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EFFECTS OF TRACKING ERRORS ON THE SOLEIL II BOOSTER

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Abstract

For the upgrade of SOLEIL II [1] a new booster with reduced transverse and longitudinal beam sizes is required. The new booster follows a 16 BA Higher-Order Achromat lattice with a reduced emittance to about 5 nm rad at 2.75 GeV. At the end of the ramp an emittance exchange is foreseen to allow for more flexibility in the injection parameters into the storage ring. In order for a good efficiency of the emittance exchange, the coupling of the lattice has to be well controlled. This is achieved with a LOCO routine for coupling using 10 skew quadrupoles, but the so-called random tracking errors from the ramping magnet power supplies introduce noise in the response matrix measurement. Furthermore, an online measurement setup for the beam sizes using visible light and a slit mirror needs a careful beam position evaluation, which may be affected by tracking errors. For both these items, this contribution outlines the efforts and results achieved.

INTRODUCTION

For machines operating in a ramping mode, especially with rapid ramping, such as booster synchrotrons, the magnet power supplies do not operate in steady state. Instead, they are in a mode of constantly changing currents and voltages. As a result, in each cycle of the ramping procedure, the voltages and currents might be slightly different from cycle to cycle. Furthermore, as there are multiple power supplies involved in the ramping procedure, each power supply might experience slight timing jitters from cycle to cycle. Overall these two effects lead to an error on the optics that changes randomly from cycle to cycle or shot-to-shot. These errors are referred to as tracking errors. They are modeled as purely random error on the strength of magnets grouped by their power supply. A level of 5×10^{-5} is deemed realistic for the SOLEIL II booster upgrade at final extraction energy of 2.75 GeV and simulations shown in this paper use this level of tracking errors.

In order to guarantee good injection efficiency for the future, an emittance exchange routine is foreseen for the SOLEIL II booster [2–4]. This routine is strongly dependent on the coupling of the machine which can be corrected using LOCO with skew quadrupoles. However, LOCO relies on a response matrix which cannot be measured with a single stored beam in the case of the SOLEIL II booster as no operation for prolonged periods of time at a steady energy will be possible. Instead, the response matrix for loco has to be measured on a shot-to-shot basis. This, however, is subject to tracking errors which spoil the results if not considered correctly.

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RESPONSE MATRIX SIMULATION FOR LOCO ON A SHOT-TO-SHOT BASIS

For mitigation of the effect of tracking errors on the response matrix used for coupling correction with LOCO, two methods were considered. The first method aims at increasing the strength of dipolar corrector magnets used for the response matrix measurement. The rationale behind this approach is the fact, that with high orbit deviations due to the dipolar corrector magnets during the response matrix measurement routine, the relatively small effect of tracking errors on the orbit might be negligible. The second method aims at reducing the effect of tracking errors by averaging multiple shots. This is expected to improve the result as the tracking errors are expected to be purely random.

In order to simulate the effect of tracking errors on the response matrix, as well as the mitigation approaches, full robustness simulations were performed (cf. [4]) with 250 random error seeds. For each seed, the response matrix for LOCO was simulated and the effectiveness evaluated. Simulations were performed using Accelerator Toolbox [5] and Simulated Comissioning [6].

LOCO RESULTS

The main motivation for LOCO is the effectiveness of the emittance exchange at the end of the ramp. Therefore, the two metrics used for judging the effectiveness of LOCO are the coupling after coupling correction as well as the horizontal emittance after the exchange.

Without considering tracking errors, the required strength of the dipolar corrector magnets is quite low at 10 µrad. This allows coupling correction with an average residual coupling of about 1.2 %. However, when considering the tracking errors during response matrix calculation, the coupling even after correction stays above any acceptable level.

Using stronger dipolar corrector magnets, at 20 µrad improves the situation and results in an average residual coupling of 12.6 %. However, the emittance exchange performance, shown in Fig. 1 (top), does not reach the goal of a horizontal emittance for most seeds below 0.5 nm · rad.

The situation improves further with higher dipolar corrector strengths, but with less effectiveness, at 50 µrad the average residual coupling is 3.5 %.

Figure 1 (middle and bottom) shows the horizontal emittance after exchange for 30 µrad and 50 µrad. It is visible, that the exchange effectiveness changes only slightly above 30 µrad.

Adding averaging into the response matrix calculation improves the situation in terms of emittance exchange drastically. Just averaging over 5 measurements (with a dipolar corrector strength of 20 µrad) yields for most of the seeds

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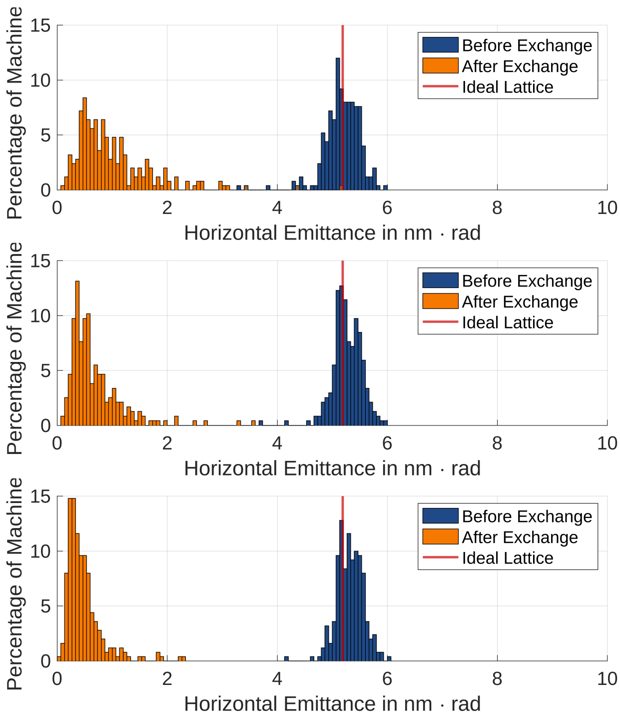

Figure 1: Horizontal emittance before (blue) and after (orange) emittance exchange after coupling correction using no averaging and 20 µrad (top), 30 µrad (middle) and 50 µrad (bottom) strength on the dipolar correctors for response matrix calculation.

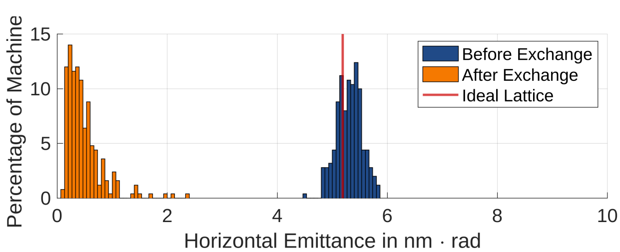

Figure 2: Horizontal emittance before (blue) and after (orange) emittance exchange after coupling correction using averaging of 5 measurements at 20 µrad strength on the dipolar correctors for response matrix calculation.

a horizontal emittance after exchange below 1 nm · rad as seen in Fig. 2. The residual average coupling is in this case at 3.5 %.

It is important to consider the strength of the skew quadrupoles that are used for coupling correction. In the case of averaging 5 times and a strength of 20 µrad, the required strength of the skew quadrupoles (and their power supplies) is significantly above their designed strength of 0.2 T at almost 0.3 T for the worst seed.

The best compromise between duration of the measurement, low dipolar corrector strength and low skew quadrupole strength was found at averaging 10 times and a dipolar corrector strength of 40 µrad. The corresponding emittance exchange and skew quadrupole strength distribu-

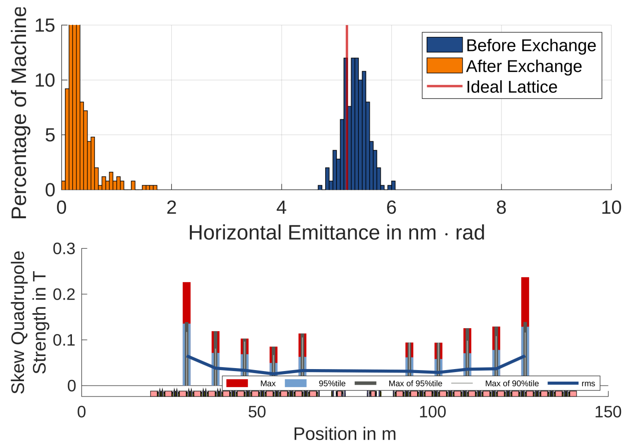

Figure 3: Horizontal emittance before (blue) and after (orange) emittance exchange after coupling correction using averaging of 5 measurements at 20 µrad strength on the dipolar correctors for response matrix calculation.

tion is shown in Fig. 3 and the average residual coupling is, with 1.7 %, only slightly above the .

LIGH SPOT POSITION VARIATIONS ALONG THE RAMP AND SHOT-TO-SHOT

For the SOLEIL II booster an emittance measurement is planned by using visible light generated towards the higher energies along the ramp from injection energy of 150 MeV to extraction at 2.75 GeV. A slit mirror is foreseen to allow X-Rays to pass through. The size of this slit is dependent on the spot movement and therefore on beam position. This position will move along the ramp and vary from shot to shot due to tracking errors and injection variations.

Tracking simulations along the ramp were performed. Due to time restrictions, for each combination of tracking error and injection error, one particle was tracked to limit simulation time. This particle represents the center of mass of the bunch.

For the simulations various representatives from the set of error configurations from robustness simulations were used as lattice. The results shown here correspond to the lattice showing the largest position variations. A total of 375 seeds of tracking errors were used in combination with 48 random injection errors per tracking error seed.

The spot on the mirror was calculated by taking into account the distance to the source point (about 1 m), the particle position as well as the particle angle.

Figure 4 shows the spot density of all seeds over all turns above 500 MeV (all tracking error seeds, all injection error seeds and all turns). The cut at 500 MeV was done due to the fact, that below this energy, the heating due to the produced synchrotron radiation is negligible. The highest density of the spots is within an about ± 0.5 mm wide vertical window as visible from the integrated profile on the right of Fig. 4. Outside of this about ± 0.5 mm vertical window around the peak, the density is over one order of magnitude lower than the peak. However, the spot density is not necessarily the full

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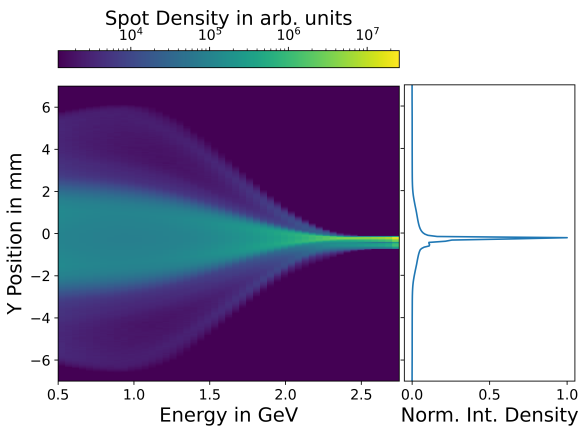

Figure 4: Density of center of spots on the mirror for all seeds and all turns above 500 MeV. The right panel shows an normalized integral over the energy of the density.

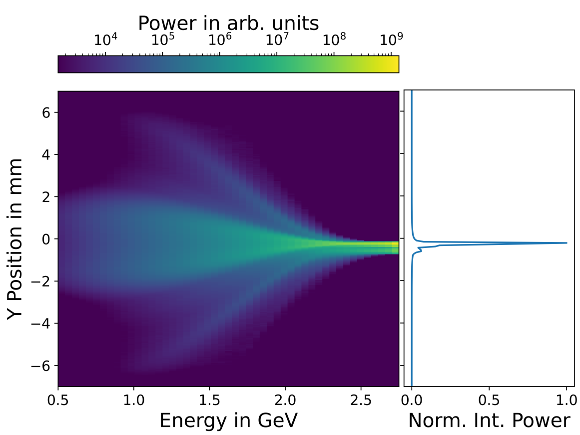

Figure 5: Density of center of spots on the mirror scaled with energy to the power of 4 for all seeds and all turns above 500 MeV. This gives an impression of the distribution of the deposited power on the mirror. The right panel shows an normalized integral over the energy of the scaled density.

picture as higher energies contribute stronger to the heating of the mirror. Therefore Fig. 5 shows the density scaled with the energy to the fourth power to give an impression on the deposited energy. From the right panel of this figure, it is visible, that the area of highest deposited power is within an even smaller window below $\pm$ 0.4 mm in width. Where the deposited power for points outside this window is over two orders of magnitude lower than the peak power.

It is important to note here, that the study here only considers the center of mass of a bunch. The area of high power deposition will be wider when considering the vertical dimension of the bunch and therefore a larger spot on the mirror.

SUMMARY

The tracking errors of a ramped machine such as the SOLEIL II booster do have an impact on various aspects of the beam. In case of the SOLEIL II booster, the impact on LOCO for coupling correction and the emittance exchange was shown as well as the strategy to mitigate the effects. Using a strong enough setting on the dipolar correctors for measuring the response matrix and averaging over multiple cycles yields good results for coupling correction and emittance exchange.

For the heating of the mirror used at the visible light diagnostics setup for beam size and emittance measurements, it was shown that the deposited power outside of a $\pm$ 0.4 mm high horizontal strip is expected to be two orders of magnitude lower than the peak power. This value, however, only considers the center of mass of the bunch and needs to be refined by taking into account the vertical dimension of the beam and light spot size on the mirror.

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