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OPTIMIZATION OF THE INJECTION KICKER BUMP LEAKAGE AT PETRA III

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Abstract

PETRA III is a third generation synchrotron light source at DESY delivering high brightness photon beams for users at 21 beam lines. It is operated at 6 GeV with a beam current of 100 mA in top-up mode and is in operation for users since 2010. An off-axis injection scheme is used to accumulate beam from the booster synchrotron DESY II in PETRA III. Three fast injection kicker magnets generate a closed orbit bump for one turn to move the stored beam near to the injection septum magnet. Ideally the orbit bump generated by the 10 µs long half-sine pulses of the kickers should be closed. Due to differences in pulse shape as well as timing and amplitude errors of the pulses there is some leakage of the injection bump which disturbs the closed orbit and affects the beam quality during top-up operation. Turn-by-turn data from the beam position monitor (BPM) system of PETRA III have been used to measure the bump leakage for different bucket positions in the filling pattern. The procedure to reduce the injection kicker bump leakage and the achieved improvement will be discussed.

INTRODUCTION

The 6 GeV synchrotron light source PETRA III [1] is in user operation since 2010. For better stability the storage ring is running in top-up mode with a beam current of 100 mA. If the current has dropped by more than 1 % the lost current is refilled automatically. An off-axis injection scheme is used to allow accumulation.

PETRA III is operated half of the time either in the continuous mode with 960 bunches or in the timing mode with 40 bunches. The lifetime and therefore also the time interval between injections is very different in both modes. In the continuous mode the lifetime is roughly 10 h and new injections are necessary every 6 minutes. In the timing mode lifetime is dominated by Touschek scattering and is typically around 1.2 h. In this mode the interval between injections is only 1 minute.

To keep the filling pattern homogenous the injected current of 1 mA is distributed to several single bunch transfers with low charge. Typically 10-20 consecutive injections into the buckets with lowest current are necessary. Limited by the pre-accelerators the time between injections is 160 ms.

The injection transients of the closed orbit disturb the user operation. Users which are measuring continuously will see a drop in intensity during each injection. An example of the relative intensity measured at beam line PU7 is shown in Fig. 1. Note that due to the limited frame rate of 5 kHz of the camera not all minima can be resolved.

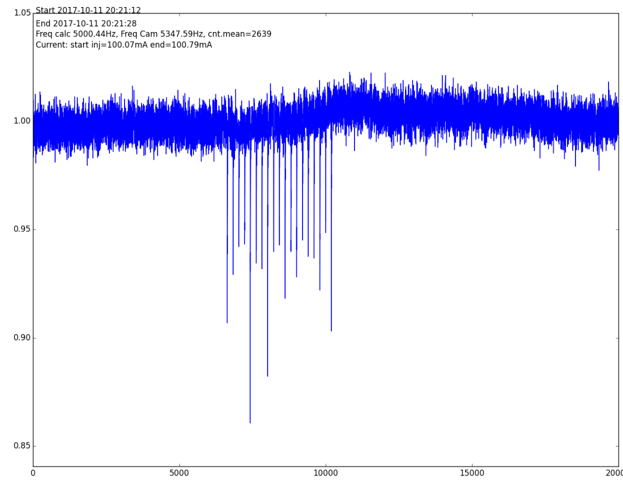

Figure 1: Drop in relative intensity during injections measured at beam line P07 [2]. The time duration is 16 seconds.

The injection transients due to the kicker magnets have been measured and optimized in this study. This helps to reduce the intensity drop and shorten the duration of the disturbance for the users.

INJECTION SCHEME

The PETRA III injection scheme uses an off-axis injection with three kicker magnets and a septum magnet. All injection components reside in one of the short straight sections in the South-East of PETRA III. The location of the septum magnet is near the maximum of the bump amplitude of the kickers.

All kickers are installed outside of the vacuum chamber and use ferrites to increase the field strength and reduce the stray field. The pulser electronics are installed underneath the kickers in the PETRA tunnel and generate half-sine pulses with a length of $T = 10\,\mu s$ (Fig. 2). At the beginning and end of the pulse small deviations from the ideal pulse shape occur. The PETRA III septum magnet has a pulse length of 160 μs and reaches its highest field when the kickers are triggered.

SOURCE OF INJECTION TRANSIENTS

Several processes contribute to the injection transients and disturb the closed orbit of the beam during injection.

Stray Field of the Septum Magnet

The septum magnet generates a non negligible stray field inside the vacuum chamber. It rises fast within 0.5 ms and decays slowly afterwards during approx. 15 ms due to eddy

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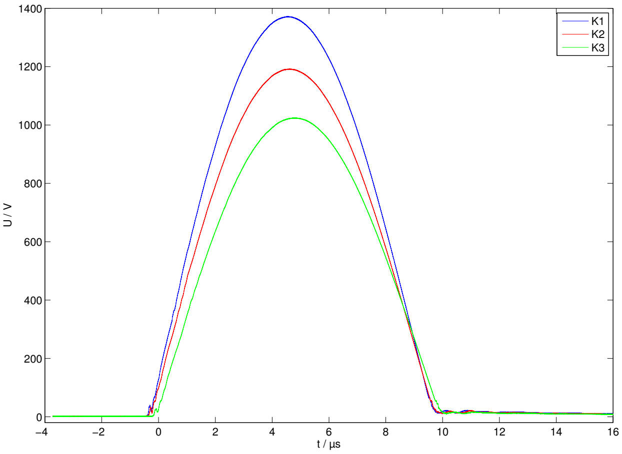

Figure 2: Pulses of the three injection kickers.

currents. Some time ago the stray field was reduced by adding a Mu-metal shielding between the septum and the vacuum chamber. Still some field remains which decreases with the distance from the shielding. The fast orbit feedback [3] has an integrated adaptive injection feed-forward to reduce this slow orbit change for a duration of 20 ms after injection.

Eddy Currents in the Vacuum Chamber

The vacuum chamber of the kicker magnets has an elliptic shape (80 mm × 40 mm) and is made from ceramics coated with a thin layer of stainless steel with a thickness of 1 μm. Eddy currents will flow in the coating during pulsing of the magnets. This will reduce somewhat the field amplitude, adds a delay and changes slightly the pulse shape [4]. Due to the inhomogeneity of the thickness of the coating even with perfect kicker pulses the amplitude and the delay of each kicker pulse has to be optimized individually.

Non-Closure of the Kicker Bump

Deviations between the pulse shapes of the three kickers produce a non-closure of the kicker bump. The kick ratios between the kickers have to be constant during the complete duration of the pulse.

The non-closure of the kicker bump can be optimized by changing the amplitudes and delays of the three kickers individually. The length of the half-sine kicker pulse is just as important. The pulse length changes with the amplitude of the high voltage in a non-linear way due to the solid-state switch [5] used in the kicker electronics. The pulse lengths were made equal for the design amplitudes of all kickers with individual adjustable capacitors.

The injection transients due to the non-closure of the kicker bump have been measured and optimized in this study. An additional damping is provided by the transverse multi-bunch feedback systems [6].

TECHNICAL IMPROVEMENTS

Several technical improvements have been applied to reduce the injection transient due to the kicker bump. The high voltage switch was replaced by a version capable of higher amplitudes. It has a reduced dependency of the pulse length with the high voltage in the operating range.

As the pulse length of $T = 10\,\mu$s is larger than the revolution time of $T_0 = 7.6\,\mu$s, bunches with a time lag of $2T_0 - T = 5.4\,\mu$s are kicked twice. All other bunches are only kicked once. To avoid this the length of the kicker pulses were shortened from 10 μs to 7.2 μs by decreasing the capacity in the oscillating circuit. This simplifies the kicker bump optimization and is also important for undisturbed turn by turn measurements with a kicked bunch.

To facilitate the fine tuning of the pulse length remote controlled inductances were installed for each electronics to change the pulse length within ±16 ns. Prior to that all three pulse lengths were made equal for the design amplitudes.

In total there are now 9 parameters available for the optimization of the injection transients. But they are not independent. A common shift in timing can be compensated by an increase of all amplitudes. To operate the kicker pulsers with the lowest voltage the bunch should be injected at the maximum of the kicker amplitude. This global timing has been optimized beforehand.

KICKER BUMP OPTIMIZATION

The preferable way to optimize the kicker bump leakage is using intensity data from the beam lines of PETRA III. Usually a special setup for the measurement is needed which prevents normal operation for users. Therefore it is not available most of the time.

Instead the injection transients have been measured using turn by turn data of the PETRA III BPM system [7]. Due to the limited bandwidth of the LIBERA electronics [8] individual bunches cannot be resolved.

To measure the influence of the 9 parameters on the injection transients for different bunch positions a single bunch was stored at a fixed bunch position. Several measurements were then performed with different values of the common delay of all kickers.

The kicker magnets were triggered without transfer of a bunch from the pre-accelerator. During top-up mode there is an additional contribution of the injection transient due to the injected bunch. Usually this can be neglected at 100 mA because the injected beam current is typical only 1 ‰ of the total current. For the measurement a BPM with a suitable phase advance has been selected which is not effected by the stray field of the septum magnet.

Data measured over 1000 turns and triggered with the injection have been used. For several delays the RMS values of the remaining oscillations in both planes were computed. An already good optimization is shown in Fig. 3. The maximum of the kicker bump is near bunch position 1.

The mean value of the RMS values over all measured bunch positions is a measure of the injection transient gen-

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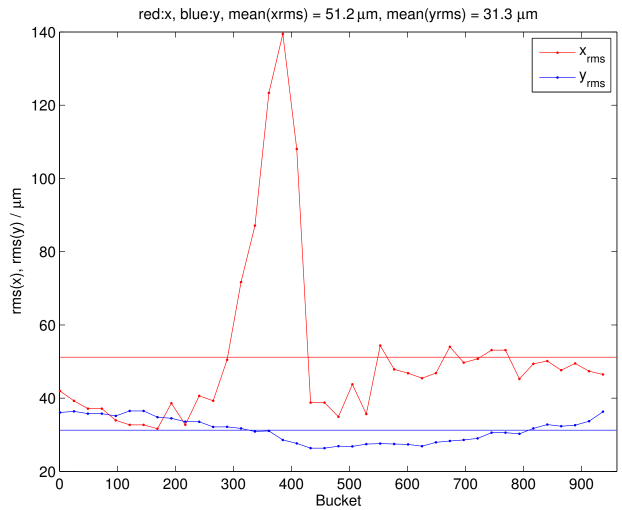

Figure 3: RMS value of injection transients by kicker magnets for different bunch positions in the filling pattern.

erated by the kicker magnets (dashed horizonal lines). The BPM noise level is around 25 µm. The measurements were done with the transverse multi-bunch feedbacks switched off.

Parameter Scans

All three amplitudes, the timing delays and the pulse lengths of the half-sine kicker pulses have been scanned. For each parameter the minimum of the horizontal RMS was determined and the appropriate values set before the scan of the next parameter (eg. Fig. 4). Because of coupling between amplitude and pulse length several iterations were necessary until a minimum of the bump leakage was reached.

The RMS value without feedback was decreased from initially 375 μm to 48 μm in the horizonal plane and from 100 μm to 33 μm in the vertical plane. As the beam is not

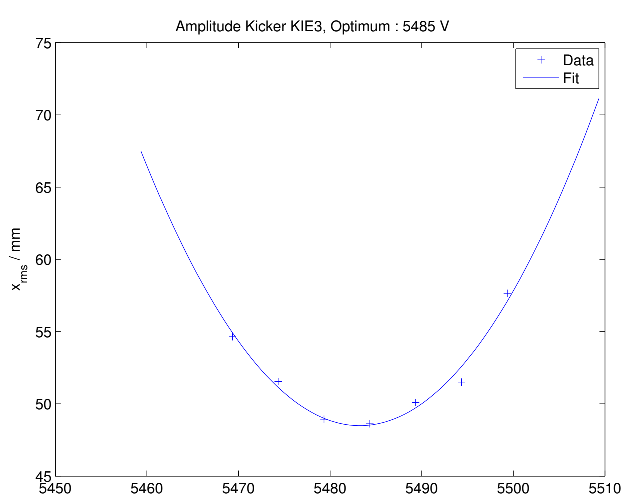

Figure 4: Parameter scan of one of the kicker voltages.

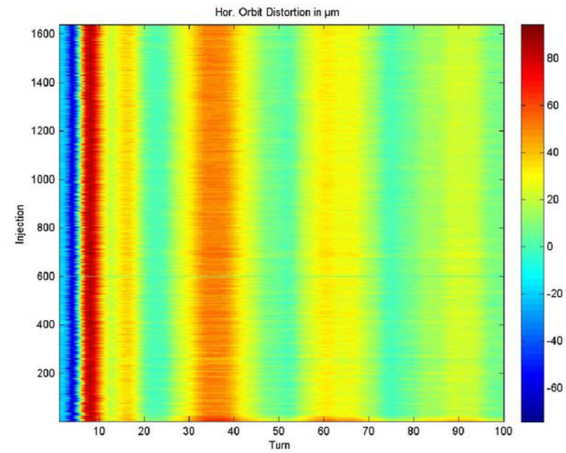

Figure 5: Stability of the horizontal injection oscillations measured for 100 turns after injection for 1600 injections which corresponds to a duration of 20 h. The deviations in µm are coded in different colors.

intentionally kicked in the vertical plane a further reduction needs a better alignment of the roll angle of the kicker magnets and the septum.

During regular top-up operation the multi-bunch feedback systems and the adaptive injection feed-forward are switched on. Both will reduce the injection transients further. The remaining orbit distortion is in the range of 20 % of the horizontal and vertical beam size.

Long Term Stability

Measurements over longer times have shown that the injection transients are rather stable if the gain and phase of the multi bunch feedback are unchanged (Fig. 5). The amplitude of the remaining transients due to the stray field of the septum can be mostly reduced by the adaptive injection feed-forward system.

CONCLUSIONS

Turn by turn data of the PETRA III BPM system have been used to optimize the injection kicker bump leakage. With several iterations of timing, amplitude and pulse length scans the contribution from the kicker bump leakage was reduced closed to the noise level of the BPMs in turn by turn mode. A significant contribution of the injection transients results from closed orbit deviations due to the stray field of the septum magnet. In the vertical plane further improvements are possible by a carefully alignment of the three kicker magnets and the septum.

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REFERENCES

[1] K. Balewski *et al.*, "PETRA III: A Low Emittance Synchrotron Radiation Source, Technical Design Report", DESY, Hamburg, Germany, 2004.

[2] Olof Gutowski, Private communication.

[3] J. Klute *et al.*, "The PETRA III Fast Orbit Feedback System", in *Proc. DIPAC'11*, Hamburg, Germany, May 2011, pp. 221-223.

[4] S.H. Kim, "Calculation Of Pulsed Kicker Magnetic Field Attenuation Inside Beam Chambers", APS, Argonne, USA, Rep. LS-291, Jan. 2001.

[5] Behlke Power Electronics GmbH, `http://www.behlke.com`.

[6] J. Klute *et al.*, "The PETRA III Multibunch Feedback System", in *Proc. DIPAC'11*, Hamburg, Germany, May 2011, pp. 494–496.

[7] I. Kroupchenkov *et al.*, "Experience With The Commissioning Of The Libera Brilliance BPM Electronics At PETRA III", in *Proc. DIPAC'09*, Basel, Switzerland, May 2009, pp. 291–293.

[8] A. Kosicek, "LIBERA Electron Beam Position Processor", in *Proc. PAC'05*, Knoxville, USA, May 2005, pp. 4284–4286.