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STUDYING THE DYNAMIC INFLUENCE ON THE STORED BEAM FROM A COATING IN A MULTIPOLE INJECTION KICKER

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Abstract

The MAX IV 3 GeV ring is the first synchrotron light source utilizing the Multi-Bend Achromat scheme to achieve a low horizontal bare-lattice emittance of 328 pm rad providing high brilliance x-rays for users. A novel Multipole Injection Kicker (MIK) designed and constructed by SOLEIL is used to allow top-up operation with only minor disturbances to the stored beam, i.e., the users. We investigate the stored beam perturbations due to quadrupole fields arising during the MIK pulse, originating from its inner coating. Maximum bunch emittance growth of 21 pm rad was found in simulations. Measurements of the stored beam impact are performed and found to be in good agreement with simulations. We conclude that the MIK at MAX IV 3 GeV has the potential to deliver quasi-transparent injections with good capture efficiency.

INTRODUCTION

The ultimate goal of injection schemes for new storage ring-based light sources is to deliver transparent injections in top-up mode with no particle loss. Current off-axis injections schemes utilizing 3- or 4-kicker bumps are not transparent, since the bump closure is not perfect, leading to betatron oscillations of the stored beam with oscillation amplitudes of several tens of microns. A potential way of achieving transparent injections is to use Multipole Injection Kickers (MIK) which have no magnetic field on-axis, while maintaining a high field off-axis. The scheme of using quadrupole- and sextupole-kickers for injections was first employed at KEK PF [1,2], and later by BESSY II [3] with an innovative MIK design. In recent years, SOLEIL further developed the MIK concept in collaboration with MAX IV [4]. Since winter 2017, MAX IV has successfully used a SOLEIL-built MIK as the primary injection scheme, demonstrating >90% transfer efficiency and only small horizontal and vertical stored beam perturbations of ±13 µm and ±8 µm, respectively [5]. A similar MIK will later be installed a the SOLEIL storage ring [6].

The ceramic chamber of the MIK is coated with a thin layer of titanium. On one hand, the coating must be thin as to not perturb the magnetic field and limit quadrupole components arising from eddy currents; on the other hand, it must be thick to decrease the deposited power on the chamber. At MAX IV, the titanium coating has a thinkness of 1 µm. It has frequently been revealed in operation that heating issues arise, indicating that a thicker coating would be preferable.

The issue of beam blow-up due to the residual quadrupole field has previously been studied using an early MIK design and found to be negligible [7]. Here, we extend these studies by including the individual bunch-by-bunch perturbation from the MIK.

SIMULATIONS

The MIK pulse has a half-sine shape with 3.52 µs width, corresponding to two revolution times. All simulations presented here is for a simulated data set with 5 µm Titanium coating. The vertical magnetic field is designed to have a octupolar shape, and is plotted in Fig. 1. To resolve the bunch-by-bunch perturbations, the data set is interpolated into time-steps of 10 ns, equal to the bunch spacing for the MAX IV 3 GeV ring 100 MHz RF system. For each time-step after the start of the pulse, we fit the simulated magnetic field to obtain the multipole components as a function of time, as presented in Fig. 2. The octupole components follows the half-sine shape, while eddy current-induced quadrupole components has a significantly different temporal shape, peaking around 0.6 µs and 3.4 µs.

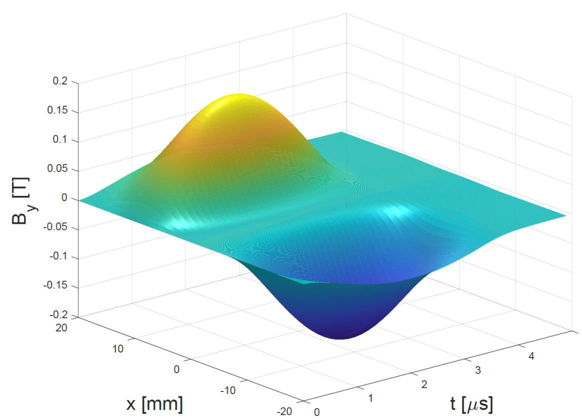

Figure 1: Temporal shape of the magnetic field from the MAX IV Multipole Injection Kicker with a 5 µm Ti-coating. Peak field is reached after and 1.76 µs.

Bunch-by-bunch Emittance Growth

All particle tracking was done using the *atfastring* function of the Accelerator Toolbox [8] including both synchrotron damping and quantum excitation. Initially, to gain an understanding of the long-term effects of the MIK, we track a total of 10^6 particles for 27000 turns, corresponding to three horizontal damping times. The lattice used is the

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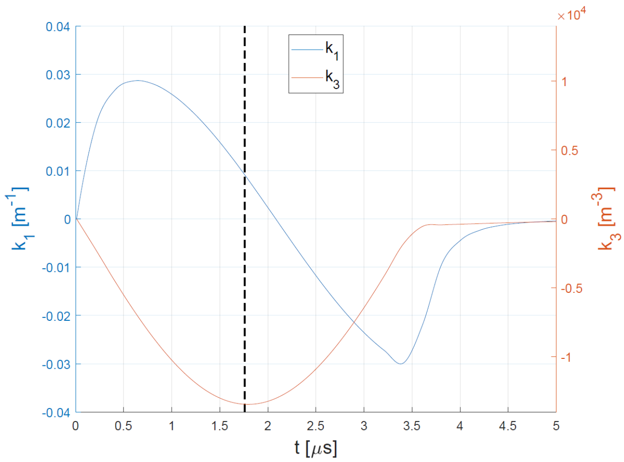

Figure 2: Temporal evolution of normalized, integrated quadrupole and octupole components. The black dotted line indicates the time at which the injected bunch arrives at the MIK. Dynamic stored beam perturbations are due to the non-zero quadrupole components.

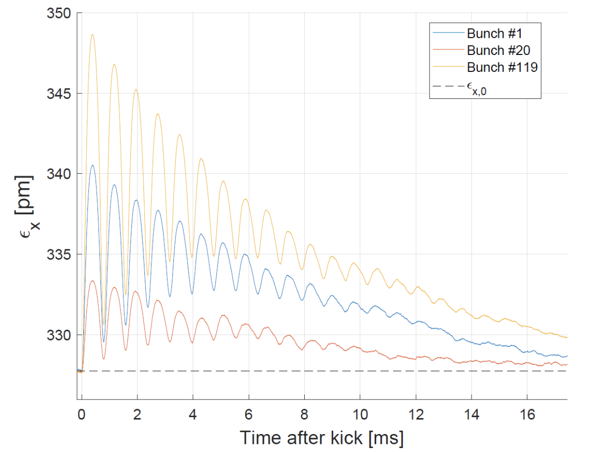

Figure 3: Emittance growth of bunches #1, #20 and #119. After the initial kick, the emittance increases to a maximum, followed by modulation with the synchrotron frequency by de-/recoherence due to the finite chromaticity.

design MAX IV 3 GeV storage ring lattice with chromaticities $[\xi_x, \xi_y] = [1, 1]$ [9]. For each turn, the horizontal bunch emittance is calculated from the covariance matrix of the particle distribution [10]:

$$\epsilon_x = \sqrt{\begin{vmatrix} \sigma_x^2 & \sigma_{xx'} \\ \sigma_{xx'} & \sigma_{x'}^2 \end{vmatrix}} \quad (1)$$

Kick effects of the MIK on 5 subsequent turns for each bunch are taken into account, 2 of which are expected to give a non-negligible kick. For most bunches, we limit simulations to around 400 turns as to reduce computational time and only calculate the maximum emittance growth. Three examples of the bunch-by-bunch emittance growth can be seen in Fig. 3. We define bunch #1 to be the bunch into which we wish to inject.

It is obvious, that the transient field from the MIK influences the bunches individually. The maximum bunch-by-bunch emittance is presented in Fig. 4, with bunch #119-#122 having the largest growth, reaching 349 pm rad. At MAX IV, a beam size increase of maximum 10%, equating to a ≈20% emittance increase, is considered within stable operation. Therefore, the transient quadrupolar field of an ideal MIK does not violate this limit, even for continuous injection operation at 10 Hz, and we conclude that an ideal MIK will deliver *transparent* injections to the user.

Considerations

The above simulations assume an ideally built and installed MIK. In reality internal misconstructions or misalignment of the MIK will increase the stored beam perturbation. The induced quadrupolar field of the MIK leads to a maximum stored beam emittance increase of ≈6.5%, indicating that additional deteriorations of the magnetic field may lead

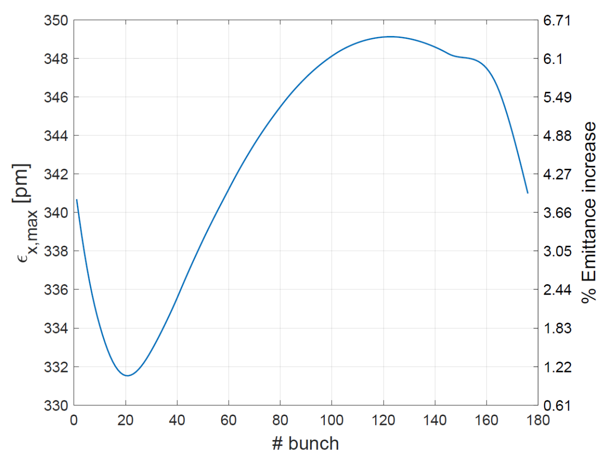

Figure 4: Maximum bunch-by-bunch emittance. The growth of the emittance varies significantly between bunches, with a maximum growth at bunch #120 of ≈6.5%. The difference stems from the difference in quadrupole field seen by each bunch

to further emittance growth, surpassing the 10% beam size increase limit for what can be characterized as a transparent injection. On top of the instantaneous emittance increase comes also potential betatron oscillations induced by a displaced MIK w.r.t. the closed orbit or visa versa.

MEASUREMENTS

A series of measurements was launched to investigate how the MIK performs in reality, and how the individual bunches are perturbed.

One of the measurements consisted of creating a range of closed-orbit bumps through the MIK, and for each bump scanning the MIK trigger delay in order to perturb the

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bunches with different parts of the MIK pulse. Beam size measurements were performed using the B320b diagnostic beamline [11], with an exposure time of 10 µs (≈5 turns). A short bunch train is preferable for measuring the bunch-by-bunch effect of the MIK. A bunch train consisting of 10 consecutive bunches was filled in order to have enough signal on the BPMs for turn-by-turn measurements. Measurements are made with a kicker voltage of 5 kV, while the nominal operation value is 7.7 kV. All results presented below are scaled to represent user operation conditions and optical functions at the centre of insertion device straight sections.

Beam Size

Bunch-by-bunch width increase for different bumps can be seen in Fig. 5. Increasing the bump height leads to an increase in beam size. We observe a structuring in the bunch-by-bunch widths with increasingly larger widths towards bunch #90 followed by a gradual decrease. The shape resembles a parabola, while the emittance simulations in Fig. 4 has a more complex shape. The apparent difference is thought to arise from the combination of betatron oscillations and true beam size increase.

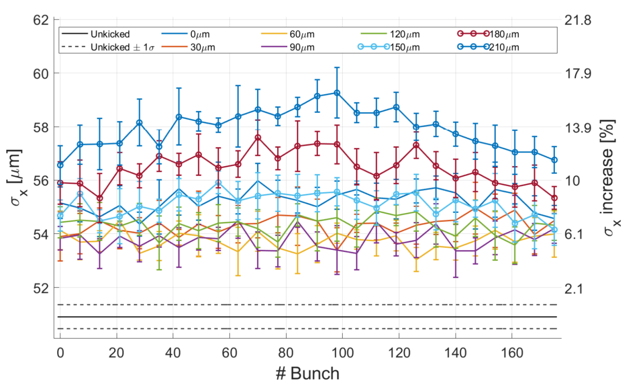

Figure 5: Bunch-by-bunch width measurements for different closed-orbit bump amplitudes through the MIK. The minimum increase is found at bump sizes between 60-90 µm. The user operation orbit has now been adjusted to have a 100 µm bump leading to a beam size increase of ≈6%, which is within stable operation af MAX IV 3 GeV. Significant differences in the beam size increase on bunch-by-bunch basis are only seen for large bumps.

In the early stages of operation, the orbit was not bumped through the MIK, causing a beam size increase from ≈51 µm to ≈55.5 µm. Now, the user operation orbit has a 100 µm bump through the MIK, limiting the increased beam size to ≈54 µm. In user operation, the injections at MAX IV 3 GeV, therefore, only cause an ≈6% growth in beam size for a short time. Only users with exposure times similar to the diagnostic beam line will see an increase. The beam size increase is below the acceptable limits for what is considered to be stable operation at the facility and therefore *quasi*-transparent.

DISCUSSION

The presented simulations show a maximum emittance increase of 6.5%, equating to a horizontal beam size increase of 3.2%. These simulations assume a design kicker voltage of 13.5 kV while the optimum operational value is 7.7 kV [12], which leads to a minimum beam size increase of 3 µm, about 6% above the unperturbed beam size. Due to manufacturing errors [13], we initially expected a larger beam size growth, which is compensated by the thinner 1 µm titanium coating and lower operational voltage. These discrepancies between simulated and actual conditions limits the comparability, but are nevertheless useful in understanding the MIKs effect on beam dynamics.

Both our simulations and measurements indicate that a MIK with a coating thicker than 1 µm is acceptable. The future and final MIK for the MAX IV 3 GeV ring will have a 3.5 µm coating thickness and is expected to be installed during summer 2019.

CONCLUSION

Issues related to the thin 1 µm Titanium coating of the ceramic chamber in the MAX IV 3 GeV Multipole Injection Kicker has lead to the question whether a 5 µm coating for a new MIK is feasible. Simulation studies of an ideal MIK has shown that the stored beam emittance increases by up-to ≈6.5%; significantly less than the 20% margin for stable beam operation at MAX IV. Measurements of the beam size growth from the currently installed MIK have turned out to be below the stability threshold. Only users with very short exposure time will see any change to the signal during top-up injections. A new MIK coated with a 3.5 µm coating is expected to be installed during summer 2019. This MIK will solve heating issues while also delivering *quasi*-transparent injections for users.

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