Beam Dynamics with Insertion Devices at BESSY

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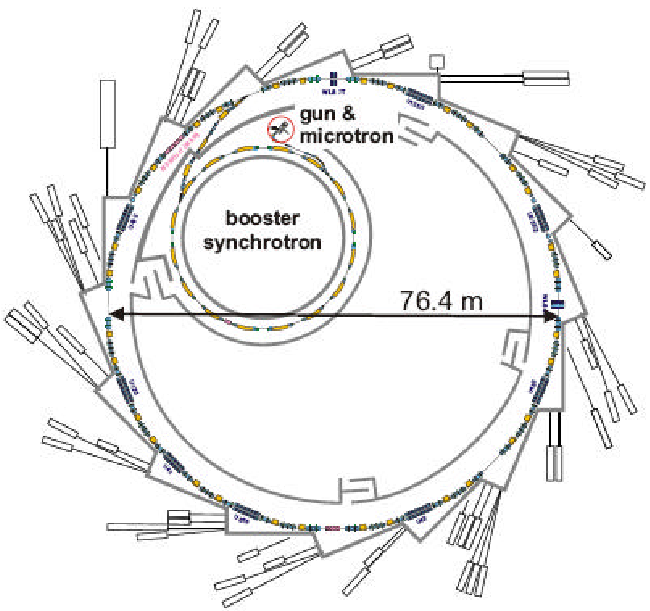
BESSY (BERLIN)

1. **BESSY II parameter**
2. **simulated ID effects**
3. **measured ID effects**

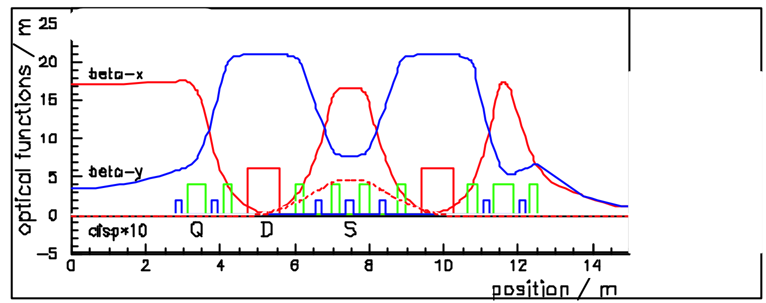
BESSY II electron storage ring



Optics: 2x8-cell DBA

15 IDs in operation

optical functions for one cell



Storage ring parameter

nom. energy	1.7 GeV
nat. emittance	6 nmrad
circumference	240 m
long. damping time	8 ms
typ. current	250 mA
rf-frequency	500 MHz
nat. chromaticity χ_x, χ_y	-52, -26

Insertion devices at BESSY

Table of present BESSY 15 IDs

Name	devices	length	B	ID-type
U-139	1	1.39 m	1.47 T	6 planar IDs
U-125	2	3.87 m	1.36 T	
U-49	2	4.10 m	0.80 T	
U-41	1	3.25 m	0.66 T	
UE-56	2	3.36 m	0.77 T	5 helical IDs
UE-52	1	4.00 m	0.74 T	
UE-49	1	3.09 m	0.71 T	
UE-46	1	3.24 m	0.68 T	
4(6)-T-WLS	1	0.008*	4 T	4 sc-IDs
7T-MPW	1	0.075*	7 T	strongest devices, emitted power = dipole rad. power = 17 kW / 100 mA
7T-WLS	2	0.020*	6.8 T	

* = vertical tune change

Numerical generating function (GF)

explicit orbit integration through the ID yields, rearranged:

$$(q_{xi}, q_{yi}, P_{xf}, P_{yf}) \Rightarrow (Q_{xf}, Q_{yf}, p_{xi}, p_{yi})$$

$i, f =$ initial, final

construct a polynomial GF of type F_2

$$F_2(q_{xi}, q_{yi}, P_{xf}, P_{yf}) = \sum_{k+l+m+n=1}^{M} a_{klmn} q_{xi}^k q_{yi}^l P_{xf}^m P_{yf}^n$$

$M = 4 \ldots 6$

with the properties

$$Q_{xf} = \partial F_2 / \partial P_{xf}, \quad Q_{yf} = \partial F_2 / \partial P_{yf}$$
$$p_{xi} = \partial F_2 / \partial q_{xi}, \quad p_{yi} = \partial F_2 / \partial q_{yi}$$

and fit numerically the a_{klmn}

implicit equations of motion solved by Newton fit routine

Analytical GF

H =**Hamiltonian,** A_u = **vector potential (analy. expression)**

$$H = (P_x - A_x / Br)^2 / 2 + (P_y - A_y / Br)^2 / 2 - A_z / Br$$

Hamilton-Jacobi-equation: $H\left(Q_x, P_x, Q_y, P_y\right) + \partial F / \partial z = 0$

where $F_2 = \sum_{l,m,n} f_{lmn} p_{xi}^l p_{yi}^m x_3^n$, $P_x = \partial F_2 / \partial Q_x$, $P_y = \partial F_2 / \partial Q_y$

and $f_{lmn}\left(Q_x, Q_y, z\right)$ **and, e.g.,** $x_3 = 1/Br$

- **first order, partial differential equation for** F_2
- f_{lmn} **solved by iteration routine (REDUCE)**

GF Example, planar ID:

scalar potential: $V = -(B_{\max}/k_y)\cos(k_x x)\sinh(k_y y)\cos(k_z z)$

expanded GF

$$F = F_{00} + F_{10}P_{xf} + F_{01}P_{yf} + F_{20}P_{xf}^2 + F_{11}P_{xf}P_{yf} + F_{02}P_{yf}^2$$

$$\begin{aligned}
F_{00} &= z\, x_3^2\,(k_y^2\cos^2(k_x q_{xi})\cosh^2(k_y q_{yi}) + k_x^2\sin^2(k_x q_{xi})\sinh^2(k_y q_{yi}))/4k_y^2\,,\\
F_{10} &= q_{xi} - z^2\, x_3^2\, k_x \sin(k_x q_{xi})\cos(k_x q_{xi})\,(k_z^2\cosh^2(k_y q_{yi}) + k_x^2)/4k_y^2\\
F_{01} &= q_{yi} + z^2\, x_3^2\, k_y \sinh(k_y q_{yi})\cosh(k_y q_{yi})\,(k_z^2\cos^2(k_x q_{xi}) + k_x^2)/4k_y^2\\
F_{11} &= z\, x_3 \sinh(k_y q_{yi})\cos(k_x q_{xi})\,(k_y^2 + k_x^2)/(k_z k_y)\\
F_{20} &= z/2 - z\, x_3 k_x \cosh(k_y q_{yi})\sin(k_x q_{xi})/k_z\\
F_{02} &= z/2 + z\, x_3 k_x \cosh(k_y q_{yi})\sin(k_x q_{xi})/k_z
\end{aligned}$$

FAST: several periods can be taken in a single step! $z = n\,l$

fast convergence $x_3 = 1/(k_z r_{\min}) \approx 1/(60*5) = 1/300$

Helical ID (APPLE II type)

Scalar potential for an APPLE II type ID:

$$V = b_0(V_1 + V_2 + V_3 + V_4)/8, \text{ with}$$

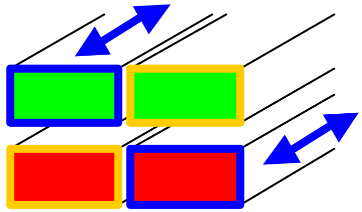
$$V_1 = (e^{+k_y y} cx_-/k_y + e^{+k_z y}/k_z) sz_+$$

$$V_2 = (e^{+k_y y} cx_+/k_y + e^{+k_z y}/k_z) sz_-$$

$$V_3 = (e^{-k_y y} cx_+/k_y + e^{-k_z y}/k_z) sz_+$$

$$V_4 = (e^{-k_y y} cx_-/k_y + e^{-k_z y}/k_z) sz_-,$$

$$cx_\pm = \cos(k_x(x \pm x_0)), \quad sz_\pm = \sin(k_z z \pm \psi/2).$$



the expanded, analytical GF is derived from this potential function

The integrated sextupole strength of one pole is comparable to the harmonic sextupole strength of BESSY II.

Helical ID: matching condition

First and second field integrals for closed orbit matching:

$$\int_{-L}^{+L} B_y dz = 0, \quad \int_{-L}^{+L}\int_{-L}^{z} B_y dz'\, dz = 0$$

and for B_x

and similar for the ID-sextupole components:

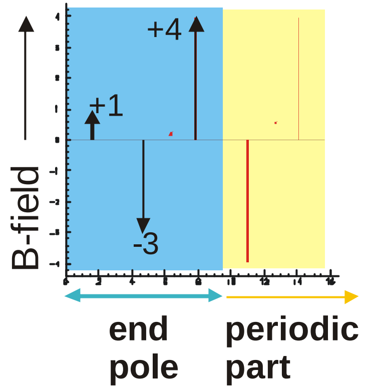
$$\int_{-L}^{+L} s(z) dz = 0, \quad \int_{-L}^{+L}\int_{-L}^{z} s(z') dz'\, dz = 0$$

proof based on
T. Collins "Distortion Functions", Fermilab Internal report 84/114

there are 4 types of sextupole-like fields:

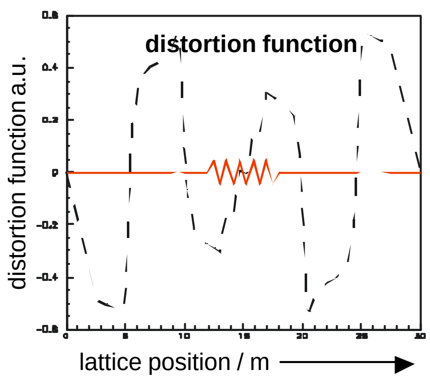
$$V_{xxx}, V_{yxx}, V_{yyx}, V_{yyy}$$

Helical ID: end poles

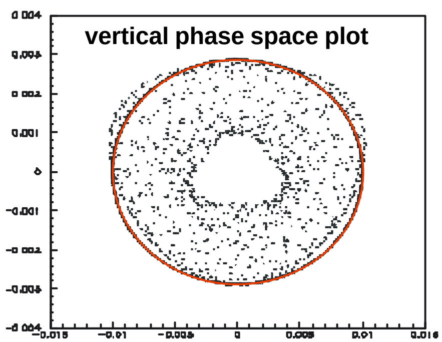


- **closed orbit has to be matched to helical orbit**
- **non. lin. fields have to be matched**

- **possible, matched end pole scheme:**
  3 poles of equal shape and at periodic location with amplitude ratio of +1 : -3 : +4



Distortion function B for the matched (red) and unmatched case along one BESSY II unit cell



Vertical phase space plot for the matched (red) and unmatched case

ID effects on the beam

ID gap	life time	orbit ff off	orbit ff on	tune ff off	tune ff on
open	5h - 8h	-	-	-	-
closed	3h - 5h	100 ☆ μm	20 μm	125 kHz	<5 kHz

ff = feed forward

☆ = per ID

UE56-module: skew 8-pol resonance,
tune moved away from resonance

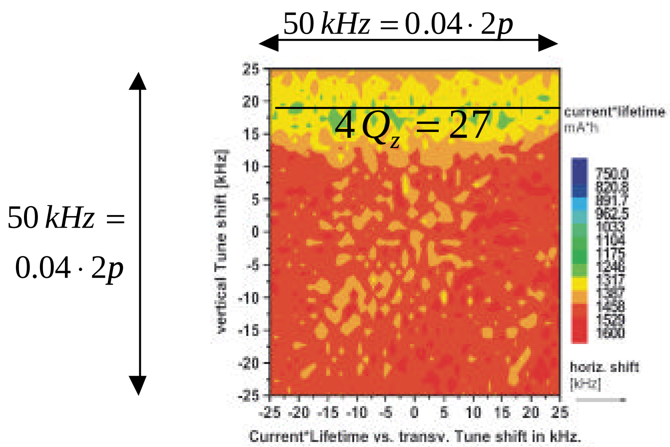
U125, 0.02 max. tune shift, large beta- and phase beat,
with correction 16% ► 10% life time reduction

7T-MPW, 0.075 max. tune shift, large beta- and phase beat,
life time affected by gas desorption

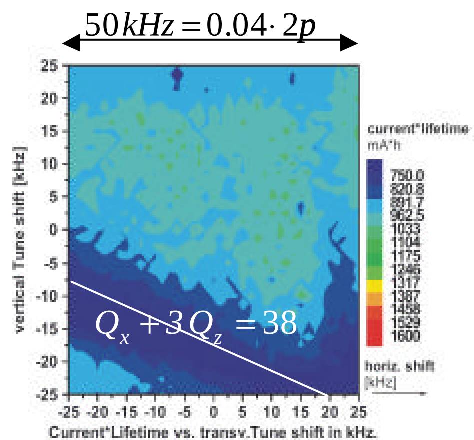
ID effects on the beam

excitation of skew octupole resonance by UE56

vertical tune scan



gap open



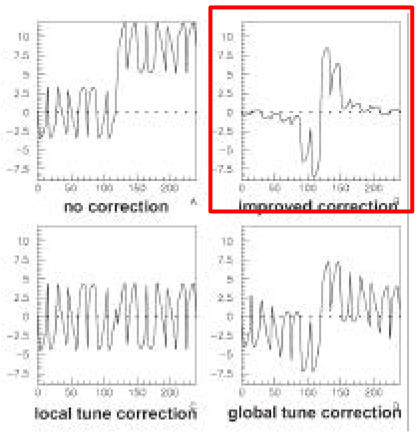
gap closed

ID effects on the beam

linear distortion by IDs can disturb the nonlinear tuning of the ring
beta and phase beating needs to be corrected

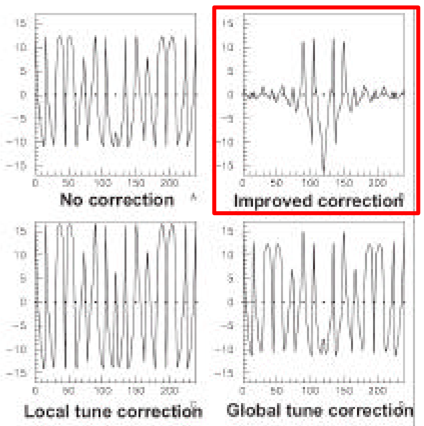
optics correction of U-125, tune shift 0.02

phase beat correction



vertical phase beat in degrees

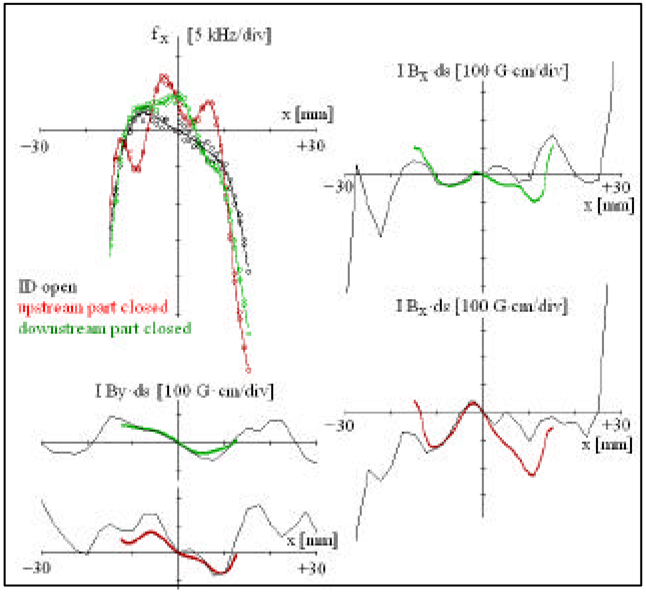
beta beat correction



vertical beta beat in %

Field integrals

Comparison of field integrals measured with beam and stretched wire, helical ID UE56



Beam-based measurement of the integrated field errors in comparison with the results obtained by a stretched wire (black). The results for the up- and downstream parts are shown in red and green.

- upstream and downstream module of ID operated as a planar device
- horizontal tune shift and vertical beam kick as a function of the horizontal displacement are measured
- vertical and horizontal field strength are derived and compared with stretched wire data

summary

- **generating functions are fast and symplectic mapping routines for IDs**
- **end poles require a careful design including the non.-lin. fields**
- **additional resonances are excited by ID-fields**
- **strong linear ID-distortions de-tune the non. lin. ring optics, beta beat and phase beat correction required**