DEVELOPMENT OF A NON-LINEAR KICKER SYSTEM TO FACILITATE A NEW INJECTION SCHEME FOR THE BESSY II STORAGE RING

T. Atkinson, M. Dirsat, O. Dressler, P. Kuske, Helmholtz-Zentrum Berlin, 14109 Berlin, Germany; H. Rast, TU Dortmund University, 44227 Dortmund, Germany

Abstract

Top-Up injections without noticeable motion of the stored beam is a challenge. The common method of beam accumulation with a local bump formed by four independent pulsed dipole kicker magnets usually causes beam oscillations. The matching of the four independent kicker systems regarding pulse jitters and shapes is technologically limited. Afterward the beam excitation was reduced more when two kicker magnets on each side of the septum were powered in series by one pulser unit.

An even more promising approach is to adopt an alternative injection method deploying a single non-linear kicker magnet with zero $B_{x,y}$-field in the center and an off-axis maximum, B_y, which is horizontally displaced by 10-12 mm. There the injected beam gets kicked and looses half of its transverse momentum. Such a magnet was designed and built as a short in-vacuum magnet with a small vertical gap height. For first beam tests the kicker was placed in the second straight section after the injection point, and the 1.5 µs pulse was designed to deflect the 1.72 GeV beam by 1 mrad. In this paper, the calculations of the magnetic fields, the mechanical design as well as the electrical pulser circuit are described. The experiences with this kicker magnet are discussed.

INTRODUCTION

The BESSY II storage ring is a 3rd generation light source, where the electron beam is injected at the nominal momentum of 1.72 GeV/c with a repetition rate of up to 10 Hz from a fast cycling booster synchrotron. The realization of a top-up mode with minimum distortion of the stored beam and highest injection efficiency is one objective for a future machine upgrade. With the conventional local bump injection layout, the four separate kicker magnets are situated in one short straight section and are powered by four autonomous pulser units with almost identical pulse currents. These pulse currents independently jitter in amplitude and ignition timing, with a small, but inherent mismatch of pulse shapes.

Provided the ceramic beam pipes inside the kicker magnet yokes have identical properties, e.g. inner surface titanium coatings, the pulsed magnetic fields in the magnet gaps resemble one another in magnitude and time. Thus improvements on the four independently pulsed dipole kickers were carried out to achieve low excitation of the already stored beam [1]. Even with the best technically possible adjustment, long-term drifts of the thyratron switches and timing jitters of the trigger generation and distribution system as well as in the gate drives led to large shot-to-shot orbit distortions. Therefore it is not possible to reliably move the stored beam as close

to the septum sheet as desirable for a high injection efficiency. The effects of drifts and jitters could be compensated if kicker magnets are powered by the same pulser unit [2]. But this means that the orbit distortions cannot be compensated by different amplitude set values.

The situation was considerably improved by powering neighboring magnets in pairs. The resulting bump is as well closed as with the best adjustment of four individual pulsed power supplies. Stability however is improved by at least 10 times in agreement with theoretical estimates.

When adopting a single pulsed quadrupole- /sextupole-like kicker magnet [3] located with an effective phase advance of 45° downstream of the injection septum, only the injected beam is deflected, as the before accumulated electron bunches ideally remain undisturbed. For this purpose any pulsed multipole magnet with vanishing on-axis field can be used. The injection process would be more efficient, if this magnet had a transverse flat top where the injected beam is kicked. A flat region on-axis will reduce the impact on the stored beam further.

DESIGN OF A NON-LINEAR KICKER MAGNET

The motivation for this design was to create a non-linear pulsed B_y-field with a high maximum in a defined horizontal distance from the center of the beam pipe, but with an extended plateau of zero value in the center. The desired non-linear vertical field component can be created with four coils. The topology of a lumped element resonant pulser circuit was given preference to generate the necessary high pulse currents for the required B_y-field distribution [4]. The non-linear kicker magnet (NLK) was conceived, designed and built as a short in-vacuum magnet for the BESSY II storage ring. So during the injection process the on axis stored beam remains undisturbed, whereas the injected beam is off axis and deflected by the maximum field and accumulated finally by radiation damping.

The following description of the non-linear kicker magnet with the parameters given in Table 1 refers to the second improved design based on the experience gained.

Table 1: Design Parameters for One Kicker Magnet

Description		Parameter
Deflection angle	(at x = 12 mm)	1 mrad
Peak field	(at x = 12 mm)	25 mT
Magnet aperture	(hor. x ver.)	42 mm x 10 mm
Magnetic length		280 mm
Current pulse length		1.5 µs, half-sinusoidal

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Model of a Non-Linear Kicker Magnet

The non-linear field distribution is achieved with a horizontal / vertical mirror symmetrical geometry of the four coils. These are in parallel with the circulating beam and preserve the 10 mm vertical aperture limit. The coils carry equal pulse currents into the same direction as marked with algebraic signs. Four pulse currents of 700 A are required for the specified B_y magnetic field strength.

The calculated pulse currents exceed technological capabilities of stripline pulsers. Thus, four low impedance coils were considered. The 2-dimensional static magnetic field calculations [5] were confirmed with a transient 3D-computation model (Fig. 1). Herein the magnetic field was excited with the longest possible (1.5 µs), half-sine pulse current, which causes minimal field attenuation by induced eddy currents in the adjacent metallic surfaces.
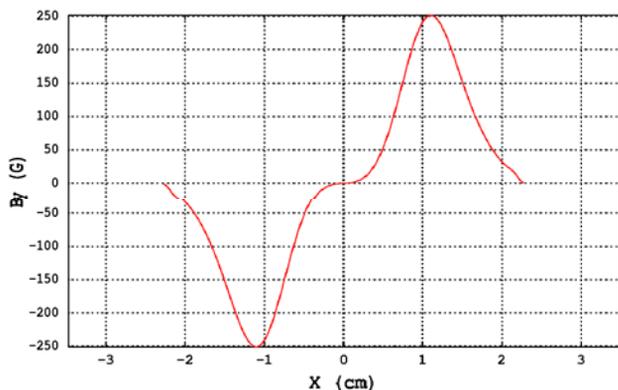
Figure 1: B_y-field of non-linear magnet in beam plane.

Even though a lumped element resonant circuit has small load impedance, a high charging voltage is required to drive the sum pulse current of at least 2800 A, as the pulser circuit and the twisted pair cable connections contribute significantly to the circuit inductance (Fig. 2).
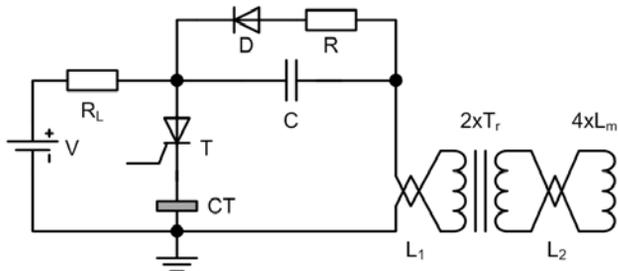
Figure 2: Schematic diagram of kicker pulser circuit and twisted pair feeds to the half-magnets with 2 coils each.

The high voltage differences to ground are mitigated by two parallel connected pulse transducers [6], between pulser unit and magnet. So the magnet to ground voltages are reduced considerably and do not exceed the insulation strength of the set-up. The unavoidable stray inductances of two transducers contribute only little to the circuit impedance, since the transformation ratio is 1:1.

The current feedthroughs are installed both on top and bottom to attain symmetry of magnet halves. Both sides are supplied by one transducer secondary respectively.

Inside the magnet vacuum vessel, coils **a** and **b** as well as **c** and **d** are connected in parallel. Thus, the four lines are powered with symmetrical pulse currents (Fig. 3). The wires are embedded in ceramic base plates with a thin titanium (10 µm) surface coating. Both structures are positioned by a stainless steel holding and maintain the undulator beam pipe aperture. Pulsed magnetic fields propagate through the ceramics and EMI is suppressed.
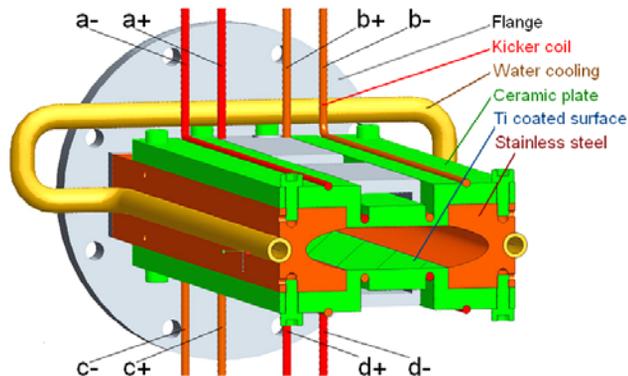
Figure 3: Sectional view of kicker magnet structure, second magnet design.

COMMISSIONING OF FIRST NL-KICKER

The first design of the NLK was installed in fall 2010, during a maintenance shutdown, in the second straight section after the injection point, next to an undulator.
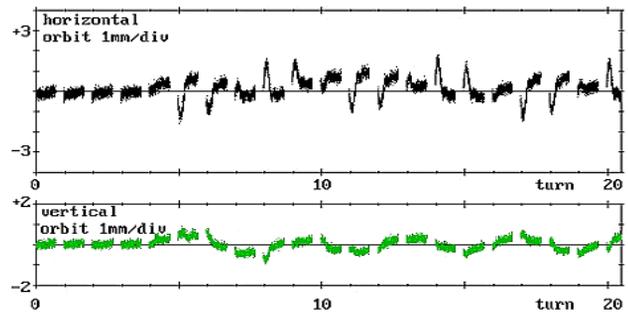
Figure 4: Turn-by-turn measurement of horizontal and vertical beam oscillations due to the local bump kickers.
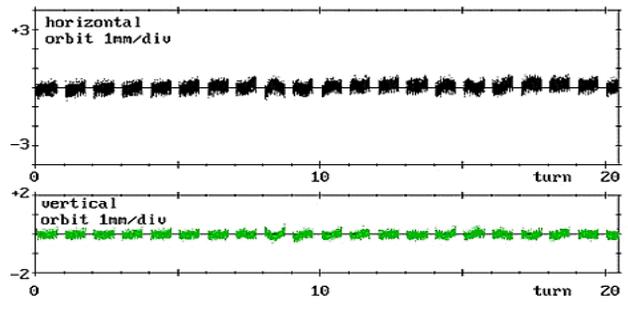
Figure 5: Turn-by-turn measurement of horizontal and vertical beam oscillations due to the NLK kick.

The injection with one non-linear kicker worked from the first moment on as predicted. The achieved injection efficiency with the NLK of about 80 % was comparable

with the local bump scheme. The stored beam oscillations however were dramatically reduced. In comparison, horizontal beam oscillation amplitudes of approximately 1 mm rms were measured with the local bump scheme, while amplitudes of only 60 µm rms have been obtained using the pulsed NLK (Fig. 4, Fig. 5).

Injection was possible up to the maximum beam current of 300 mA without excitation of instabilities. Even though the injection outmatched expectations, the operation of the first design suffered from extensive heat load at high beam currents $I_{beam} > 200$ mA, even when not being used. A later inspection of the NLK components showed molten components and tarnish on the NLK vacuum chamber indicating temperatures above 500 °C. From the temperature a total power loss within the NLK of 1 kW was estimated.

MEASUREMENT & SIMULATION RESULTS

From a measurement of the synchronous phase shift, by the method proposed in [7], with and without the NLK being installed, its longitudinal lossfactor could be estimated to $k|| = (4.8 \pm 1.4)$ V/pC resulting in 900 W power loss at a 300 mA multibunch beam. This result is in good agreement with the observed heat load.

The wake potential in the NLK was calculated with CST Particle Studio [8]. The Fourier transform gives the beam impedance of the NLK shown in Fig. 6. Simulation and theory [9] agree, that no field penetrates the titanium coated ceramic, the basic idea for the second approach. Hence, no rf-eigenmodes of the vacuum tank are excited.
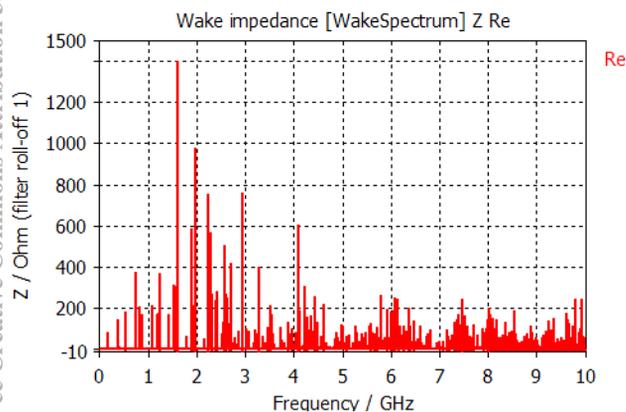
Figure 6: Calculated wake impedance (real part) of the first nonlinear kicker magnet design, consisting mainly of eigenfrequencies of the wire structure.

The four inner wires of the first design are close to the beam, and were not shielded by the titanium layer. These wires act as two different kinds of transmission lines. In one case, a pair of wires acts as a shorted transmission line. In the other case, the steel chamber wall acts as second wire. This transmission line is open ended. The eigenfrequencies of these transmission lines can be found in the impedance spectrum with values up to several hundred Ohms at frequencies up to several GHz.

OUTLOOK

Since the injection studies with the first NLK design outmatched our expectations, the herein described second NLK design is in preparation. It includes improvements based on the experience made, e.g. placing the inner wires behind the titanium coating and increasing the layer thickness from 5 µm to 10 µm to reduce the heat load. The beam induced wakefields will be confined better to the inner vacuum chamber, since the beam is completely enclosed and the surrounding beam pipe geometry is kept.

In the second design the wires are a little further away from their optimal position for the required B_y-field shape as the wire geometry is stretched. The titanium layer has a small shielding effect on the field excited by the pulse currents. Both effects require the mentioned peak current.

SUMMARY

The improved design of the non-linear kicker magnet will be tested first in the laboratory and than installed into the BESSY II storage ring. Intensive machine studies will follow to verify this technology for top-up injection.

ACKNOWLEDGEMENTS

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