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STATUS OF INJECTION STUDIES INTO THE FIGURE-8 STORAGE RING

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

Abstract

The ongoing investigations on the design of the Figure-8 Storage Ring [1] at Frankfurt University focus on the beam injection. The research includes simulations as well as a scaled down experiment. The studies for an optimized adiabatic magnetic injection channel, starting from a moderate magnetic field up to a maximum of 6 Tesla, with a realistic field model of toroidal coils due to beam dynamics with space charge will be shown. For the envisaged ExB-kicker system the simulations deal with beam potential constraints and a multi-turn injection concept in combination with an adiabatic magnetic compression. To investigate the concept of the beam injection into a toroidal magnetic field, a scaled down room temperature experiment is implemented at the university. It is composed of two 30 degree toroidal segments, two volume ion sources, two solenoids and two different types of beam detectors. The experiment is used to investigate the beam transport and dynamics of the laterally injected and "circulating" beam through the magnetic configuration. To set up the injection experiment, theoretical calculations and beam simulations with bender [2] are used.

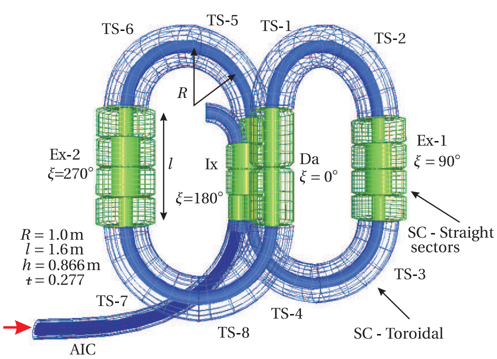

Figure 1: Figure-8 Storage Ring with the proposed adiabatic injection channel (AIC).

INTRODUCTION

The Figure-8 storage ring (*F8SR*) concept is under development at Frankfurt University. Different from traditional storage rings, a guiding longitudinal magnetic field confines the charged particle beam continuously with high transverse momentum acceptance. Due to the strong magnetic field level (B=6 T), high current low energy proton (W~150 keV) and ion beams of several amperes can be confined. Many characteristic features and key components were developed in the past. The current developments are concentrated on the design of a realistic injection system and test campaign in scaled down experiments.

* j.wagner@iap.uni-frankfurt.de

SIMULATIONS OF THE INJECTION SYSTEM

An injection system composed of an adiabatic magnetic compression channel and an $\mathbf{E}\times\mathbf{B}$-kicker was designed and 3D multi particle simulations with realistic static magnetic and electric fields were performed.

The shape of the injection channel follows the curve of a hyperbolic spiral $R(\theta) = \frac{a}{\theta}$ within the interval of the parameter $\theta \in [\frac{\pi}{3} : \pi]$, see Fig. 1 (AIC). The channel has a length of L=4 m and a minimum radius R_1 of 1 m, hence a=π. The chosen channel geometry was implemented in the design code *segments* with solenoidal coils of decreasing distance $\sim \frac{1}{\theta}$ and constant current . The results of a Biot-Savart solver delivers a smooth ascending magnetic field, see Fig. 2 (blue). Concerning the curvature κ the channel

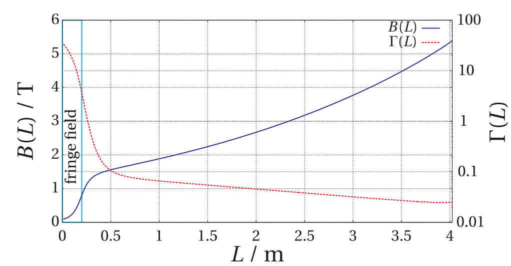

Figure 2: Rise of the magnetic flux and the adiabatic condition, on axis along the injection channel.

provides a small value at the entrance to avoid an instant kick to the injected beam. At the junction to the ring a high curvature keeps the perturbation of the ring flux low. For an adiabatic magnetic compression the magnetic field has to obey the condition for the parameter Γ in Eq. (1)

$$v_{\parallel}\frac{\Delta B}{\Delta s} < B\frac{\omega_c}{2\pi} = \frac{|q|B^2}{2\pi m} \rightarrow \Gamma = v_{\parallel}\frac{\Delta B}{\Delta s}\frac{2\pi m}{|q|B^2} < 1 \qquad (1)$$

The calculated Γ shows that this condition is fulfilled along the whole proposed injection channel. The only exception can be found at the magnet fringe at the beginning. Single particle tracking in *segments* with protons at E_{kin}=150 keV injected on axis show an expected rise of the transversal velocity $v_{\perp}$ due to the $\mathbf{R}\times\mathbf{B}$-drift with an acceptable ratio to the parallel velocity. The off plane drift amounts to 17 mm. Field maps of the whole injection system area were exported to the multi-particle code *bender* and simulations were qualitatively confirmed, see Fig. 3.

Further, an $\mathbf{E}\times\mathbf{B}$-kicker system with two fixed and two movable electrodes with a total length of 1170 mm, at a gap width of 30 mm and 90 kV voltage, i.e. E=3 MV/m, were integrated into the simulations. Single particle tracking shows the velocity components in Fig. 4. The increase in $v_{\perp}$ occurs respectively to the shift of the magnetic flux due to the

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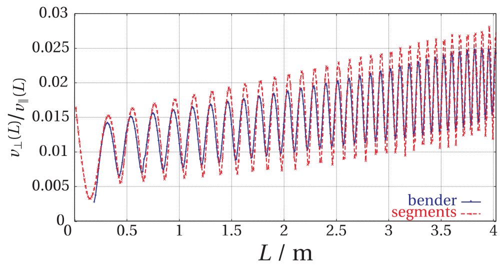

Figure 3: Ratio of transversal and parallel velocities of a design particle in the adiabatic injection channel.

approaching ring flux which can be controlled by coil current settings.

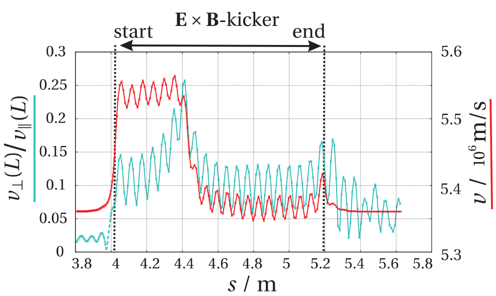

Figure 4: Ratio of transversal and parallel velocities and the total velocity of a design particle in the $\mathbf{E} \times \mathbf{B}$ -kicker.

Parallelized multi particle simulations with space charge were performed in *bender*. A 100 mA proton beam at an input radius of $r_{\mathrm{b,in}}$=25 mm was fully accumulated and transported into the kicker area without losses. The beam potential has a maximum value of Φ=840 V and the electric space charge field E=30 kV/m is well below the kicker field. Within the kicker the beam is shifted 139 mm horizontally

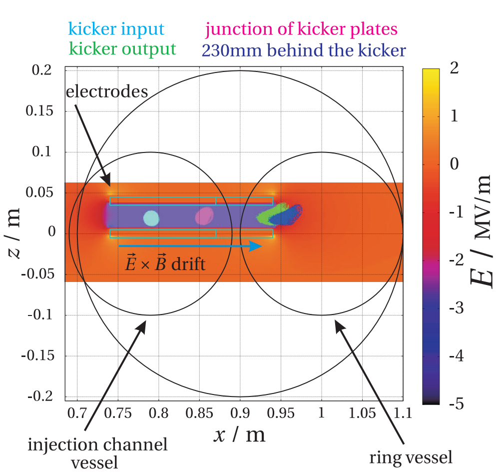

Figure 5: Kicker area with beam monitor profiles of the shifted injected beam.

which is needed for the injection into the stable area of the *F8SR*.

EXPERIMENTS

Scaled Down Experiment

To build up the proposed injection system experiment at the scaled down experiment at Frankfurt University, particle simulations using *bender* were done to find the optimum geometrical and physical parameters for the transported and the injected hydrogen ion beams.

Figure 6: Top view picture of the scaled down experiment at Frankfurt University with two ion sources.

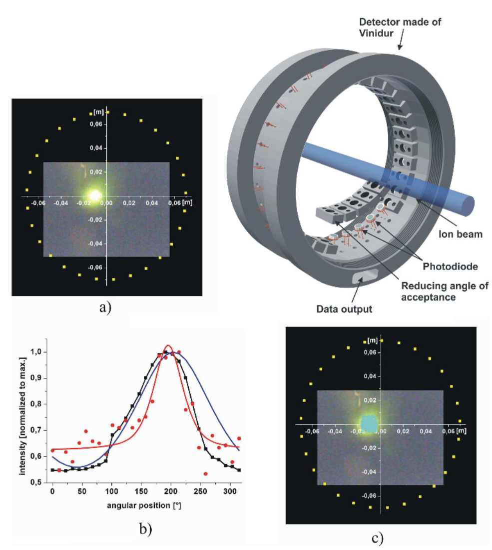

Figure 7: a) Beam on the scintillation screen within the coordinates of the vacuum vessel and the photodiode-detector in yellow. b) Approximation of experimental results (red), scintillation screen data (black) and simulated data (blue). c) The simulated luminescence distribution (cyan) is mapped on the scintillation screen picture for comparison and proving the detection of position and diameter of the beam.

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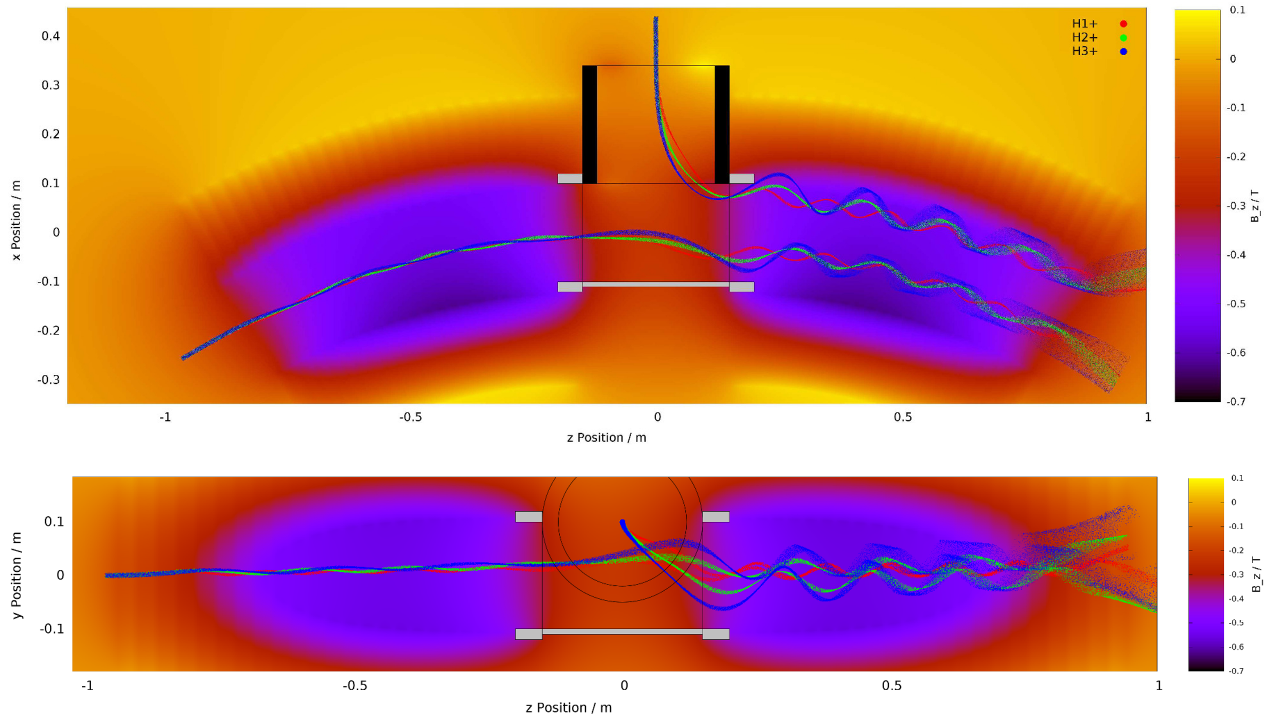

Figure 8: Particle simulations using the multi-particle code *bender*: Simulation of the injection experiment using two 7.8 keV hydrogen ion beams, two toroidal magnets with 0.6 T and a solenoidal injection coil with 0.2 T.

An example of tracking simulations through the magnetic field of the toroidal magnets and a solenoidal injection coil is shown in Fig. 8. The experimental setup was further prepared to build up the planned and simulated injection experiment. Figure 6 shows a top view picture of the current status of the experiment with two injectors, two toroidal magnets, one filter channel and peripheral equipment. The setup of the second filter channel for the injection line will be approached in the next step.

After completing the simulations, the development of the injection coil and the belonging vacuum chambers will be finished and the parts will be ordered.

The Diagnostics System

An optical detector was developed (Fig.7), which detects the beam induced fluorescence. The main components of the detector are photodiodes which are insensitive to magnetic fields, and a very fast data acquisition system.

Investigations on a helium ion beam at 6.5 keV beam energy with 1 mA current at a residual gas pressure of 10^{-5} mbar have been performed. Using the detector, beam position and diameter can be determined. The measurements of the photodiode detector are compared with measurements with a scintillation screen and simulated data in Fig. 7.

CONCLUSION AND OUTLOOK

The proposed injection system for the *F8SR* consisting of an adiabatic injection channel and an $\mathbf{E}\times\mathbf{B}$-kicker has been studied. Multi-particle simulations were performed with realistic field configurations (magnetic and electric) and show no beam losses, for beams up to 100 mA beam current. The next step will be the optimization of the kicker electrodes and position to improve the quality of the injected beam. The combination of an $\mathbf{E}\times\mathbf{B}$-kicker and bumper coils for perturbation of the closed flux surfaces in the injection area I_x (see Fig. 1) seems promising for multi-turn injection with an envisaged accumulated beam current of 1 A. In parallel, scaled down experiments were prepared and will be performed this year. The crucial topics are to check the diagnostics system, ion species filtering, beam dynamics and to compare simulation results with experiments. Further, the $\mathbf{E}\times\mathbf{B}$-kicker will be build and tested.

REFERENCES

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