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ONLINE OPTIMISATION OF THE MAX IV 3 GeV RING DYNAMIC APERTURE

D. K. Olsson*, MAX IV Laboratory, Lund University, Lund, Sweden

Abstract

In order to improve the resilience of the MAX IV 3 GeV ring's beam to a horizontal dipole kick while at the design tunes (42.20, 16.28) the optimisation algorithm RCDS (Robust Conjugate Direction Search) was deployed. The algorithm was able to increase the horizontal acceptance by finding new settings for the sextupole and octupole magnets, whilst leaving the vertical acceptance virtually unchanged. Additionally, the optimisation increased the momentum acceptance of the lattice, increasing beam lifetime.

THE RCDS ALGORITHM

The RCDS algorithm [1] (graciously provided by Xiaobiao Huang) is a combination of Powell's method and a robust line search method. The algorithm scans each parameter and finds the parameter value which minimises a fitness function along a line in parameter space. The next parameter scan is done from this point. Once all parameters have been scanned a new direction in parameter space is constructed using the initial and final points.

Application to the MAX IV 3 GeV Ring

The 3 GeV MAX IV storage ring has a lattice containing five sextupole magnet families and three octupole families. All eight families were used to construct a parameter space for the RCDS algorithm to operate in. In the interest of time, the algorithm changed magnet families of each magnet type by the same amounts in all 20 achromats. Additionally, a chromaticity response matrix was use to construct tree chromaticity independent knobs from the five sextupole magnet families. These three knobs and the three octupole families resulted in a 6-dimensional parameter space.

The fitness function was the proportional loss rate of stored current in the ring when kicking the beam with a fast horizontal dipole pinger magnet (the single dipole injection kicker [2]). The strength of the pinger magnet was set at a high enough value to give an adequate signal to noise of the fitness function signal.

Before the optimisation the sextupole and octupole set values where determined using magnetic field maps which were measured by the manufacturer. In order to achieve (1, 1) chroamticity two magnet families had been changed to non-nominal values [3]. The working point during the optimisation was (0.20, 0.28).

Results

The difference in both sextupole and octupole values between the design and final RCDS settings can be seen in Fig. 1, intermediate results are presented in Table 1. The chromaticity was periodically corrected to account for the small drift present during the optimisation process. The beams resilience to a horizontal dipole kick was determined by monitoring the beam loss rate (using a DCCT) while kicking the beam with a horizontal or vertical pinger magnet. The horizontal kick needed to detect a beam loss rate increased from 1.1 mrad to 2.1 mrad, while the vertical kick resilience remained at 0.51 mrad. The increase in resilience remained after cycling. This optimisation is a continuation of the optimisation work presented in [4].

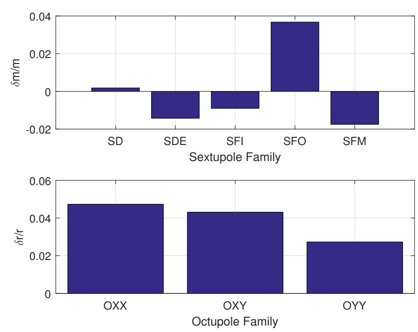

Figure 1: Relative change in sextupole and octupole settings post optimisation.

Table 1: Intermediate RCDS Results

Iteration #	Max. H. Kick [mrad]	(H,V) Lin. Chro.
1	1.2 mrad	(0.99,1.12)
2	1.8 mrad	(1.02,1.01)
3	1.9 mrad	(1.19,0.99)
4	2.1 mrad	(0.95,1.04)

DYNAMIC APERTURE EVALUATION

The dynamic apertures of the design setting and the RCDS setting were evaluated using three separate measuring methods.

Turn-by-Turn Transverse Dynamic Aperture Measurement

The transverse dynamic aperture can be evaluated by looking at the turn-by-turn beam loss and beam amplitude after kicking the beam with a fast dipole kicker. Similar measurements have been done at several other facilities [5, 6]. All beam positions recorded after the turn-by-turn beam loss has stabilised are assumed to be within the dynamic aperture. The strength of the dipole kicker was increased until a beam loss of $> 1\%$ for a single kick was detected by the DCCT.

* david_k.olsson@maxiv.lu.se

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This low relative beam loss was chosen in order to avoid frequent re-injections. In order to scan over the entire transverse plane the beam was excited using linear combination of both the horizontal and vertical pingers.

As there are no magnetic elements in the long straight sections of the ring, the two flanking BPMs can be used to calculate the transverse dynamic aperture (x, y, x', y') over the entire straight section. Unlike the scraper measurements presented below, this type of measurement allows us the calculate the acceptance without relying on a separate measurement of the beta functions, e.g. LOCO.

In order to account for the BPM non-linearities at large beam displacements the BPM button response was modelled using the procedure found in [7]. The model was then used to linearise the data from the BPMs.

Results The measured dynamic aperture at a beam current of 3.5 mA for the two different sets of sextupole and octupole settings can be seen in Figs. 2 through 4. The simulated dynamic aperture corresponding to Fig. 2 can be seen in Fig. 5 [8]. The acceptance can be calculated as the product of the maximum phase-space position and angle. Using this method the acceptances was found to be $A_x = 2.18$ mm mrad and $A_y = 1.96$ mm mrad for the initial non-linear optics and $A_x = 4.54$ mm mrad and $A_y = 2.01$ mm mrad for the new non-linear optics. At the centre of the straight sections we have $\beta_x = 9$ m and $\beta_y = 2$ m.

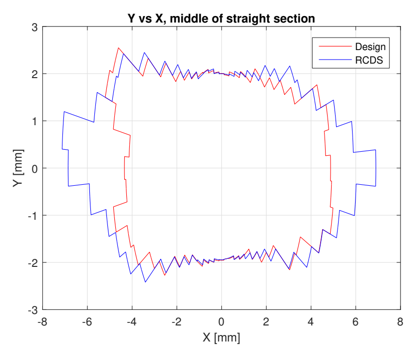

Figure 2: Transverse dynamic aperture measured using turn-by-turn data and the horizontal and vertical pingers.

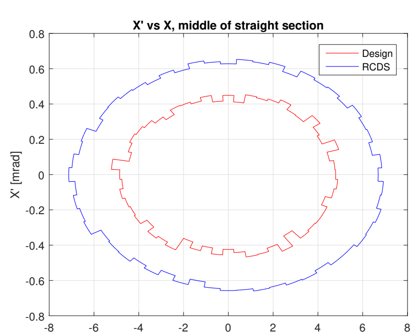

Figure 3: Horizontal dynamic aperture measured using turn-by-turn data and the horizontal and vertical pingers.

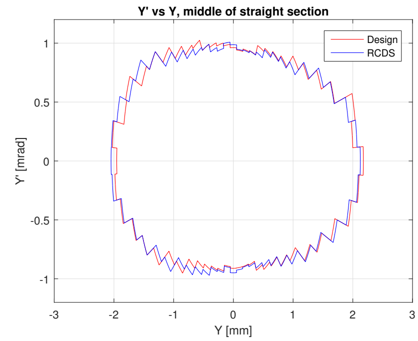

Figure 4: Vertical dynamic aperture measured using turn-by-turn data and the horizontal and vertical pingers.

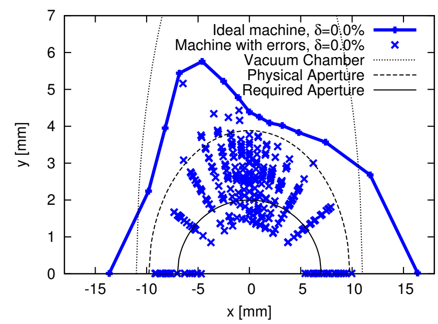

Figure 5: Simulated transverse dynamic aperture at the centre of a long straight section [8]. The required aperture is was determined by the injection process and lifetime considerations.

Scraper Dynamic Aperture Measurement

The transverse dynamic aperture was also evaluated using a horizontal and a vertical scraper located in a straight section. The dynamic aperture is determined by monitoring the beam lifetime while moving the scraper closer to the beam. The distance from the beam centre at which the scraper starts affecting the beam lifetime is taken as the dynamic aperture limit. This measurement only measures one dimension of the dynamic aperture (x or y, depending on whether the beam is scraped horizontally or vertically) at the position of the scraper.

Results For the design sextupole and octupole magnet settings the scrapers were found to affect the lifetime at a distance of 7.4 ± 0.1 mm horizontally and 2.7 ± 0.1 mm vertically from the beam centre at a beam current of 75 mA. The corresponding results for the RCDS sextupole and octupole magnet settings was 7.7 ± 0.1 mm horizontally and 2.7 ± 0.1 mm vertically. During the scraper measurements it was noted that the beam lifetime was ~23 h and ~30 h for the design and RCDS non-linear settings respectively.

Using LOCO the beta functions of the two machine settings could be found. From these and the results from the scraper measurements the acceptances were found to be $A_x \geq 5.9 \pm 0.2$ mm mrad and $A_y = 1.8 \pm 0.15$ mm mrad for

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the design settings, and $A_x \geq 6.3 \pm 0.2$ mm mrad and $A_y = 1.8 \pm 0.15$ mm mrad for the RCDS settings.

Momentum Acceptance Measurement

The optimisation process' effect on the momentum acceptance was also investigated. The effect is already visible in the results of the scraper measurements where the beam lifetime was several hours longer for the optimised sextupole and octupole settings. The momentum acceptance of the MAX IV 3 GeV storage ring is dominated by the dynamic acceptance of the lattice at nominal RF voltage values. By decreasing the RF voltage until a clear decrease in lifetime can be seen it is possible to compare the momentum acceptance of the two lattices.

Results The results for the initial and the optimised lattices, measured at 75 mA, can be seen in Fig. 6. Here, as in the scraper measurements, the increased lifetime of the optimised non-linear optics can be seen. Additionally the lifetime of the initial optics appears unaffected by the decrease in RF voltage, indicating that the lattice dynamic acceptance dominates during the entire measurement. In the case of the optimised non-linear optics a clear decrease in lifetime can be seen as soon as the RF voltage is decreased. This indicates that the RF acceptance dominates the momentum acceptance, i.e. the lattice dynamic acceptance is equal to, or greater than, the RF acceptance at nominal RF voltage.

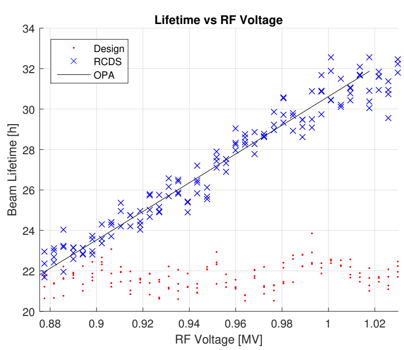

Figure 6: Result of momentum acceptance measurements for the two different non-linear optics. The measurements where taken at a beam current of 75 mA. The black solid line is the fitted results of a simulation in OPA corresponding to a gas lifetime of 95 h.

The lifetime contribution from the RF acceptance could be simulated using OPA. By fitting these results to the momentum acceptance measurement the gas lifetime was determined to be 95 h. The lifetime together with the simulated RF acceptance indicates that the dynamic acceptance is ≥ 4.5 % which is the design goal value in [8].

CONCLUSION

The RCDS algorithm was applied to the MAX IV 3 GeV storage ring in order to increase the beam's resilience to a horizontal kick, thus increasing the horizontal dynamic aperture. The dynamic aperture was evaluated pre- and post-optimisation using two different independent measurements. Although there is some discrepancy between the two methods in the horizontal plane they both revealed an increase in horizontal dynamical aperture without any significant change in vertical dynamic aperture.

One difficulty with the TbT DA measurement is determining what relative beam loss constitutes the edge of the DA. The discrepancy in the horizontal plane is attributed to this, to a possible issue with the BPM synchronisation, and the decoherence of the BPM signal. The maximum transverse amplitude of the electrons with a high energy deviation appears after a few hundred turns. At this point the decoherence is unfortunately so large that this amplitude is not detected.

In addition to the horizontal increase the momentum acceptance of the lattice appears to have increased significantly, as indicated by the momentum acceptance measurement and the Touschek lifetime.

At the time of writing the RCDS sextupole and octupole settings are to be used in the MAX IV 3 GeV production optics.

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