ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPRO045

SIMULATION STUDIES ON BEAM INJECTION INTO A FIGURE-8 TYPE STORAGE RING

M. Droba, A. Ates, O. Meusel, H. Niebuhr, D. Noll, U. Ratzinger, J. F. Wagner, Goethe University, Frankfurt am Main, Germany

Abstract

The proposed figure-8 storage ring at Frankfurt University [1, 2] is based on longitudinal guiding magnetic fields and will have special features with respect to the beam dynamics. A crucial part of the ring is the injection section, where the low energy beams have to cross an area of steeply rising field – up to B = 6 T into the main ring field. An optimized magnetic channel is designed to bring the injected beam close enough to the magnetic ring flux. An ExB kicker is needed to move the injected beam from the injection channel to the main magnetic field flux allowing multi turn injection. Simulation studies concentrate on this part and will be presented, results will be discussed. A comparison with simulations for prepared scaled down experiments with existing room temperature toroids will be done.

INTRODUCTION

Traditional ring concepts are based on finite focusing and bending elements, which define a stable area for a bound particle motion, the so called dynamic aperture.

In contrast, the guiding longitudinal magnetic field in the figure-8 concept (Fig. 1) confines charged particle beam continuously.

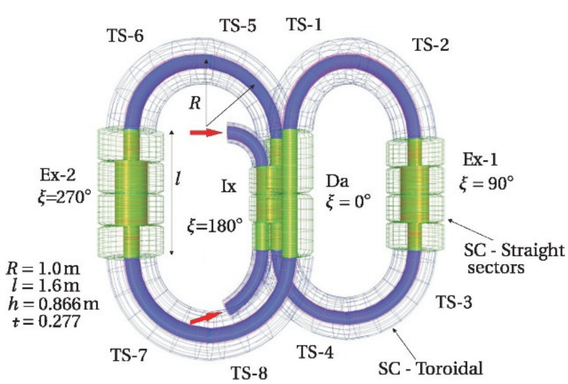

Figure 1: Figure-8 Storage Ring (F8SR) layout.

However, field curvature and particle momentum generate a partitioning of phase space drift surfaces and nested magnetic flux surfaces (Fig. 2). Additionally, the imperfection of the magnetic field distribution leads to a reduction of the dynamic aperture and should be avoided. Especially, careful coil design with optimized curvature along the injection channel and sufficient aperture at the injection point is mandatory (Fig. 3).

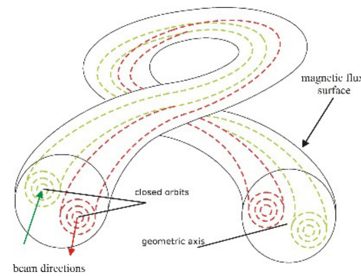

Figure 2: Schematic partitioning of the nested magnetic flux surface and the momentum surfaces dependent on the direction of the beam circulation (in red and green).

INJECTION SYSTEM

The proposed injection access point of the figure-8 storage ring is positioned in the middle of the central straight section on the ground plane. It consists of an adiabatic magnetic channel, which is designed to guide the particles from a field free region with B = 0 T to the high field area of B = 6 T. Due to the curved injection path in this area a special approach was chosen with respect to the curvature drift of a low energy beam (W = 150 keV). The best results were achieved in the particle transport simulations by the assumption, that the particle drift velocity v_D (Eq. 1) is constant along the whole adiabatic channel.

$$v_D = \frac{mv_{\parallel}^2}{qBR}. \quad (1)$$

This could be done by two different approaches. First, the product B•R is kept constant. By the smooth variation of the magnetic field strength from B_{min} to B_{max} = 6 T, the curvature radius will be changed simultaneously.

Figure 3: Coil system of F8SR.

In a second approach the curved region can be overlapped by a vertical magnetic dipol field [3]. In that way, the centripetal force will be compensated by the

5th International Particle Accelerator Conference IPAC2014, Dresden, Germany JACoW Publishing
ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPRO045

Lorentz force and there will be no drift. The influence of the adiabatic channel on nested magnetic flux surfaces was investigated near the injection point. In a simple approximation, the existing magnetic flux system was overlapped by a different kind of error fields (quadrupole, sextupole and coil misalignment). Single particle simulations were done in those fields with the aim to define the dynamic aperture. An example of particle trajectories (blue) with simulated magnetic fields (red) are shown in Fig. 4.

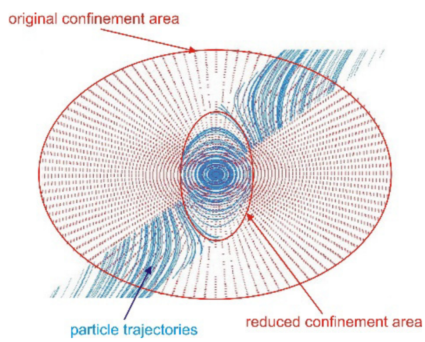

Figure 4: Confinement of particles in the figure-8 ring by assumption of quadrupole error field.

MULTI - PARTICLE SIMULATION CODES

The 3D Particle-in-Cell (PIC) simulation code *Bender* was written by D. Noll [4] with the intention to have a tool which can simulate multi-specie transport under various external and internal field conditions. Non-relativistic particle motion is integrated in the time coordinate by a symplectic second order mover. Space charge forces are given by a Poisson-solver, with an option to use the Fast Fourier solver or the iteration solver in the Sparse-Matrix format.

The simulation code *Lintra* is a 2D PIC Code, which solves the beam transport in cylindrical symmetry and was written especially for low energy beam transport (LEBT) sections.

These two codes were used in the following simulations.

EXB KICKER

Main component of the whole injection system is an ExB kicker (Fig. 5).

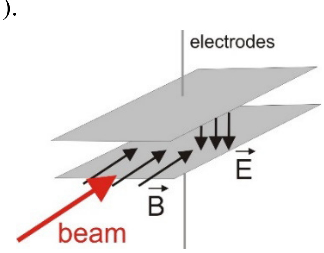

Figure 5: Schematic view on the ExB kicker. Due to the particle drift in crossed fields between the electrodes the beam will be kicked horizontally.

The electric field and the electrodes length were first calculated theoretically with respect to the beam energy (W = 150 keV), the magnetic field strength (B = 6 T) and the proposed drift of about 3 - 5 cm. The technically feasible values were adjusted to the electric field E = 2 MV/m and the electrodes length L=1m.

In the next step multi-particle simulations by the *Bender* code were done through the ideal homogenous fields under various space charge conditions and electric field levels. The beam current varied from 10 to 100 mA and the electric field E varied from 0 to 2.5 MV/m. The beam trajectory for the case with an electric field E = 1 MV/m is shown in Fig. 6.

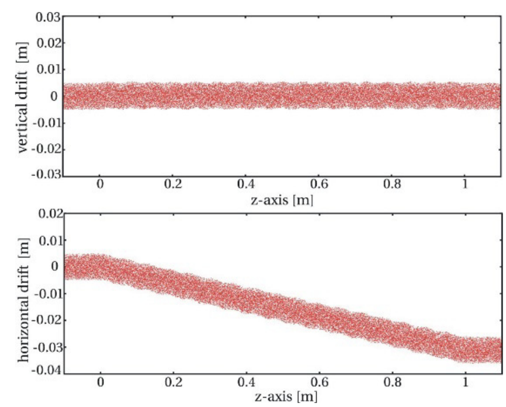

Figure 6: Beam transport simulation through the ExB kicker (along the z-axis) is shown in the vertical and the horizontal planes.

The beam is drifted 3 cm horizontally while staying constant vertically after passing the kicker with planar plates and ideal fields. Small oscillations of the beam envelope correspond to the cyclotron motion in a strong magnetic field B = 6 T. The beam drift dependence on electric field level is shown in Fig. 7.

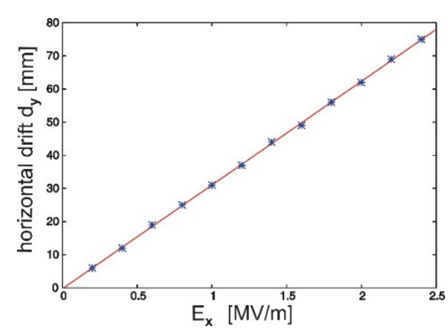

Figure 7: Horizontal beam drift as a function of used electric field.

The drift is growing linearly with higher electric field levels. No evidence of a beam drift and a beam radius dependence on an ion beam current was found in simulations.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPRO045

SCALED DOWN EXPERIMENTS

A beam transport in magnetic guiding fields and beam injection are investigated in the scaled down experiments at Frankfurt University. Main objectives are a proof of principle for the proposed injection scheme and a comparison between measurements and simulation codes.

Due to the multi-specie extraction from the hydrogen plasma there is a necessity to design the separator system before injection, as reported earlier [1, 2].

A new filter channel was designed and species separation was calculated theoretically as well as proved experimentally last year [5].

The momentum separator consists of a focusing solenoid, of 800 mm drift and an aperture with diameter d = 20 mm. Simulations of a three species (H^+, H_2^+, H_3^+) transport at a beam energies between 7 keV and 9 keV were done by simulation code *Lintra* and the results are plotted in Fig. 8.

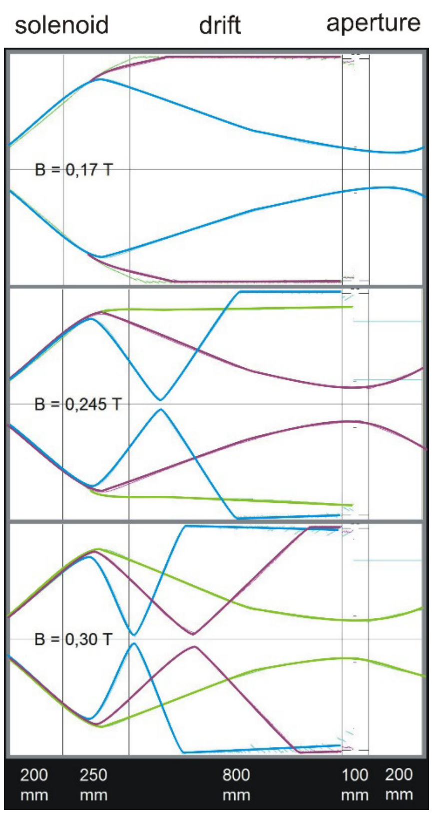

Figure 8: Beam envelopes of low energy W = 8.6 keV (H^+, H_2^+, H_3^+) beams.

Three magnetic field strengths were determined to select the desired specie. Simulations were compared with measurements, where an example of the detected beam current are shown in Fig. 9. Three peaks are evident in the detected signal and distances between the peaks are in agreement with theory.

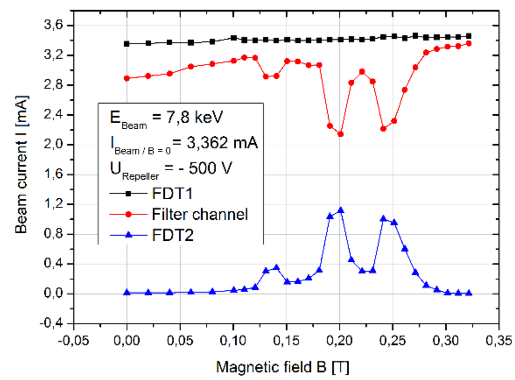

Figure 9: Measurement results from scaled down experiments with a separator channel. The blue curve corresponds to the measured beam current after the aperture. The red curve corresponds to the beam current losses collected in the whole filter channel (vessel plus aperture).

CONCLUSION AND OUTLOOK

First beam simulations on an injection system for the proposed figure-8 storage ring were presented. The proposed scheme with a curved adiabatic channel and ExB kicker seems promising.

It is planned to simulate the complete system under real field configuration with optimized electrode design with respect to the magnetic field.

Scaled down experiments are in preparation with the aim to proof the proposed scheme under realistic conditions.

REFERENCES

[1] M. Droba et al., “Confinement, Accumulation and Diagnostic of Low Energy Ion Beams in Toroidal Fields”, Proc. of IPAC2011, San Sebastian, Spain, p. 2487.

[2] M. Droba et al., “Beam Accumulation in a Stellarator Type Storage Ring”, Proc. of IPAC´10, Kyoto, Japan, p. 4473.

[3] E.V. Boltushkin et al., “Storage Ring with Longitudinal Magnetic Field LEPTA (Stellatron)”, Phys. of Particles and Nuclei Letters, 2006, Vol. 3, pp. S46-S49.

[4] D. Noll, *private communication,* 2014.

[5] H. Niebuhr, MSc Thesis, urn:nbn:de:hebis:30:3-327538, Frankfurt am Main, Germany, 2014.