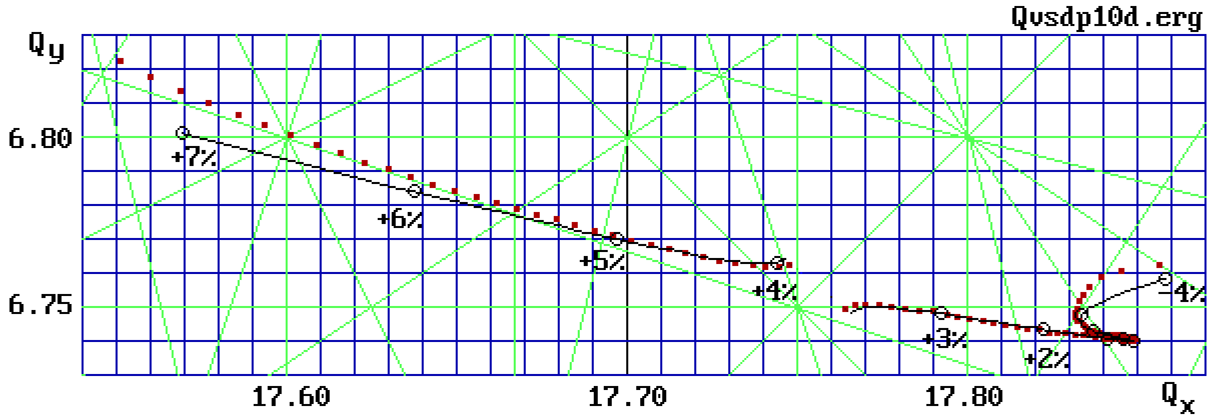
E. Forest and many others





Modification of the calculated frequency map due to the quadrupole fringe field (right).

Quadrupole fringe field important as soon as amplitude dependent tune shifts are small



Momentum dependent tune shift calculated taking dipole and quadrupole fringe fields into account. Measurement is shown in red.

Refinements: Sextupole Magnets

Fringe Field

has very small impact

$$p_x^f = p_x \pm \frac{S}{24(1+\delta)}\left\{11x^2 y p_y + y^3 p_y - x^3 p_x - x p_x p_y^2\right\}$$

$$p_y^f = p_y \pm \frac{S}{24(1+\delta)}\left\{3x^3 p_y + 3xy^2 p_y - 3x^2 y p_x + 5y^3 p_x\right\}$$

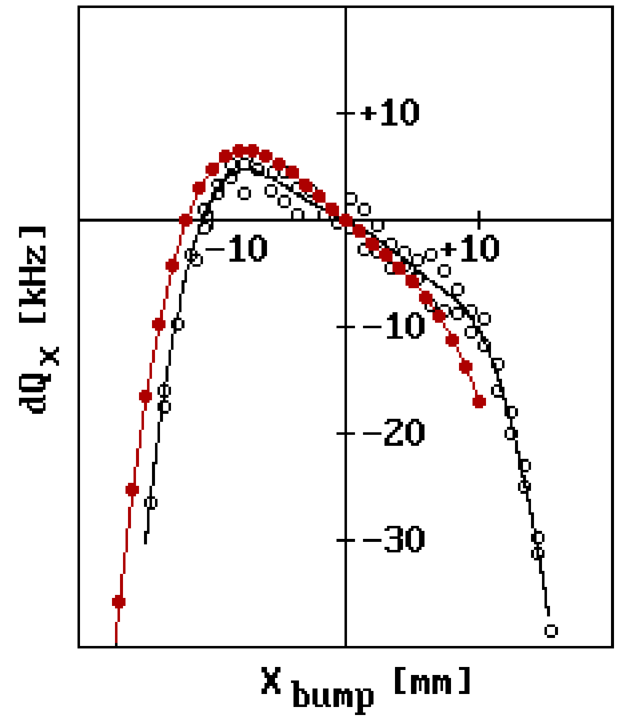
Added Functions : Horizontal and vertical steering, skew quadrupole component

Result of rotating coil measurements BESSY TB 209/97:

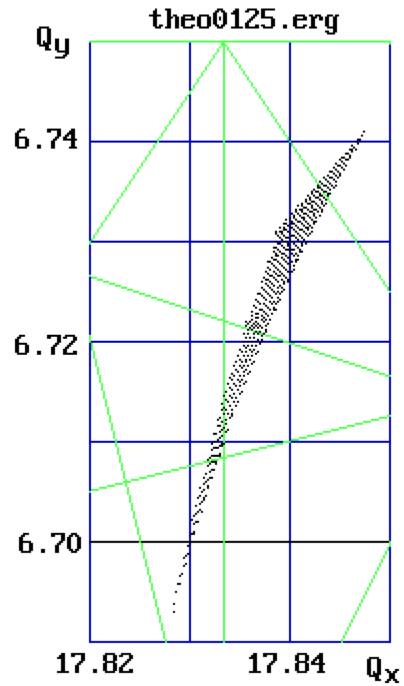
	Multipole	S1-sextupole (21 cm long)	S2-sextupole (16 cm long)
Vertical field B_y	b_1L/I	$6.019\ 10^{-3}$ Tm/A	$5.031\ 10^{-3}$ Tm/A
	b_3L/I	$6.6\ 10^{-1}\ Tm^{-1}/A$	$5\ 10^{-1}\ Tm^{-1}/A$
	b_5L/I	$3.41\ 10^{2}\ Tm^{-3}/A$	$2.67\ 10^{2}\ Tm^{-3}/A$
	b_7L/I	$3.10\ 10^{4}\ Tm^{-5}/A$	$2.27\ 10^{4}\ Tm^{-5}/A$
	$b_{11}L/I$	$-5.43\ 10^{9}\ Tm^{-9}/A$	$-4.16\ 10^{9}\ Tm^{-9}/A$
	$b_{13}L/I$	$-7.72\ 10^{12}\ Tm^{-11}/A$	$-6.20\ 10^{12}\ Tm^{-11}/A$
Horizontal field B_x	a_1L/I	$-3.455\ 10^{-3}$ Tm/A	$-2.883\ 10^{-3}$ Tm/A
	a_5L/I	$1.88\ 10^{2}\ Tm^{-3}/A$	$1.46\ 10^{2}\ Tm^{-3}/A$
	a_7L/I	$-1.72\ 10^{4}\ Tm^{-5}/A$	$-1.26\ 10^{4}\ Tm^{-5}/A$

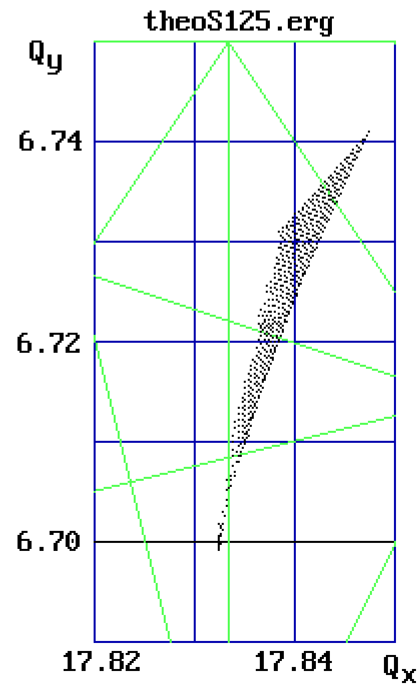
b_3, b_5, and a_5 are noticeable

Importance of the Decapole Component

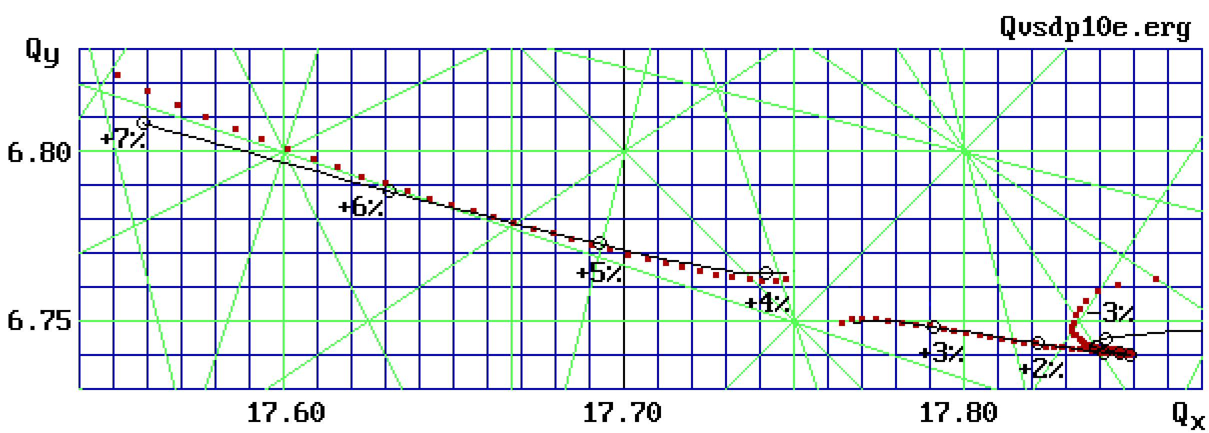


Horizontal tune as a function of a horizontal closed orbit bump. Theoretical prediction is shown in red and experimental result in black. Harmonic sextupole magnets were turned off and the chromaticity was set to zero during the experiment.



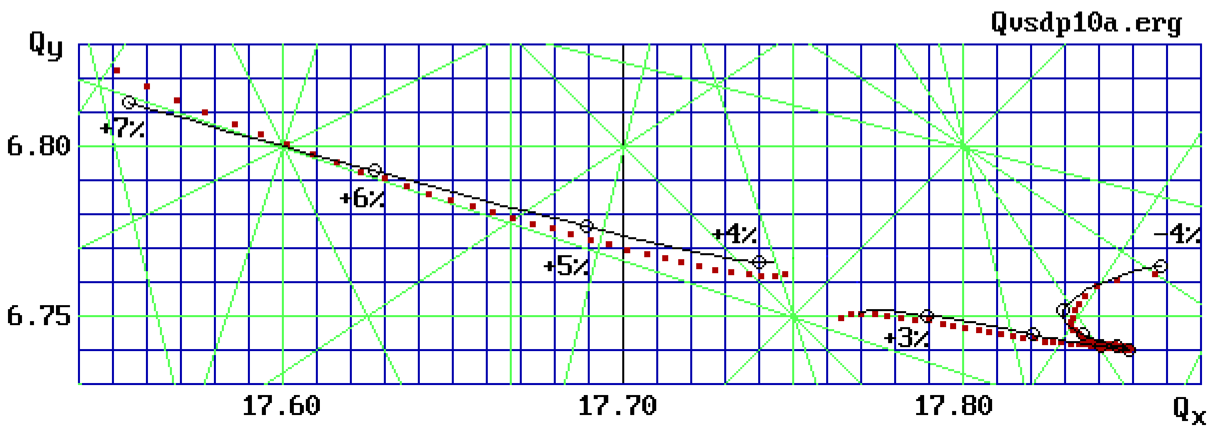


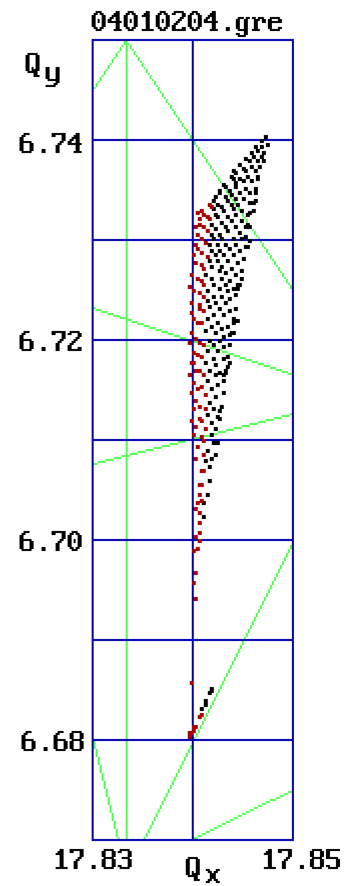
Predictions if sextupole and decapole components are taken into account.

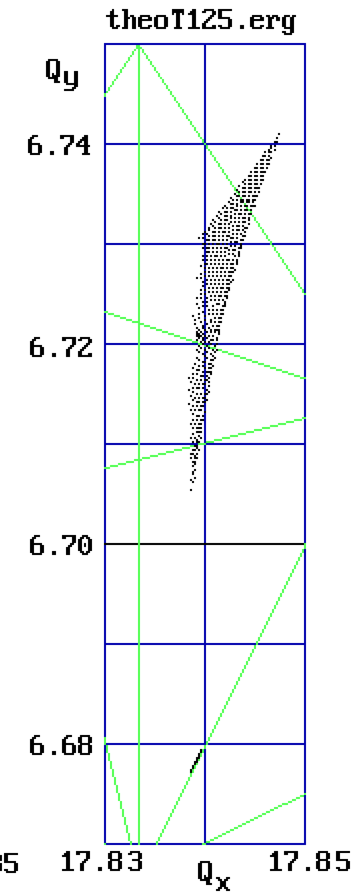


Adjustments of the Harmonic Sextupole Strengths

Small corrections (±1.2 %) give generally better agreement between experiment and theory:







State-of-the-art in non-linear modeling of the BESSY storage ring.

Conclusions

Predictions with (symplectic) tracking codes based on the correct linearly coupled lattice model are in good agreement with experimental observations if:

- Realistic dipole fringe fields (at least up to 3rd order)
- Theoretical quadrupole fringe fields and
- Perturbations in the sextupole magnets

are included.

Small corrections to harmonic sextupole fields could be real or just compensate for overlapping fringe fields of other magnets.

This deserves further studies for advanced lattice designs.

These points are less important for lattices without harmonic sextupole magnets (like the ALS).