Impact of Insertion Devices on the MAX IV Storage Rings

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IMPACT OF INSERTION DEVICES ON THE MAX IV STORAGE RINGS

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Abstract

There will be multiple compensations employed for insertion devices in the MAX IV storage rings. Apart from well-known dipole corrections and previously detailed local and global linear optics matching, certain insertion devices in the MAX IV storage rings will also require nonlinear optics adjustments and/or skew quadrupole corrections. The goal of such corrections is ensuring sufficient dynamic aperture as well as low residual emittance coupling. This paper will present a few studies that rely on tracking through kick maps in order to quantify detrimental effects of insertion devices on dynamic aperture and vertical emittance, develop suitable countermeasures, and finally, verify restored storage ring performance.

INTRODUCTION

During the design phase of the MAX IV storage rings several example insertion devices (IDs) were used to develop compensation strategies [1–4]. This resulted in ID compensation schemes where the storage ring optics are matched in a two-stage process both locally and globally to each ID thus making the ID transparent to other users [3,4]. The first step is *local*: the beta functions of the achromats adjacent to the ID are matched to the ID by adjusting quadrupole gradients (implemented as a feedforward table depending on ID gap and phase settings). This is a rather fine adjustment because of the low beta functions in the ID straights. Nevertheless, a small phase advance leading to a tune shift for the entire ring results. This is then corrected in the second matching step: a *global* matching is carried out where quadrupole gradients around the ring are gently adjusted to restore the design working point (implemented in a feedback scheme relying on an online tune measurement). Ideally, the result of these two matching steps is that the ID becomes transparent to the rest of the ring. The beta functions in the sextupoles and octupoles are virtually unchanged and the working point is at its design value. Therefore, the chromatic and amplitude-dependent tune shifts (ADTSs) are restored to their design behavior thus replicating the tune footprint of the design lattice with its large dynamic aperture (DA) and good lifetime.

Already during the design process limits were set for acceptable multipole content in IDs [4] and used for ID specification. In the meantime, RADIA kick maps for the Phase I IDs [5] have been prepared so actual tracking studies can now be performed to verify the proposed compensation scheme leads to acceptable storage ring performance. The kick maps are inserted into the Tracy-3 lattice model and the optics matching is carried out (assuming that all first and second-order ID integrals have been canceled using dedicated dipole correctors at the IDs). The effect on optical functions, tune shifts, and coupling is then assessed and additional nonlinear and/or skew quadrupole matching requirements are derived where necessary. Performance of all optics adjustments combined is again verified using 6D tracking including imperfections (misalignments as well as field and multipole errors) [6] to determine overall resulting DA, lifetime, and coupling. Examples of such studies will be discussed in this paper. It should be pointed out, however, that several effects of IDs on the storage rings are not treated here: firstly, the effect of IDs on emittance, energy spread, bunch length, and lifetime can become severe in the ultralow-emittance lattice of the 3 GeV storage ring [7]; the effect of optics matching and choice of coupling on resulting brightness [8]; and finally, IDs can have many implications for collective behavior and instabilities; this is, however, also beyond the scope of this paper.

Optics Matching in the 3 GeV Storage Ring

In the 3 GeV storage ring local matching (cf. Fig. 1) is achieved by adjusting the quadrupole doublets (QFend/QDend) in the matching cells adjacent to the ID so the beam is over-focussed in the ID [1, 3]. This allows compensating the ID focusing without actually increasing the beam size in the ID. Global matching is then carried out by adjusting all QFend/QDend around the ring coherently by a small amount. Such corrections leave the optical functions in the unit cells virtually unchanged and the working point is exactly restored. Note that this matching does not involve excitation of the pole-face strips (PFSs) that are used to adjust the vertical focusing in the gradient dipoles.

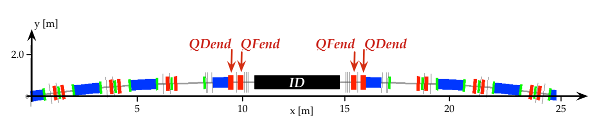

Figure 1: Schematic of an ID installed in a long straight section between two achromats of the 3 GeV storage ring. The two quadrupole families involved in the optics matching are indicated.

Furthermore, the 3 GeV storage ring lattice contains three octupole families that allow direct shaping of the ADTSs [9]. These can be used to counteract amplitude detuning that arises from strong IDs. Finally, all sextupoles and octupoles in the 3 GeV storage ring carry auxiliary coils that can be powered, among other ways, as a skew quadrupole. This opens the possibility for strong local coupling corrections around specific IDs.

Optics Matching in the 1.5 GeV Storage Ring

In the 1.5 GeV storage ring local matching (cf. Fig. 2) is achieved by adjusting the combined quadrupole/sextupole

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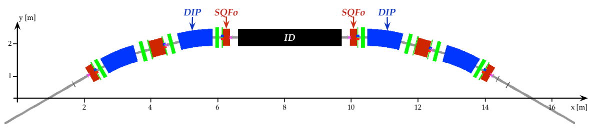

Figure 2: Schematic showing an ID installed in a straight section between two achromats of the 1.5 GeV storage ring. The two magnet families involved in the optics matching are indicated.

SQFo as well as the PFSs in the dipoles flanking the ID [10]. Global matching is then carried out by adjusting all SQFo and dipole PFSs around the ring coherently by a small amount. Since all the SQFo magnets and all PFSs are series-connected, the local ID compensation has to be performed via "floating" power supplies.

Note that since the compensation involves a PFS excitation, the dispersion and hence the chromaticities are perturbed. Furthermore, since SQFo is implemented as a quadrupole that creates a sextupole gradient through its pole shape, any change of current in SQFo results in a change of sextupole gradient. Independent sextupole correction coils are available so the linear chromaticities can be restored on a 10^{-1} or better level. Finally, as in the 3 GeV storage ring, the 1.5 GeV storage ring contains auxiliary coils that can be used (among others) as skew quadrupoles thus enabling strong local coupling corrections around specific IDs if required.

INSERTION DEVICES IN THE 3 GeV STORAGE RING

In Phase I of the MAX IV beamline project there will be five IDs in the 3 GeV storage ring [5]: two 2 m long Hitachi in-vacuum undulators (IVUs) for the BioMAX and NanoMAX beamlines; one elliptically polarizing undulator (EPU) called epu53 for the HIPPIE beamline; the mechanically almost identical epu48 for the VERITAS beamline; and finally, SOLEIL is building an in-vacuum wiggler (IVW) for the BALDER beamline.

Hitachi IVU

The Hitachi IVU is a 2 m long planar undulator with 18 mm period length, 4.2 mm magnetic gap, and 1.26 T peak field. Since this device is substantially shorter than the original IVU [1] and pmuL [3] used during the design phase of the 3 GeV storage ring, no substantial matching problems were expected. The required gradient matching for the Hitachi IVU at minimum gap is shown in Table 1 and confirms only minor adjustments are required. With this optics matching the resulting DA (cf. Fig. 3) is beyond requirements even when imperfections are included. Note what appears to be a vertical DA restriction is in fact the vertical acceptance limitation of the IVU when operated at fully closed gap [4].

Table 1: Adjustments Required to Match Optics to the Hitachi IVUs in the 3 GeV Storage Ring

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

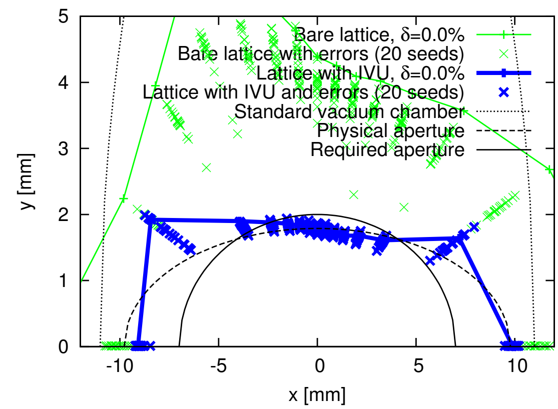

Figure 3: On-energy DA from 6D tracking with Tracy-3. The Hitachi IVU was modeled using a kick map assuming a fully closed gap (note the vertical acceptance limitation).

epu53

The epu53 is a 3.9 m long EPU with 53 mm period length and 11 mm magnetic gap. For each EPU mode appropriate gradient matching has been determined (cf. Table 2). In inclined mode an increase of coupling to ≈ 0.8% was observed. This can be compensated entirely by exciting the auxiliary winding in the two octupoles flanking the ID (OXX) in skew quadrupole configuration so that a skew gradient of −0.3 T/m is achieved. In vertical mode a decrease of DA was observed despite the linear optics correction. Frequency map analysis revealed that the ADTS $\partial\nu_x/\partial J_x$ was perturbed significantly compared to its design [9] pushing the working point closer to the $2\nu_x + 2\nu_y = 117$ resonance as horizontal amplitudes approached ±8 mm. This can be corrected by exciting all OXX octupoles by 15% and all OXY octupoles by 5% above their nominal settings which adjusts the first-order contributions to $\partial\nu_x/\partial J_x$ and $\partial\nu_x/\partial J_y = \partial\nu_y/\partial J_x$, respectively (cf. Fig. 4). In user operation this can be done in a feedforward scheme. After applying the appropriate corrections, each mode of epu53 renders a DA exceeding the requirements (cf. Fig. 5).

Table 2: Adjustments Required to Match Optics to Various Modes of epu53 (at 11 mm gap) in the 3 GeV Storage Ring

	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%

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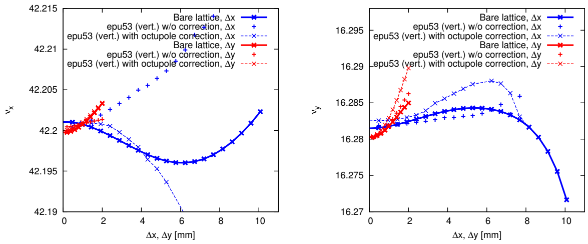

Figure 4: Amplitude-dependent tune shift from 6D tracking with Tracy-3. The epu53 was modeled using a kick map for vertical mode assuming a fully closed gap. The correction from adjusting two octupole families can be recognized.

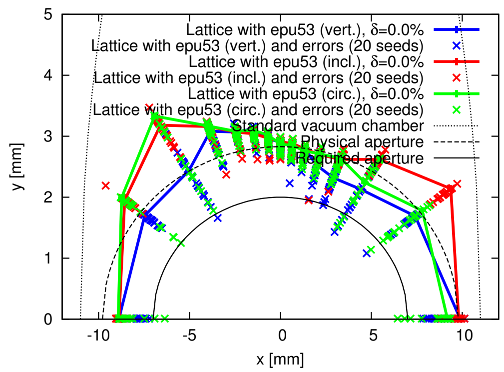

Figure 5: On-energy DA from 6D tracking with Tracy-3. The epu53 was modeled using kick maps for vertical, inclined, and circular modes assuming a fully closed gap.

INSERTION DEVICES IN THE 1.5 GeV STORAGE RING

In Phase I of the MAX IV beamline project there will be two IDs in the 1.5 GeV storage ring [5]: one EPU called epu95.2 for the FinEstBeaMS beamline and the mechanically similar epu84 for the ARPES beamline.

epu95.2

The epu95.2 is a 2.6 m long EPU with 95.2 mm period length, and 14 mm magnetic gap. For each EPU mode appropriate gradient matching has been determined (cf. Table 3). Vertical mode cannot be compensated by over-focusing the beam in the ID as is revealed by the sign of the PFS excitation and therefore the source size has to be slightly increased. Circular mode requires the strongest excitation of the PFSs, however, it is still within their ≈ ±5% tuning range. In inclined mode an increase of coupling to ≈ 5.8% was observed. This can be compensated by exciting the auxiliary winding in the two sextupoles flanking the ID (SCo) in skew quadrupole configuration to achieve a skew gradient of −2 T/m. Once these corrections have been applied[1], however, each mode of epu95.2 renders sufficient DA (cf. Fig. 6)

Table 3: Adjustments Required to Match Optics to Various epu95.2 Modes (at 14 mm gap) in the 1.5 GeV Storage Ring

	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%

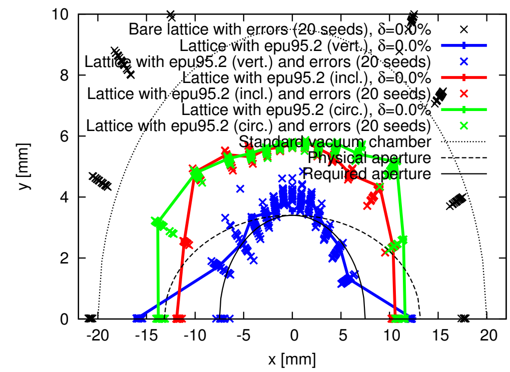

Figure 6: On-energy DA from 6D tracking with Tracy-3. The epu95.2 was modeled using kick maps for vertical, inclined, and circular modes assuming a fully closed gap.

CONCLUSIONS AND OUTLOOK

So far all Phase I IDs and modes can be matched properly and the resulting ring performance is satisfactory. Ongoing studies will render matching requirements for epu48 (similar but weaker than epu53 detailed here) and the SOLEIL IVW (similar to the PMDW used in the design phase [1–3]) in the 3 GeV storage ring as well as epu84 (similar but weaker than epu95.2 detailed here) and epu61 (presently in operation in MAX II) in the 1.5 GeV storage ring. This will be followed by similar studies for an additional four IDs in Phase IIa [5].

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