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FULL SIMULATIONS OF THE DIAMOND-II STORAGE RING COMMISSIONING AND POSSIBLE IMPROVEMENTS OF PROCEDURES

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Abstract

To provide confidence in the future commissioning of the Diamond-II storage ring, realistic specifications for the error tolerances have been established. Based on these values, commissioning simulations have been conducted starting from on-axis injection through to stored beam and finally the establishment of nominal lattice. The goal of these studies is to develop a robust commissioning procedure that stays within the magnet strength limits using the statistics of many random machines simulated. In this paper we summarize these studies and present the final results. A study of a special BBA procedure developed to handle the issue of disturbance from strong sextupoles is also presented.

INTRODUCTION

The Diamond-II storage ring commissioning procedures can be divided into different phases, depending on the ability to store on-axis injected beams, accumulate off-axis injected beams, and whether the linear lattice including coupling is well corrected. The steps basically follow the plans outlined in previous publications [1, 2].

In a follow-up study [3], larger misalignment errors were assigned to 200 random machines for simulations. We were always able to have enough transmissions for the next procedures by just varying correctors until the step when RF is tuned. After the motion in the longitudinal phase space was corrected, a quadrupole scan was performed to correct the integer tune and achieve a stored beam.

More recently, the simulations were extended to cover off-axis injections and beam accumulation [4]. In this article, the latest simulation results up to a well corrected linear lattice are shown and some statistics of magnet strengths are presented. Moreover, a special beam-based alignment (BBA) scheme has been developed to reduce the impact of strong sextupole perturbations and improve measurement accuracy. Finally, a conclusion and a summary are given.

SIMULATION RESULTS

Once a stored beam exists, the commissioning procedure moves on to multiple applications of BBA and linear lattice corrections by Linear Optics from Closed Orbits (LOCO) [5]. Here we present the results starting from the step where a stored beam is first achieved until the step where the linear lattice is well-corrected after the third application of LOCO. Their dynamic apertures are shown in Fig. 1. At the final status 97.5 % of 200 simulated seeds have negative-x dynamic aperture larger than 6 mm and off-axis injected beams can be comfortably accumulated.

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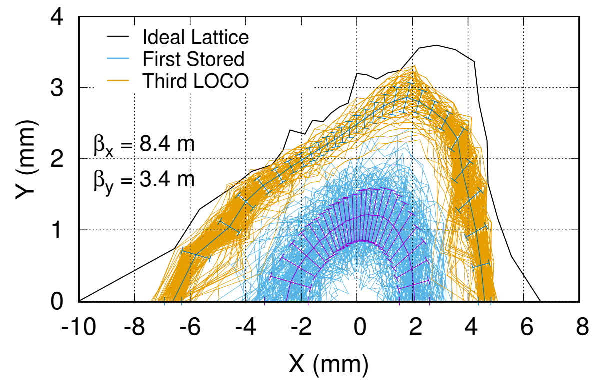

Figure 1: Dynamic apertures at the steps of the first stored beams and after third LOCO. The averages and standard deviations are also shown.

First stored beam is assumed to be from on-axis injection of a single multi-bunch train and 0.5 mA total current. In worst case, the Touschek lifetime at this stage is estimated to be 26 minutes. At the final step, the Touschek lifetime is estimated to be 2.17 ± 0.2 hours for a 300 mA beam (without harmonic cavities), compared to 2.53 hours for the ideal lattice.

The horizontal emittance is corrected close to the design value while the vertical emittance is corrected to small values, shown in Fig. 2.

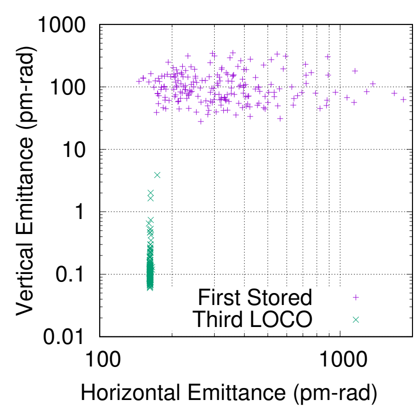

Figure 2: Emittance of first stored beams and after third LOCO.

LOCO STATISTICS

Different linear optics correction steps are interleaved between BBA procedures. In the first LOCO all the 300 pure quadrupoles are used. In the second LOCO all the 240 skew quadrupoles are added for coupling correction. In the third LOCO, the rest of the tuning knobs from the

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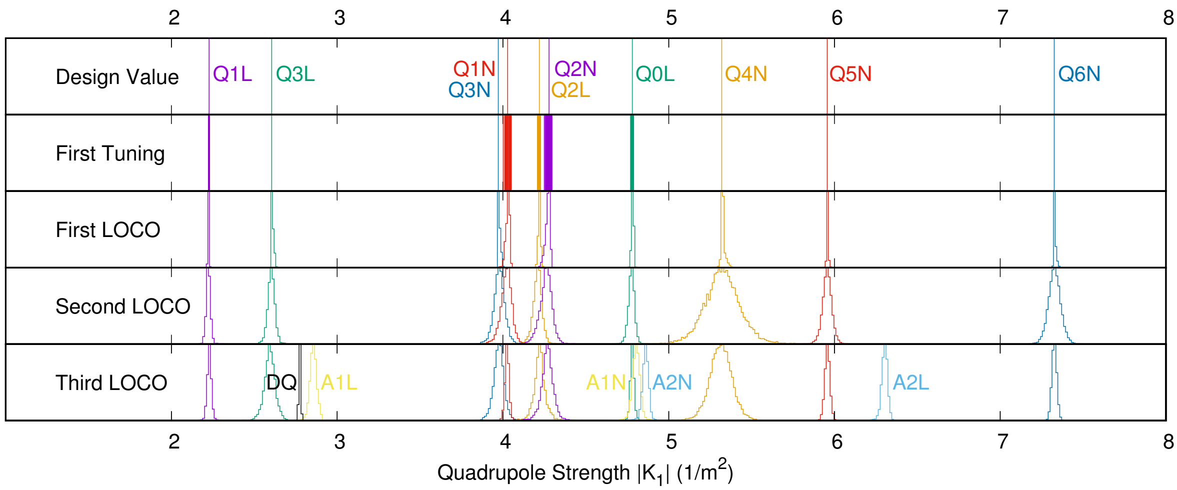

Figure 3: Histograms of magnet gradient setpoints at different commissioning steps.

gradient dipoles including anti-bend elements are used. In the end, all seeds have a small closed orbit response matrix fitting penalty (χ^2 per degree of freedom < 8) with very few outliers.

The field gradients following these commissioning procedures are categorised by family names and their histograms from all 200 seeds are shown in Fig. 3. This information is helpful validating the magnet and power supply design specifications. Throughout the commissioning procedures all the maximum strengths are within the engineering limits. For reference the magnet names as well as the linear optics are depicted in Fig. 4.

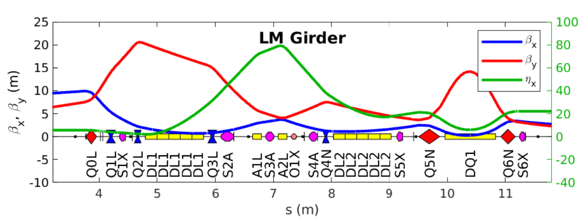

Figure 4: Optical functions and magnets in a LM girder. A black dot indicates a BPM.

One characteristic observed is the significance of Q4N, as a large spread in setpoints occurs after the second LOCO. This is reduced after the third LOCO when all tuning knobs are used. There are some statements still to be verified by further simulations. For example, introducing the gradient dipoles at an earlier LOCO step may prevent the spread in Q4N setpoints from occurring, or it may be effective to tune Q4N at early stages. Moreover, one would like to know whether the commissioning can be simplified with a reduced number of tuning variables.

SPECIAL BBA

During the BBA the BPM offsets are updated according to the measured centres of the adjacent quadrupoles. The offsets residuals between BPM and quadrupoles, broken down by quadrupole families, are revealed in Fig. 5. The largest residuals are thus identified at the quadrupole families Q3 (Q3N/Q3L).

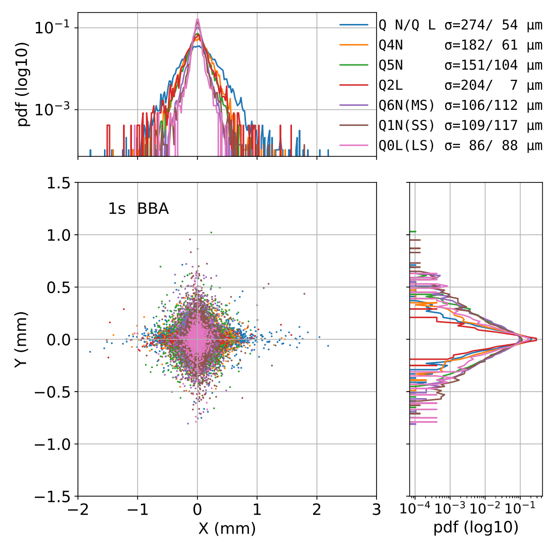

Figure 5: BPM-quad offset residuals for the first BBA. The bin size of the probability density function is 0.02 mm.

The large distance between Q3 and the closest BPM is one of the factors causing poor BBA convergence but unfortunately it is difficult to change the hardware design to bring them closer. Another factor is the nonlinearities from the sextupole (S2A) sandwiched in between them. To see the impact of sextupoles a trial simulation is carried out applying the same BBA procedure without the presence of sextupoles. For simplicity we have assumed a closed orbit exists although in reality a beam doesn't survive without sextupoles. Figure 6 shows that the residuals are indeed smaller and the outliers are reduced compared to Fig. 5.

One option to avoid the disturbance from local sextupoles but maintain stored beam would be to temporarily switch off only the local sextupoles. The chromaticities can be maintained at the same level by scaling up the remaining sextupoles of the same families. This is because the optics

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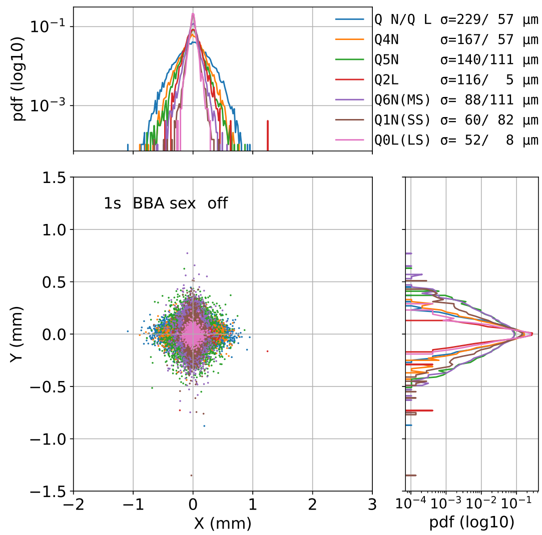

Figure 6: BPM-quad offset residuals for the first BBA when sextupoles are off.

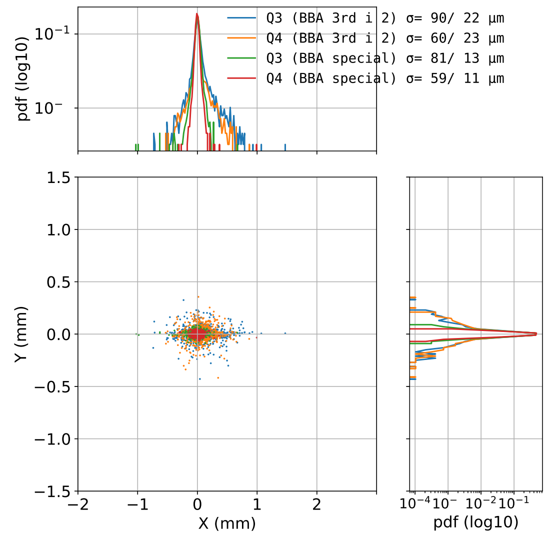

Figure 7: Comparison of the BBA-quad offset residuals before and after applying the special BBA.

are nearly the same at the same sextupole families. This operation is feasible because all sextupoles are individually powered and their strengths are designed with sufficient margins. Tracking studies show that the impact on dynamic apertures would be acceptable.

A more practical special BBA procedure is therefore proposed as follows. The six local chromatic sextupoles (S2/S3/S4) in a single H6BA cell are ramped off temporarily while the sextupoles of the same families in other cells are scaled up accordingly. After the new centres of Q3 and Q4 are found, we can then resume the sextupole setpoints and re-align the beam to the new centres. This procedure is then iterated over all H6BA cells in the ring. The improvement of the residuals from this additional special BBA applied after the third LOCO is shown in Fig. 7. The robustness of this method still needs to be improved as a few seeds failed to converge, contributing the outliers.

One can further generalise this method on harmonic sextupole families and try this approach at earlier phases as long as there is a stored beam with enough lifetime.

DISCUSSION

Given 200 random machines generated with practical error specifications and following the planned commissioning procedures [1–3], we have simulated the Diamond-II storage ring commissioning until the linear lattice is well-corrected. Here are some findings that give us good confidence for the commissioning of Diamond-II storage ring coming in the future.

- Good beam transmissions can always be reached by applying the beam threading procedures with a relaxed regularisation of corrector strengths.
- Sufficient turns can be achieved by just varying the correctors to allow RF tuning to be carried out.
- After RF is switched on, a first quadrupole tuning can be carried out simply by a quadrupole scan with a small tune variation to achieve a stored beam.
- First BBA and LOCO can be performed with a stored beam with reasonable lifetime, avoiding the need to use low resolution shot-by-shot BPM data.
- During the commissioning procedures the magnet strengths are all within the engineering limits.

Alternative procedures such as correcting the optics before stored beam and delaying having sextupoles on are expected to be helpful for a good beam transmission but optional. Some major challenges foreseen for these methods come from the noisy BPM signals when the current is low and the early stage BBA.

The Diamond-II lattice is found to be relatively more relaxed compared to storage rings with smaller dynamic apertures. Applying the alternative early-stage commissioning strategies planned for rings with swap-out injection [6] can also lead to a successful Diamond-II commissioning. One method under consideration is a trajectory-based BBA before sextupoles are switched on. A requirement to do so is a single shot injection of higher current to lower the BPM noise. With the recent success of APS-U storage ring commissioning, it is worth investigating the feasibility of this approach for our injector.

Other works in this paper are summarised as follows.

- The distributions of field gradients at each stage have been explored. Some ideals to improve the commissioning procedures need further study.
- Poor BBA results have been identified by inspecting BPM-quad offset residuals broken down by location.
- A special BBA procedure was developed to handle the issues when a strong sextupole is sandwiched between a BPM/quadrupole pair.

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