ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-WEPAB113

STRIPLINE KICKERS FOR INJECTION INTO PETRA IV

G. Loisch*, I. Agapov, S. A. Antipov, M. A. Jebramcik, J. Keil, F. Obier
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Abstract

PETRA IV is the planned ultralow-emittance upgrade of the PETRA III synchrotron light source at DESY, Hamburg. The current design includes an on-axis beam injection scheme using fast stripline kickers. These kickers have to fulfill the requirements on kick-strength, field quality, pulse rise-rate and a matched beam impedance. 3D finite element simulations in conjunction with Bayesian optimisation are used to meet these requirements simultaneously. Here, we will discuss the requirements on the PETRA IV injection kickers and the current design status.

PETRA IV INJECTION SCHEME AND KICKER REQUIREMENTS

PETRA IV is the ongoing project to upgrade the existing PETRA III synchrotron light source to an ultralow-emittance source [1,2]. Similar to PETRA III, injection will be implemented in the southeast straight section of the storage ring (see Fig. 1). In the existing ring, bunches are injected off-axis using slow ferrite kicker magnets. This allows top-up injection, i.e. accumulation of charge in the ring. Such a scheme is difficult to implement in PETRA IV due to the lower dynamic aperture of the accelerator lattice. Therefore, the baseline design for injecting bunches into the PETRA IV storage ring is an on-axis, swap-out injection of full-charge bunches with fast stripline kickers [3].

Table 1 summarises the current requirements and design parameters for the stripline kickers for PETRA IV. Uncertainty in the necessary kick angle arises from the accelerator lattice layout still being refined. Electrode distance/size of the good-field region (GFR) and kick voltage are defined by beam dynamics and by the availability of compact, N-type electrical vacuum feedthroughs, respectively.

Table 1: Kicker Requirements and Preliminary Design Parameters in the On-axis Baseline Injection Scheme of PETRA IV

Particle energy	**6 GeV**
Kick angle	(1–1.8) mrad
Aperture	14 mm
GFR diameter	9 mm
Field flatness	≤ 1 %
Kick voltage	(±) 5.5 kV
Stripline length	1 m
No. of striplines	4 (+1 spare)
Pulse rise/fall time	(6–8) ns
Pulse flattop duration	80 ns
Electrical impedance	50 Ω

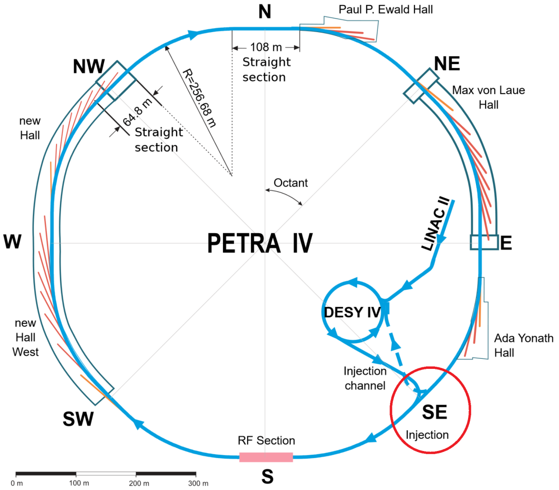

Figure 1: Overview of the PETRA IV facility with the southeast straight injection section (red circle) [2].

A spare kicker is foreseen to ensure high availability of the machine in case of the failure of a stripline kicker or its driving electronics. The pulse rise time is defined by the capability of currently available solid-state high voltage switches. In the baseline on-axis injection scheme bunch trains of 20 bunches with a bunch separation of 4 ns would be injected. Between these bunch trains a gap of 20 ns is foreseen to allow for the fields in the kicker to rise and decay before passage of circulating bunches.

Due to the advantages of top-up injection, namely the reduced disturbance of user operation, a possible realisation of such a scheme is still being investigated for PETRA IV. One possibility would be an orbit bump created by a series of 4 kickers to bring circulating and injected beam close enough to each other. The use of ferrite-loaded kicker magnets is unfavourable as their pulse lenghts in the μs range would result in disturbance of a large fraction of the circulating bunches, again resulting in disturbance of user operation. Instead, an injection based on 4 modules of fast stripline kickers is considered. In this case, e.g. the current design length of the stripline kickers would significantly increase the number of bunches that are affected during an injection process. Possible design changes on the stripline kickers, the needed number of striplines and further requirements imposed by such an injection scheme are currently being investigated.

BAYESIAN OPTIMISATION OF STRIPLINE GEOMETRY

Simulations using CST Microwave Studio have been performed to investigate the electrical parameters of the stripline

---

[*] gregor.loisch@desy.de

and the field quality in the good-field region. For efficient iteration of the various geometric parameters of the stripline cross-section geometry a Bayesian optimisation algorithm is used. The goal parameter that is optimised is defined as

$$V_{goal} = (Z_{odd}[\Omega] - 50) + \frac{1}{10}(Z_{even}[\Omega] - 50) + FF[\%]. \quad (1)$$

Here, Z_{odd} is the impedance of the stripline for the odd excitation mode, i.e. when the two stripline electrodes have opposite polarity. This mode is excited by the pulse electronics for kicking the beam and its impedance has to be matched to the impedance of the pulse electronics of 50 Ω to avoid reflections of the fast HV pulses in the circuit. The even mode impedance Z_{even} describes the stripline electrical impedance in case of similar polarity of the two electrodes.

This mode is excited by the particle bunches themselves and as reflections of such induced fields at mismatched impedances of the stripline to the connected electronics could deteriorate circulating bunches, the impedance for this mode has to be as close to the nominal impedance of the electronics of 50 Ω as well. Furthermore, beam impedance is expected to drop with even mode impedance [4], making the reduction of Z_{even} even more favourable. The field flatness FF is defined as the ratio between the second and the first multipole components of the electrical field. Multipole components are derived via fast Fourier transformation of the electrical fields on the edge of the good-field region. In the definition of the goal value the odd mode impedance is emphasised as reflections of the high voltage pulses are considered the main concern for beam disturbance. As the even mode impedance cannot be equal to the odd mode (due to the capacity between the electrodes) but should be as close as possible to 50 Ω it is included in the goal value with reduced weight.

General layout of the stripline geometry is based on existing designs of similar striplines [4–6] and features e.g. so-called fenders, parallel rails between the two stripline electrodes, which are attached to the outer vessel for decoupling the odd and even mode impedances. The geometry parameters that were varied to minimise V_{goal} are the inner radius of the stripline outer conductor $R_{i,pipe}$, width of the electrode arc w, the outer radius of the electrode arc R_{Arc}, the angle that the electrode arc spans ϕ and the length that the side fenders reach into the beam pipe from $R_{i,pipe}$, which is titled L_{Fender} (see Fig. 2). During the optimisation process the three slightly different cross-section designs shown in Fig. 3 have been optimised and best results for the design constraints of PETRA IV have been found for the layout shown in Fig. 3 a). It should be noted that this is not necessarily a general fact but might only be true for the parameter ranges chosen here. Results of a typical optimisation run of the simulation model are shown in Fig. 4. The best results found so far are an even mode impedance of 60.6 Ω at an odd mode impedance of 50 Ω and a field flatness of < 0.1%. Mechanical tolerances of the geometry for these results are currently under investigation.

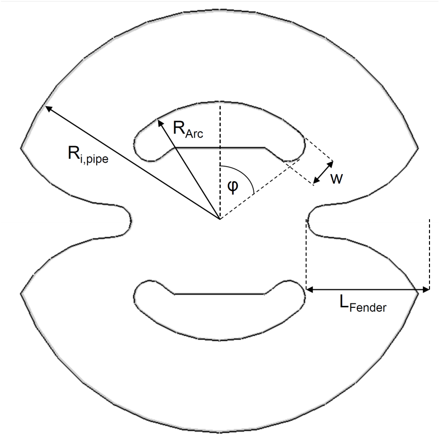

Figure 2: Cross-section geometry of the designed stripline with indicated variable parameters.

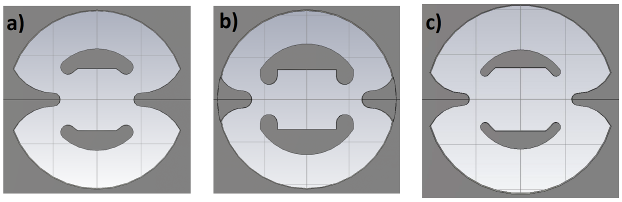

Figure 3: Different cross-section geometries that were compared in simulations.

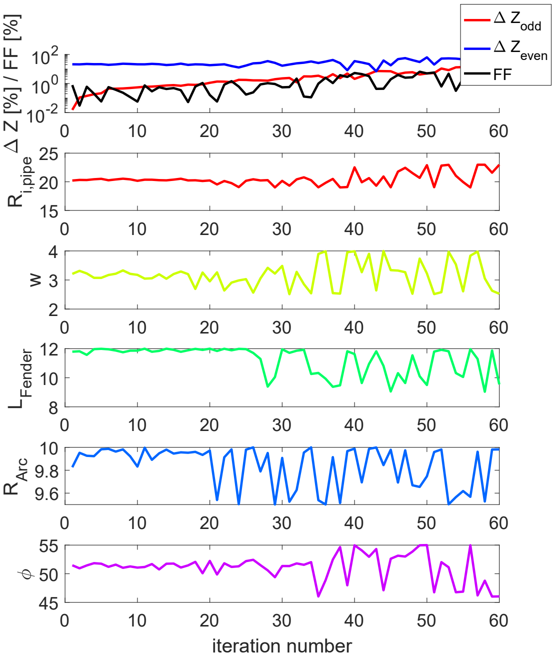

Figure 4: Results of a Bayesian optimisation run sorted by the corresponding goal values. The top graph shows deviations of odd and even mode impedances from 50 Ω and the field flatness, the other graphs the geometric parameters according to Fig. 2.

KICKER MODULE AND PULSE ELECTRONICS DESIGN

As a next step in the design of the stripline kickers the electrical connection regions and the transition between accelerator beamline and the kicker module will be simulated and optimised for minimum impedance mismatch. Different designs for the mechanical implementation of the kickers are under consideration, including single kicker modules that are placed in the synchrotron as well as integration of several striplines into one module with shared beam impedance matching sections at the ends of the module [7]. For providing the high voltage pulses for the striplines an inductive voltage adder as well as a Marx generator topology, both based on fast SiC MOSFETs, are under investigation. A collaboration with the High Power Electronics laboratory at the ETH Zurich has been established for developing such a system and in parallel commercially available solutions are being reviewed.

SUMMARY

Design of the injection scheme for the PETRA IV light source is ongoing. The baseline, on-axis injection as well as a possible off-axis layout require fast stripline kicker magnets. Based on existing stripline designs, an optimisation of electrical impedances and field quality has been performed using a Bayesian optimisation algorithm and in simulations of the stripline cross-section all requirements on the stripline are fulfilled so far. Further work will concentrate on the optimisation of the full stripline model. The full model also includes electrical vacuum feedthroughs and e.g. tapers at the ends of the stripline electrodes and tapers of the beamline vacuum pipe for optimising electrical and beam impedances. Development of solid-state-based pulse electronics and review of possible commercial options to drive the kicker magnets has started in parallel to the stripline design.

REFERENCES

[1] C. G. Schroer *et al.*, “PETRA IV: the ultralow-emittance source project at DESY”, *J. Synchrotron Rad.*, vol. 25, pp. 1277-1290, 2018. `https://doi.org/10.1107/S1600577518008858`

[2] C. G. Schroer *et al.*, “PETRA IV: upgrade of PETRA III to the Ultimate 3D X-ray microscope”, DESY, Hamburg, Germany, Rep. PUBDB-2019-03613, 2019.

[3] J. F. Power *et al.*, “The Los Alamos proton storage ring fast-extraction kicker system”, *IEEE Trans. Nucl. Sci.*, vol. 32, no. 5, pp. 3021–3023, 1985. `doi:10.1109/tns.1985.4334261`

[4] C. Belver-Aguilar *et al.*, “Stripline design for the extraction kicker of Compact Linear Collider damping rings”, *Phys. Rev. ST Accel. Beams*, vol. 17, p. 071003, 2014. `doi:10.1103/physrevstab.17.071003`

[5] C. Yao *et al.*, “Development of Fast Kickers for the APS MBA Upgrade”, in *Proc. 6th Int. Particle Accelerator Conf. (IPAC’15)*, Richmond, VA, USA, May 2015, pp. 3286–3288. `doi:10.18429/JACoW-IPAC2015-WEPTY014`

[6] G. C. Pappas *et al.*, “Fast Kicker Systems for ALS-U”, in *Proc. 5th Int. Particle Accelerator Conf. (IPAC’14)*, Dresden, Germany, Jun. 2014, pp. 564–566. `doi:10.18429/JACoW-IPAC2014-MOPME083`

[7] N. Wang *et al.*, “Impedance optimization and measurements of the injection stripline kicker”, *Phys. Rev. ST Accel. Beams*, vol. 24, p. 034401, 2021. `doi:10.1103/physrevaccelbeams.24.034401`