Impact of Insertion Devices on the MAX IV Storage Rings

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In a Nutshell

• Strong insertion devices (IDs) can have significant impact on optics and emittance of the MAX IV storage rings.
PRST-AB **17**, 050705 (2014)

• Already during ring design phase, set limits for acceptable multipole content in IDs.
PAC'11, TUP235, p.1262

• Apart from orbit feedback as well as local dipole correctors to correct first and second-order ID integrals, the ring optics are matched to strong IDs to minimize beta beating and tune shifts *in two stages*.

• *Local optics matching*: quadrupole gradients around ID are adjusted to minimize beta beating while maintaining lowest source size.

• *Global optics matching*: quadrupole gradients in two families are adjusted coherently around the entire ring to restore the working point.

• During operation, optics matching can be performed in a combination of feedforward (on ID gap and phase settings) and feedback (using an online tune measurement to restore the design working point).

• With this matching, ID gap and phase movements shall become transparent to other users and IDs can be hidden from the nonlinear optics optimization. This should result in preservation of high injection efficiency and good lifetime.

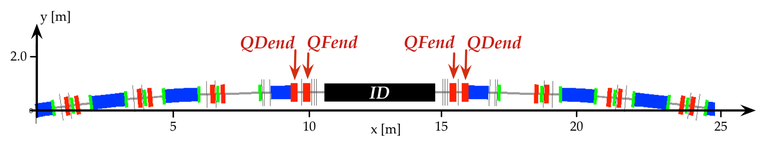
• In the work presented here, RADIA kick maps have been used for tracking studies in Tracy-3 including magnet and alignment error models.
PRST-AB **12**, 120701 (2009)

Matching in the 3 GeV Ring

• *Local*: match quadrupole doublet QDend/QFend adjacent to the ID in order to over-focus the beam in the ID ➞ compensate ID without increasing source size.

• *Global*: adjust all QDend/QFend around the ring coherently by a small amount.

• Matching does not involve the pole-face strips used to adjust the vertical focusing of the gradient dipoles.

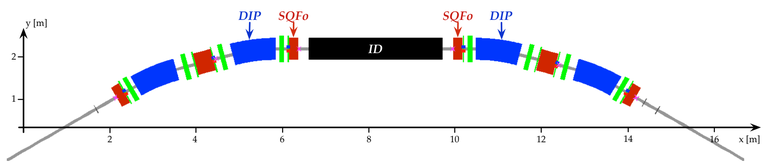


Matching in the 1.5 GeV Ring

• *Local*: adjust gradient in combined quadrupole/sextupole SQFo as well as the pole-face strips in the dipoles flanking the ID (requires "floating" power supplies).

• *Global*: adjust all SQFo and dipole pole-face strips around the ring coherently by a small amount.

• Dispersion & chromaticity perturbed ➞ adjust chromaticity via correction sextupoles.



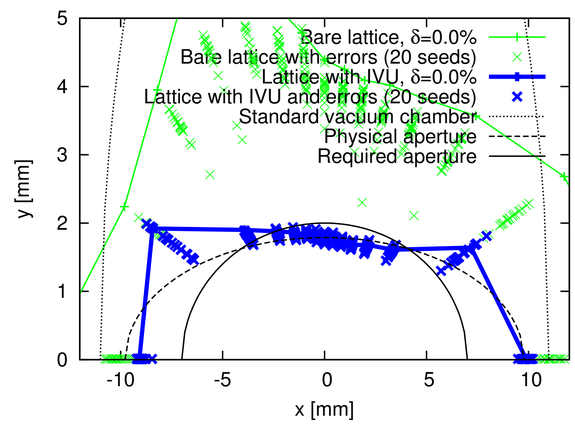
Hitachi IVU (3 GeV Ring)

• 18 mm period, 1.26 T peak field (K=1.95), 2 m long, kick map at 4.2 mm magnetic gap.

• Once proper matching applied, no nonlinear optics issues or coupling blowup observed.

• Vertical "dynamic" aperture limitation is actually caused by physical acceptance of the ID.

	Local		Global	
Gap	QFend	QDend	QFend	QDend
4.2 mm	+0.106%	+0.429%	−0.009%	−0.035%



On-energy DA from 6D tracking with Tracy-3. The Hitachi IVU was modeled using a kick map assuming a fully closed gap (note the vertical acceptance limitation).

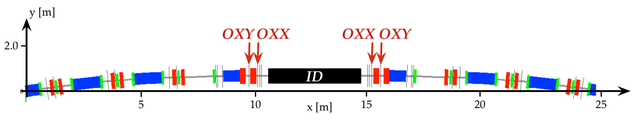
epu53 (3 GeV Ring)

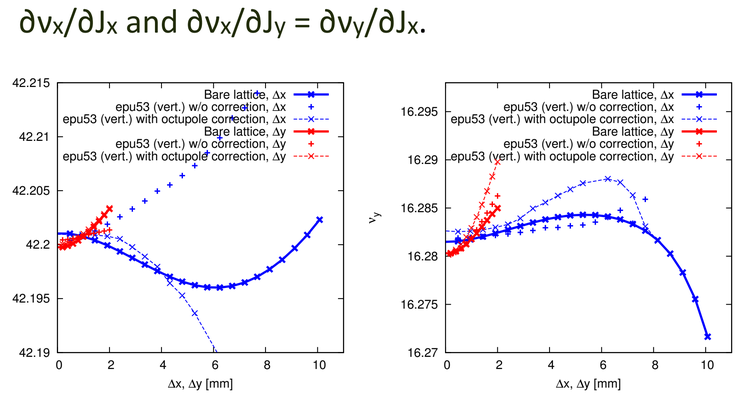
• 53 mm period, 1.1 T peak field (K=5.2), 3.9 m long, kick maps for each EPU mode at 11 mm magn. gap.

• Inclined mode increases coupling to ~0.8%. Can be compensated for by exciting skew quadrupole windings on adjacent octupoles OXX (-0.3 T/m).

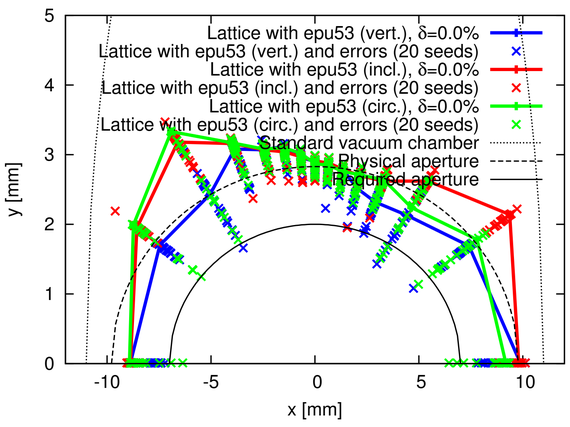
• Vertical mode showed a reduction of DA. FMA reveals this is caused by a perturbation of $\partial\nu_x/\partial J_x$ pushing towards $2\nu_x+2\nu_y = 117$ for large horizontal amplitudes
PRST-AB **14**, 030701 (2011)
➞ +15% on OXX and +5% on OXY to re-adjust $\partial\nu_x/\partial J_x$ and $\partial\nu_x/\partial J_y = \partial\nu_y/\partial J_x$.

	Local		Global	
Mode	QFend	QDend	QFend	QDend
Planar	−0.496%	−0.004%	−0.005%	−0.033%
Vertical	+2.28%	+1.92%	−0.032%	−0.075%
Inclined	+0.054%	+0.508%	−0.014%	−0.057%
Circular	+1.22%	+1.18%	−0.022%	−0.058%





Amplitude-dependent tune shift from 6D tracking with Tracy-3. The epu53 was modeled using a kick map for vertical mode assuming a fully closed gap. The correction from adjusting two octupole families can be recognized.



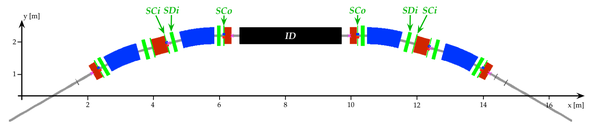
On-energy DA from 6D tracking with Tracy-3. The epu53 was modeled using kick maps for vertical, inclined, and circular modes assuming a fully closed gap.

epu95.2 (1.5 GeV Ring)

• 95.2 mm period, 1.2 T peak field (K=10.5), 2.6 m long, kick maps for each EPU mode at 14 mm magnetic gap.

• All modes studied so far show only minor change of chromaticity ➞ correct by exciting sextupole families SDi (3-4% increase) and SCi (~50% decrease).

• Inclined mode increases coupling to ~5.8%. Can be compensated for by exciting skew quadrupole winding on the adjacent correction sextupoles SCo (-2 T/m).



	Local		Global	
Mode	SQFo	DIP	SQFo	DIP
Vertical	+9.36%	−2.36%	−0.173%	+0.164%
Inclined	+0.328%	+3.41%	−0.035%	−0.373%
Circular	+5.23%	+4.18%	−0.104%	−0.365%

On-energy DA from 6D tracking with Tracy-3. The epu95.2 was modeled using kick maps for vertical, inclined, and circular modes assuming a fully closed gap.

Conclusions & Outlook

• So far all Phase I IDs can be matched properly in all modes at minimum gap.
• Satisfactory ring performance after matching (verified with 6D tracking in Tracy-3 incl. errors).
• Matching for remaining Phase I IDs (weaker than the IDs presented here) to be investigated soon.