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BEAM-BASED CHARACTERIZATION OF A NON-LINEAR INJECTION KICKER AT BESSY II

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Abstract

Top-up operation at BESSY II is performed with average injection efficiencies of 98%. However, the four-kicker bump and the septum, that form the present injection system, both contribute to a distortion of the stored beam with an amplitude of about two millimeters for several thousand turns after injection. A non-linear injection kicker (NLK) could be used to reduce the distortion due to the kicker bump by a factor of approximately 30 - a necessary condition for transparent injection. Studies with an NLK and optimized sextupole settings have shown that it is also possible to achieve injection efficiencies of up to 97%. The NLK was characterized beam-based with regards to the application of the NLK for BESSY II user operation, a possible injection method for BESSY III and to get a better understanding of the limiting effects of the injection efficiency. Additionally, measurements and simulations were compared.

INTRODUCTION & MOTIVATION

BESSY II is operated in top-up mode to ensure a constant beam current. As the machine was not constructed for this operation mode injection efficiencies of more than 90% are required due to radiation protection guidelines [1]. Presently, a four-kicker bump and a septum operated by a half-wave pulser are used to inject electrons from the synchrotron into the storage ring with average injection efficiencies of 98% during user operation. However, the present injection system causes a stored beam oscillation of a few millimeters.

Using an NLK instead of the four-kicker bump could reduce the distortion of the stored beam as the field of the NLK is zero at the center where the stored beam passes it and has a field off-axis where the incoming beam is.

For almost 10 years, an NLK prototype is installed in the storage ring of BESSY II. Previously, only injection efficiencies of about 80% were reached. But one and a half years ago injection efficiencies of 97% with open IDs and 95.5% with the in-vacuum undulator at its smallest gap were achieved by optimizing the settings for harmonic sextupoles and NLK timing/amplitude. Therefore, the NLK is now investigated in more detail for the next decade of user operation of BESSY II [2] and possibly the successor machine BESSY III [3].

SIMULATIONS

To specify the acceptance at the end of the transfer line for a successful injection with the NLK a particle tracking with MAD-X (PTC) was performed. An approximation to describe the NLK field $B_y(x)$ as presented in Eq. (1) with a peak at a horizontal position of x = -11.5 mm was used whereby a, b and c are parameters determined by fitting the function to a field model. All particles that survived 1000 turns where defined as successfully injected. As the strength of the NLK field can be varied by changing the pulse current also different kick strength amplitudes were investigated.

$$B_y(x) = a \cdot x^3 \cdot \exp(b \cdot x^2) + c \cdot x \qquad (1)$$

In Fig. 1 examples of the determined acceptance at the location of the septum for three different amplitudes of the kick strength A_{kick} of the NLK are presented. With increased kick strength amplitude also the acceptance increases until it is limited by the septum geometry.

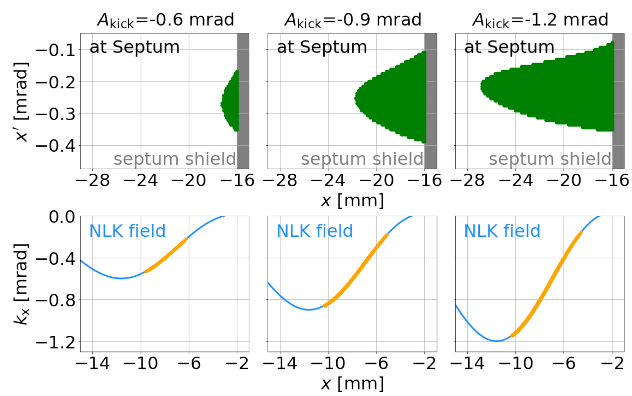

Figure 1: Top: Acceptance of injected beam (green) determined by particle tracking for different kick strength amplitudes of NLK, Bottom: NLK field k_x rescaled in mrad (blue) with area that corresponds to used values for successful injection highlighted (orange)

The NLK was designed in such a way that the incoming beam should see the field at the peak region so that the field gradient is as small as possible. But the simulations show that a successful injection does not seem to be feasible with a horizontal beam position of -11.5 mm. The explanation for this is that particles that would see the plateau of the NLK field will have such a big action that they will be lost due to the septum aperture.

MEASUREMENTS

Studies have been performed to investigate the injection with the NLK at BESSY II standard user operation.

Timing and Amplitude

As the NLK is a pulsed kicker its field will build up and also decrease with time. Additionally, the field strength depends on the charging voltage applied to the NLK pulser. To

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find the optimal NLK settings for high injection efficiencies this quantity was measured while changing voltage and timing. Here the timing is measured as the time between firing the kicker and the injected beam arriving at the NLK. The measurement results are presented in Fig. 2.

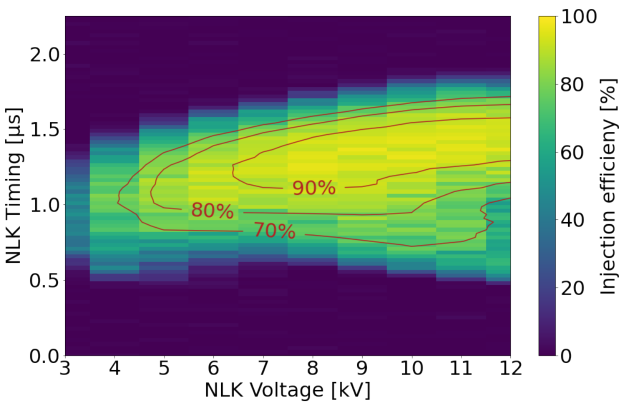

Figure 2: Measurement of injection efficiency depending on timing and voltage of NLK

A similar maximum injection efficiency for the measurements with NLK voltages between (7.8 and 10.8) kV could be seen. For all those measurements the maximum injection efficiency was around 97%. For smaller and larger voltages the maximum injection efficiency decreased. Additionally, a double humped behavior of the injection efficiency depending on the timing was observed for voltages higher than ≈ 9 kV. As this behavior did not occur at lower voltages it seems that for higher amplitudes the field is still strong enough, when the beam passes the NLK at the next turn, that it has an effect on it for a second time. To work with high injection efficiencies and investigate the single-turn injection first for further measurements an NLK voltage of 8 kV was used.

Field Mapping

To characterize the NLK field beam-based the beam distortion of the stored beam at a beam position monitor (BPM) was measured turn-by-turn and the horizontal and vertical position of the beam in the straight was changed by creating local orbit bumps with steerers. As can be seen in Fig. 3 the center of the NLK, where the field is minimal and therefore the stored beam should pass ideally for a reduced distortion, is shifted vertically and horizontally by a few millimeters with respect to the orbit. Here the positions x_{NLK} and y_{NLK} are the scaled set values of the closed orbit bump and the kick strength was determined using the equation $k_{x,y} = \frac{\sqrt{2}}{\beta_{x,y}} \cdot \mathrm{RMS}_{x,y}$ whereby $\beta_{x,y}$ is the beta-function at the position of the NLK and $\mathrm{RMS}_{x,y}$ is the RMS-amplitude of the first 42 turns of the measured oscillation in the corresponding plane.

Furthermore, the kick strength of the NLK depending on the position of the injected beam was determined in the region of high injection efficiencies as presented in Fig. 4. Therefore, the horizontal beam parameters (x, x') were changed by using a steerer in the transfer line and the injection septum of the storage ring. The beam position was measured for the first turn up- and downstream of the NLK at BPMs. First the NLK was turned off and in a second measurement it was switched on so that the position of the beam x_{NLK} at the location of the NLK and the kick strength k_x could be calculated based on the difference of the beam positions acquired with and without the kicker acting on the beam. A fit based on Eq.(1) was used to determine the amplitude of the field. This value of A_{kick}= (-1.135 ± 0.006) mrad was utilized to scale the field describing function for a simulation in which the kick strength depending on the beam position at the NLK that would correspond to a successful injection was determined. As shown in Fig. 4 the measured data fits well with the simulation whereby the simulated acceptance covers a wider range than the measured values.

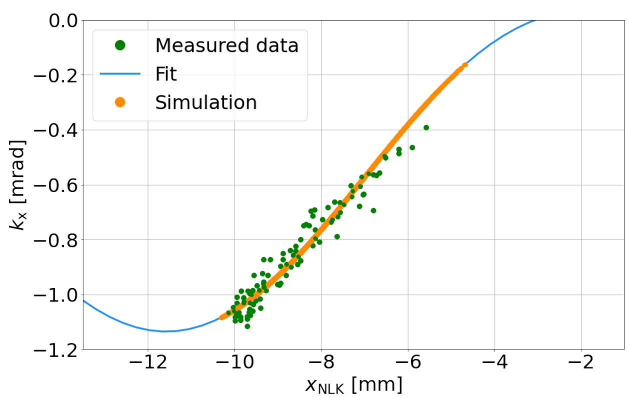

Figure 4: Beam-based characterization of the kick strength k_x of the NLK in the region of high injection efficiencies

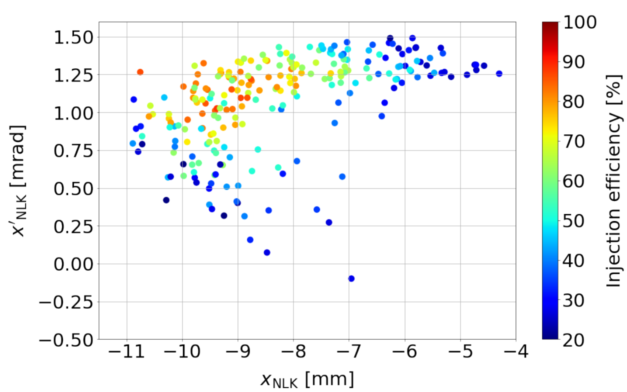

Figure 5: Injection efficiency depending on horizontal beam parameters (x, x') at the location of the NLK

To determine the horizontal beam parameters (x, x') at the NLK that correspond to high injection efficiencies, the parameters where varied again by using the steerer and septum in the transfer line. This time after measuring the beam parameters up- and downstream of the switched off NLK with BPMs for the first turn, the NLK was turned on and the injection efficiency was determined for the same changing

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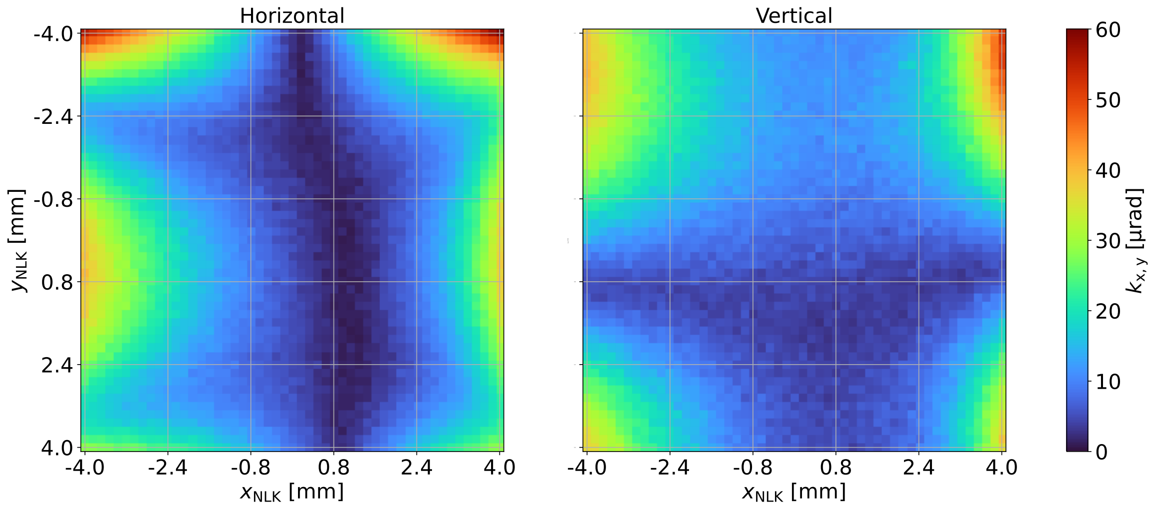

Figure 3: Beam-based mapping of the kick strength of the NLK in the horizontal and vertical plane measured using the stored beam varied with a closed orbit bump in the straight of the NLK

settings of the steerer and septum. From the BPM measurement the horizontal beam parameters could be calculated and the injection efficiency depending on those quantities could be plotted as shown in Fig. 5. The highest injection efficiencies were observed for beam parameters of around x_{NLK} = -9.4 mm and x'_{NLK} = 1.0 mrad.

Injection Distortion

In order to investigate the orbit distortion due to the NLK and to be able to compare it with the present four-kicker bump injection the stored beam oscillation has been measured turn-by-turn with the help of a BPM.

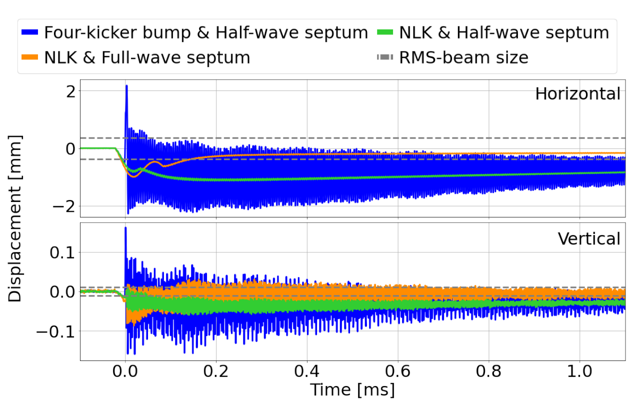

Figure 6: Distortion of stored beam due to different combinations of injection elements measured with a BPM and RMS-beam size at the injection point

As can be seen in Fig. 6 the fast oscillation due to the kicker could be reduced horizontally by a factor of approximately 30 going from the four-kicker bump to the NLK and also vertically the distortion could be reduced. However, a slow and strong distortion due to the half-wave septum remains. Therefore, a full-wave septum pulser was used in a test operation together with the NLK and it was observed that the distortion decreased much faster. The horizontal oscillation amplitude was reduced below the RMS-beam size after less than 0.15 ms.

CONCLUSION & OUTLOOK

In recent injection studies at BESSY II a highly efficient injection with the NLK was achieved and the injection distortion of the stored beam could be reduced significantly compared to the present injection with the four-kicker bump. The investigations revealed the feasibility of a highly efficient transparent injection at BESSY II.
To improve the injection with the NLK simulations should be done to investigate if a new positioning of the septum would improve the acceptance. Furthermore, the optimal sextupole and transfer line settings should be studied. As the studies have shown the potential of the NLK injection, this method could also be investigated as a candidate for an injection system for BESSY III.

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