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Leemann, Simon

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LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

PULSED MULTIPOLE INJECTION FOR THE MAX IV STORAGE RINGS

S.C. Leemann*, MAX-lab, Lund University, SE-22100 Lund, Sweden

Abstract

The MAX IV facility presently under construction will include two storage rings for the production of synchrotron radiation. The 3 GeV ring will house insertion devices for the production of x-rays while the 1.5 GeV ring will serve UV and IR users. Both rings will be operated at a constant 500 mA of stored current with top-up shots supplied by the 3.5 GeV MAX IV linac acting as a full-energy injector. So far, injection into both storage rings has been designed using a conventional approach: a closed four-kicker injection bump brings the stored beam to the septum blade where the injected bunches are captured in a single turn. Recently, studies have been carried out to investigate the feasibility of using a pulsed multipole for injection into the storage rings. Pulsed multipole injection does not require an injection bump and has the potential to make top-up injection transparent to users. This paper reports on these studies and summarizes requirements for the pulsed sextupole magnet to be installed for injection into the MAX IV storage rings.

INTRODUCTION

Both the 3 GeV [1] and the 1.5 GeV storage rings [2] of the MAX IV facility [3] will operate at 500 mA stored current in top-up mode. The 3.5 GeV MAX IV linac [4] will be used as a full-energy injector delivering low-emittance shots with 300 pC at up to 10 Hz to either ring via two transfer lines. At the end of the transfer lines, a vertical Lambertson septum bends the injected bunch into the horizontal plane. The septum blade is at -10 mm (-15.5 mm) from the position of the unperturbed stored beam in the 3 GeV ring (1.5 GeV ring). The horizontal acceptance of the storage ring is 10.6 mm mrad (40.5 mm mrad). Previously, a local four-kicker injection bump (FKIB) was foreseen in order to bring the stored beam to -8 mm (-12 mm), that is, within 5.5 mm (7 mm) of the injected bunch (cf. Fig. 1). After the injection bump, the injected bunch is within the acceptance of the storage ring and proceeds to damp down while it oscillates around the stored beam. With a transverse damping time of roughly 15 ms (6 ms), there is ample time for the injected bunch to damp down before the next shot is injected. Because of the horizontal tune of 42.20 (11.22), the injection bump needs to be closed within less than 4–5 revolution periods, i.e. 8.8 μs (1.5 μs).

Since continuous top-up injection is foreseen, an important criterium for the choice of injection scheme is that top-up shots should be as transparent to users as possible. In light of this aspect, the conventional FKIB scheme has several disadvantages:

* simon.leemann@maxlab.lu.se

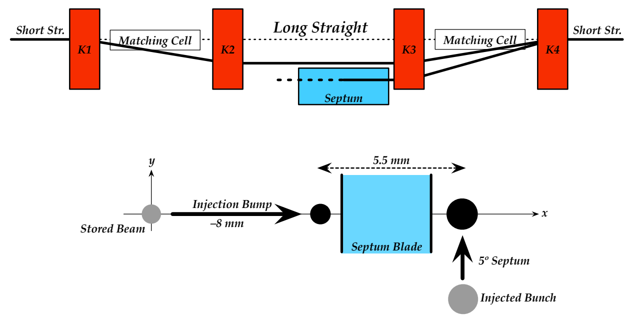

Figure 1: Conventional injection with a local bump in the MAX IV 3 GeV storage ring. Injection is displayed as seen from above (top) and in the transverse plane (bottom).

- Four dipole kickers and their pulsers need to be perfectly matched, synchronized, and aligned so the bump reaches its design amplitude and is properly closed.
- If the local injection bump is not fully closed, a coherent betatron oscillation of the stored beam is excited. This leads to fluctuations of the electron beam position and intensity in the insertion device (ID) thus degrading the photon beam at the experiments (the positional stability requirement for the electron beam in the user straights of the 3 GeV ring is 200 nm).
- Much space is required to house four strong dipole kickers and the septum. If more space is required than available in the injection straight, injection elements may take up space otherwise reserved for IDs.
- If sextupoles and/or octupoles are contained within the injection bump, the bump cannot be perfectly closed for all particles within the stored beam.

The first two points underline the complexity introduced by a FKIB. Although this injection scheme is common in third generation light sources, operational experience shows that despite vigorous correction and optimization efforts, top-up injection with a FKIB cannot be made entirely transparent to users [5]. As stability criteria become tougher in newer storage ring designs, this method of injection becomes less favorable. Therefore, several labs have started investigating alternative injection schemes, e.g. [6, 7, 8, 9, 10].

For the storage rings in the MAX IV facility, especially the two last points present a problem. In the 3 GeV ring, strong sextupoles and octupoles are used to optimize chromatic and amplitude-dependent tune shifts [11]. Therefore, nonlinear behavior for particles at large amplitudes (such as the injected bunch) is very pronounced (cf. Fig. 3).

In the 1.5 GeV ring there is only a single 3.5 m long straight between each of the 12 achromats. Because of the space required for all elements in the FKIB, the bump would have to span at least two achromats (containing strong sextupoles and significant dispersion). In addition, the length available for installation of IDs in the upstream and downstream straights is limited by two of the four the kickers. Therefore, alternative injection schemes for the MAX IV storage rings are being investigated. A promising candidate is pulsed multipole injection (PMI) where a single multipole magnet is used to capture injected bunches without perturbing the stored beam.

PULSED MULTIPOLE INJECTION

In PMI capture is achieved without bumping the orbit of the stored beam. Instead, the injected bunch is kicked into the storage ring acceptance by a pulsed multipole magnet. Since the stored beam passes the multipole magnet through the magnetic center, it sees approximately zero field. The only synchronization required is between the pulser and the passage of the injected bunch. Alignment also becomes easier than in conventional FKIB: the stored beam has to pass the magnetic center of only a single pulsed magnet. This can be achieved either by the orbit correction system or beam-based alignment of the pulsed magnet. The pulse can last up to several revolution periods depending on the fractional tune. In most cases the exact pulse shape is not crucial as long as fall time is sufficiently fast. Since besides the septum, only a single magnet is required for capture, PMI requires substantially less space than a conventional FKIB scheme.

The most basic setup uses a pulsed quadrupole magnet (PQM). Such an injection scheme has been successfully designed and commissioned at the PF-AR at KEK [6]. However, there are advantages to using higher-order multipole magnets, for example a pulsed sextupole magnet (PSM). Around the magnet center, the PSM field is symmetric and flat so that stored beam particles receive a much lower kick from the PSM compared to the PQM. In fact, since the ideal magnet for PMI has a large field component at the amplitude of the injected bunch and zero field elsewhere, even higher-order multipoles or irregular multipole magnets can be considered [5].

Injection with a PSM was demonstrated recently at the PF at KEK [10]. First experience with PSM top-up injection has been very positive with unprecedented levels of beam stability observed during injection [12]. The MAX IV facility will use PSM injection in both storage rings. Its feasibility has been demonstrated and it is regarded as a reasonable compromise between expected performance and required development effort. In fact, the MAX IV storage rings will be the first light sources designed from the start to use PSM injection. A conventional FKIB will not be implemented at all.

PULSED SEXTUPOLE INJECTION FOR THE MAX IV STORAGE RINGS

Starting with the coordinates of the injected bunch at the injection point (IP), i.e. at the end of the septum, and taking into account the storage ring's acceptance, an optimum location for a PSM can be derived. Assuming linear betatron motion, a location within available drift spaces can be chosen where the minimum injection invariant using a PSM of minimum strength can be achieved [10]. In general however, betatron motion is nonlinear (especially for the large amplitudes of the injected bunch) and the actual PSM injection scheme has to be derived from tracking.

3 GeV Storage Ring Injection

At the IP in the 3 GeV ring, the injected bunch is at $x_{\rm inj} = -13.5$ mm. The PSM is at the end of the second long straight. With $b_3 l = 54$ m^{-2} the PSM kicks the injected bunch to the minimum injection invariant of 2.3 mm mrad (cf. Fig. 2), well within the storage ring acceptance and substantially below what was achieved using a conventional FKIB scheme.

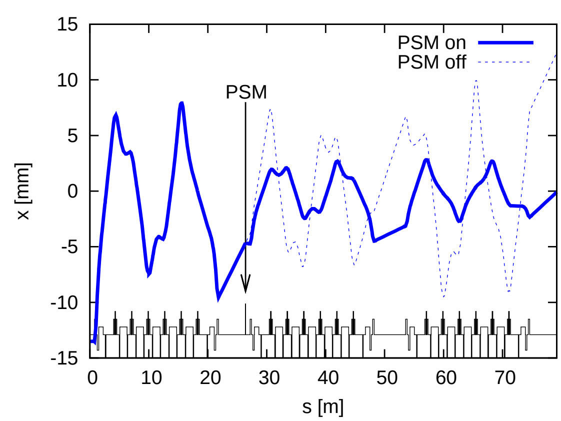

Figure 2: Tracy-3 tracking results for injection and capture with the PSM in the 3 GeV ring (only first three achromats shown).

In order to relax pulser requirements (and potentially also PSM strength) it is of interest to investigate multi-turn PSM injection, where the PSM is excited by a half-sine pulse with a base length longer than two revolution periods so the injected bunch sees the PSM kick on its first *and* second passage. An example is shown in Fig. 3 where a maximum PSM strength of only $b_3 l = 27.5$ m^{-2} is delivered at the first passage. At the second passage the available strength is reduced by a factor $\sin(3\pi/4)$. In this way, the base length of the half-sine PSM excitation can be increased to 7 μs (four times the revolution period). Despite increased pulse length and reduced PSM strength, a final injection invariant of 3.1 mm mrad is achieved.

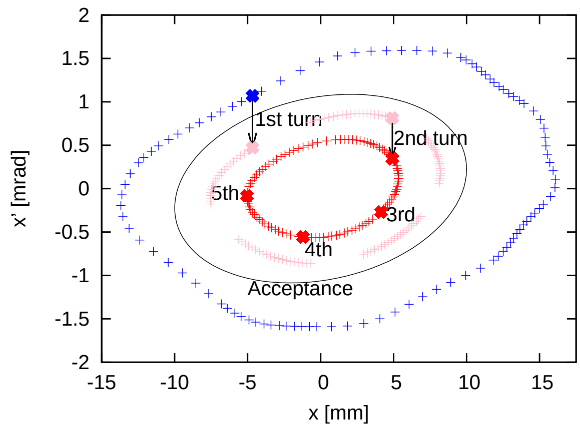

Figure 3: Tracy-3 tracking results at the 3 GeV PSM (two-turn injection). The + show 100 turns without PSM kicks or aperture limitations. The × show actual coordinates of the injected bunch during capture.

1.5 GeV Storage Ring Injection

The injected bunch is at $x_{\rm inj} = -19$ mm at the 1.5 GeV ring IP. It reaches the PSM in the third straight where $b_3 l = 47$ m^{-2} kicks it down to a minimum injection invariant of 8.8 mm mrad well within the storage ring acceptance. The negligible perturbation of the stored beam by the PSM is displayed in Fig. 4. A difficulty with PSM injection in the 1.5 GeV ring is the pulse length (the revolution period is only 0.32 μs). In order to facilitate pulser design, a two-turn injection scheme has been designed so the required base length for the half-sine pulser excitation can be increased to 1.3 μs. At the same $b_3 l$, the resulting injection invariant is increased by only 3.5%. Alternatively, a reduced $b_3 l = 32$ m^{-2} still allows capture in two turns.

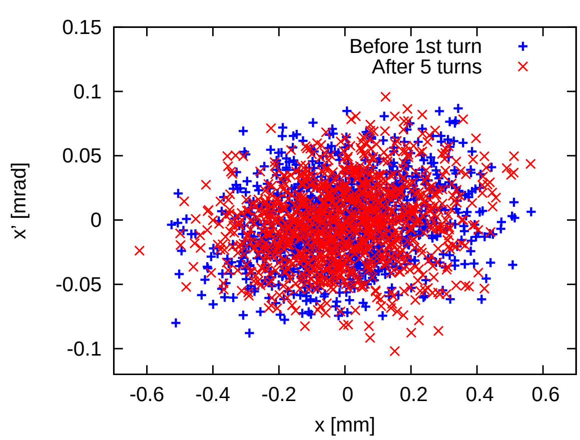

Figure 4: DIMAD tracking results at the 1.5 GeV IP showing the effect of the PSM in single-turn injection mode on the stored beam ($\varepsilon_x = 6$ nm rad, $\sigma_\delta = 7.5 \times 10^{-4}$, Gaussian distribution with cut-off at 3σ).

SUMMARY AND OUTLOOK

Injection schemes using PSMs have been designed for both storage rings in the MAX IV facility. Preliminary magnet and ceramic chamber designs have been completed and specifications for the pulsers have been compiled. The required field strengths and pulse durations are considered feasible so that a call for bids is being prepared.

Studies have been carried out to investigate sensitivity to optics mismatches and misalignments. The MAX IV linac injects low-emittance bunches with low energy spread which can easily be fitted into the storage ring acceptance despite optics mismatches at injection, thus rendering a robust injection with high efficiency. Tracking studies reveal that the effect of the PSM on the stored beam is indeed very low, however exact (beam-based) alignment of the PSM will be necessary to reduce perturbations to the stored beam to the very low levels required for fully transparent top-up injection.

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REFERENCES

[1] S.C. Leemann et al., Phys. Rev. ST Accel. Beams, 12, 120701 (2009).

[2] S.C. Leemann et al., “Status of the MAX IV Storage Rings”, IPAC10, Kyoto, Japan, May 2010, WEPEA058, p. 2618.

[3] M. Eriksson et al., “Challenge of MAX IV Towards a Multipurpose Highly Brilliant Light Source”, this conference, TUOBS4.

[4] S. Thorin et al., “Design of the MAX IV Ring Injector and SPF/FEL Driver”, this conference, THP178.

[5] P. Kuske, “Novel Injection Schemes”, presentation at the Top-Up Workshop, Melbourne, Australia, October 2009.

[6] K. Harada et al., Phys. Rev. ST Accel. Beams 10, 123501, (2007).

[7] P. Kuske et al., “Preparations of BESSY for Top-Up Operation”, EPAC08, Genoa, Italy, June 2008, WEPC037, p. 2067.

[8] T. Shaftan et al., “Alternative Designs of the NSLS-II Injection Straight Section”, PAC09, Vancouver, BC, Canada, May 2009, TU5RFP012, p. 1114.

[9] C. Sun et al., “Pulsed Multipole Injection for the ALS Upgrade”, IPAC10, Kyoto, Japan, May 2010, WEPEA068, p. 2642.

[10] H. Takaki et al., Phys. Rev. ST Accel. Beams 13, 020705, (2010).

[11] S.C. Leemann, A. Streun, Phys. Rev. ST Accel. Beams, 14, 030701 (2011).

[12] H. Takaki et al., “Stored Beam Stability During Pulsed Sextupole Injection at the Photon Factory Storage Ring”, PAC09, Vancouver, BC, Canada, May 2009, TU6RFP045, p. 1647.