FIGURE-8 STORAGE RING – INVESTIGATION OF THE SCALED DOWN INJECTION SYSTEM

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Abstract

To store high current ion beams up to 10 A, a superconducting storage ring (F8SR) is planned at Frankfurt university. For the realisation, a scaled down experimental setup with normalconducting magnets is being built. Investigations of beam transport in solenoidal and toroidal guiding fields are in progress. At the moment, a new kind of injection system consisting of a solenoidal injection coil and a special vacuum vessel is under development. It is used to inject a hydrogen beam sideways between two toroidal magnets. In parallel operation, a second hydrogen beam is transported through both magnets to represent the circulating beam. In a second stage, an ExB-Kicker will be used as a septum to combine both beams into one. The current status of the experimental setup will be shown. For the design of the experiments, computer simulations using the 3D simulation code bender were performed. Different input parameters were checked to find the optimal injection and transport channel for the experiment. The results will be presented.

F8SR – FIGURE-8 STORAGE RING

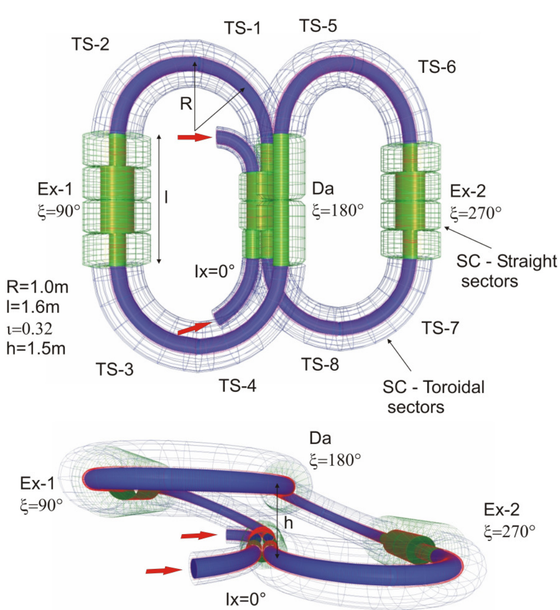

Figure 1: F8SR – Low-Energy Superconducting Magnetostatic Storage Ring.

The F8SR is a low-energy superconducting magnetostatic storage ring for high current beams, for example proton beams up to 10 A with an energy of up to 150 keV. Higher charged ion species can be stored with higher energies. In order to focus the high current beams, toroidal magnets (called toroids) and solenoids are used around the whole ring. The twisted Figure-8 geometry is necessary because of the RxB drift of beams transported through the toroidal magnetic fields. An additional advantage of this structure is the possibility to transport two different beams independently, one in each direction, and to perform interaction experiments at two areas of the ring where the beams cross. The F8SR is shown in Fig. 1.

SIMULATIONS USING THE PARTICLE-IN-CELL CODE BENDER

To investigate the dynamics of ion beams in solenoidal and toroidal magnetic field systems and for the development of the scaled down injection experiment, simulations using the Particle-in-Cell code bender [1] were performed. For this purpose, the external fields of the magnets used in the experiment were calculated using CST (M-Static Solver) on a mesh of 1x1x1 mm resolution and the beam tube geometry was included (required for losses calculations). Different geometries, injection coils and magnetic field strengths were used to investigate the beam behavior and to find a working and realizable injection system with a high acceptance and transmission.

To get a look on the beam path and behavior from different points of view, the tracking results of the ring beam and the injection beam are plotted together with the magnetic field strength B_z. One result is shown in Fig. 2. In this figure the upper picture shows a top view on the drift of the two beams, the ring beam moves from left to right and the injection beam from above to right. The lower picture shows the side view.

Using this view the basic idea of the injection system can be seen and how it works. The injected beam drifts from the injection channel to the transport channel and then gets transported trough the second toroid. Using the plotted parameters, the injected beam is matched perfectly, so no gyration occurs and the beam adjustment does not change. In this process, the beam also drifts down to the level of the ring beam. The possibility of using a kicker system to merge the two beams is available. In this simulation, the ring beam was not matched perfectly and so the beam adjustment – visible by the different gyration inside the first and the second toroid – changed. By using different parameters for the ring beam, this effect can be reduced.

For the characterization of an injection system, a set of simulations with different parameters were necessary. To compare the results, a method to figure out how large the

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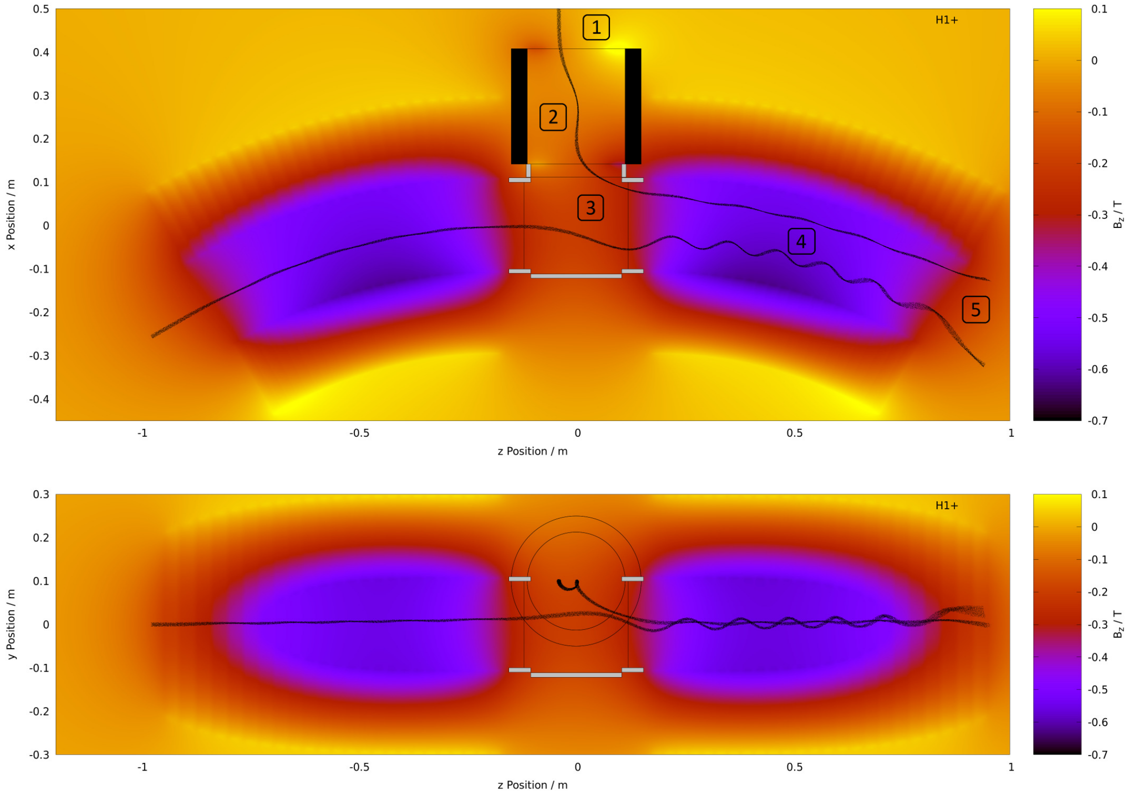

Figure 2: Looking on the beam path (upper picture from above / lower one from the side) of the ring beam and the injection beam. The magnetic field of the injection coil was B_{axis} = 0.326 T, the offset of the injection channel 100 mm and the injection position x=508 mm, y=100 mm and z=-40 mm.

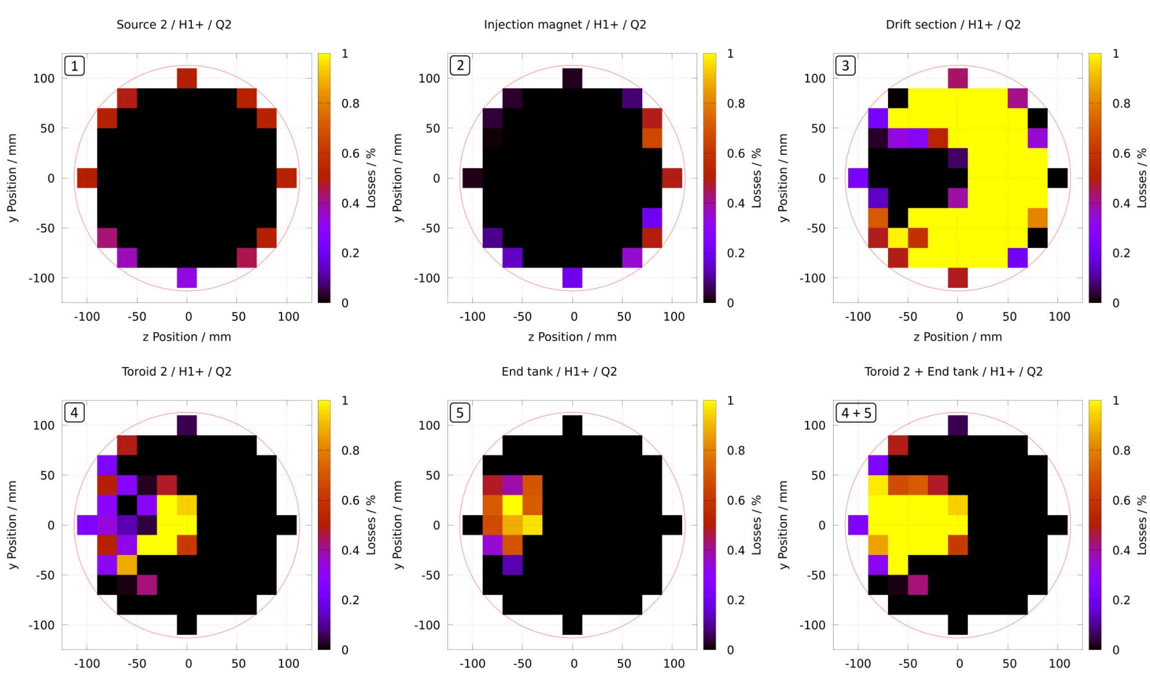

Figure 3: The picture shows the losses in each component of the transport and injection channel for 81 simulations with different starting positions in front of the injection magnet (z/y-coordinates). The magnetic field of the injection coil was B_{axis} = 0.326 T and the offset of the injection channel 100 mm.

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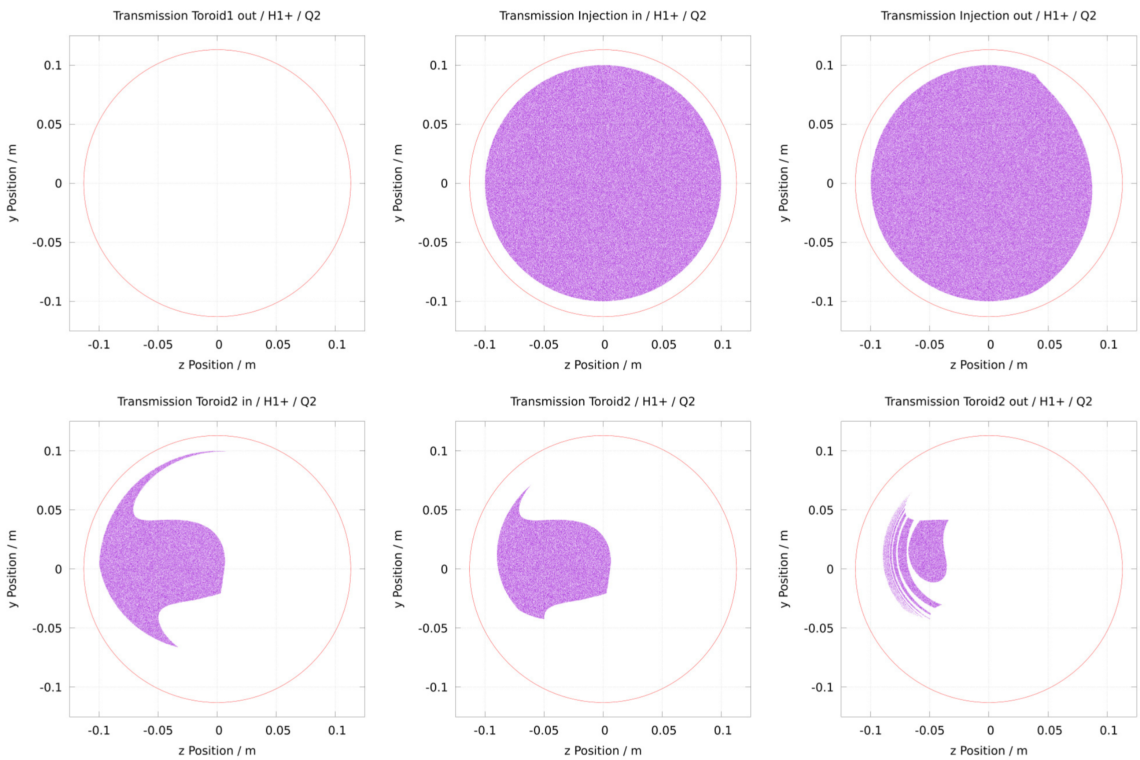

Figure 4: The picture shows the starting position in front of the injection magnet (z/y-coordinates) against the transmission until the entrance, center or exit of different components of the injection and transport channel. The magnetic field of the injection coil was B_{axis} = 0.326 T and the offset of the injection channel 100 mm.

injection channel, the transmission and the acceptance is had to be developed. Simulations with different magnetic field structures and strengths, geometries and injection parameters were performed to find the realizable injection system as described here.

To check one setup 81 simulations were done using the same geometry and magnetic field strength and structure and only the starting position of the beam in front of the injection channel varying across the whole zy-surface. The losses were tracked and assigned to the components in which they took place. A loss map was generated which shows at which position to start the beam in the zy-surface 100 mm in front of the injection coil to get beam losses in a specific component.

A result of this analysis method is shown in Fig. 3. By having the possibility to see where the beam gets lost if it starts at different transverse positions, it is possible to investigate how far the beam gets transported through the beam line. Here, the started beams mostly go through the injection coil and mainly get lost in the drift section (area between the three magnets). Only a bunch of started beams reaches the entrance of the second toroid. Still less of them get transported trough the toroid and reach the end tank behind the magnet.

Finally, the sum of the losses in the second toroid and the end tank is of interest (second row / third picture (Fig. 3)). Beams reaching one of these two components get transported through the injection system. It will be possible to kick these beams completely into the middle of the tube and then combine them with the ring beam by using a kicker system at the entrance of the second toroid. The yellow area of around 8x10 cm is the acceptance of the injection system. The transmission shown by color is mostly around 100 % in this area.

Another way to investigate the acceptance and transmission of an injection system is to use a homogeneous distribution (without starting angle) with the radius of the injection vacuum tube and transport this "beam" trough the whole experiment. In this kind of simulation, monitors are positioned at the entrance, center and exit surfaces of the components. A transmission map is generated which shows where to inject in front of the injection magnet (in the zy-surface) to get the beam transported until a monitor. This type of simulation runs faster and gives a more precise view on the acceptances and the injection planes. Another difference is that the transmission until a specific monitor is plotted and not the losses. So a direct view on the acceptance is possible. Disadvantages of this simulation type are that calculations with an actual beam distribution need more postprocessing and simulations with space charge are not possible.

In Fig. 4, results of this method are shown. The same simulation parameters were used than in the simulations shown before in Fig. 3.

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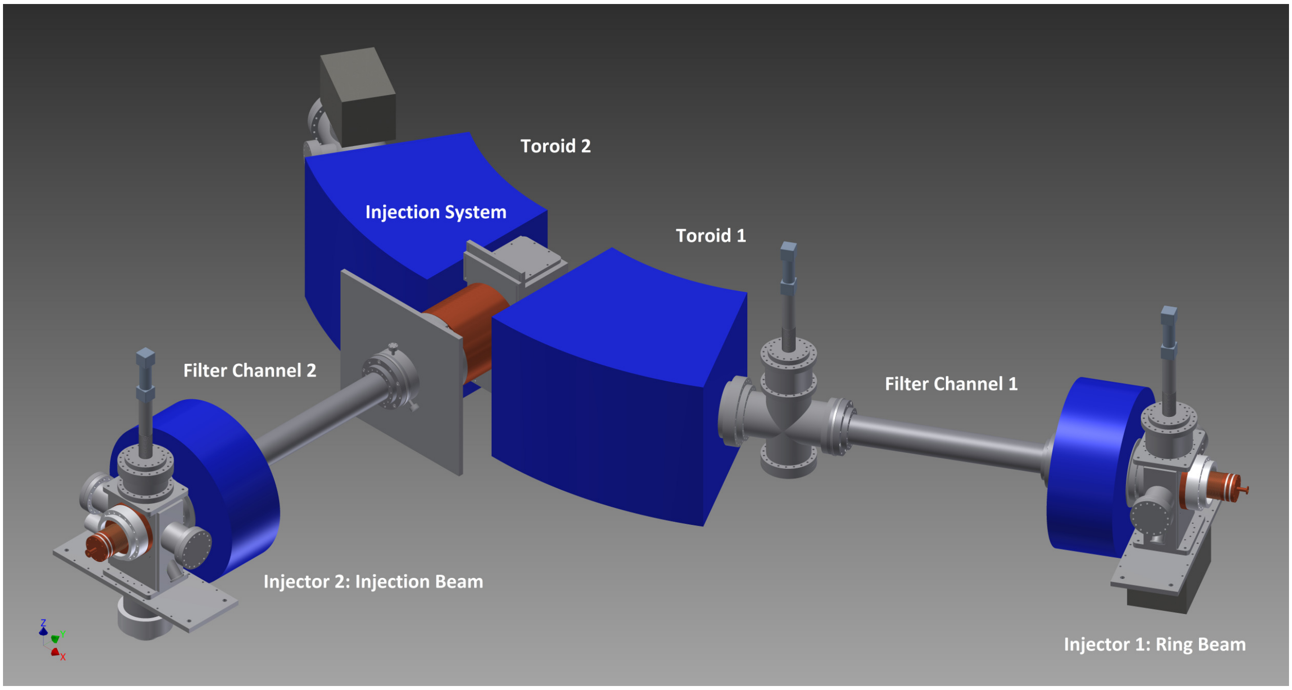

Figure 5: The complete layout of the experiment.

Here, the acceptance of the injection system can be seen very precisely. The results are comparable to the one shown before using the other simulation method. Using this method, it is possible to see the structure of the acceptance. Especially the acceptance at the exit of the second toroid shows an unexpected and rare structure. But for the development of the injection system the monitor at the entrance of the second toroid (second row, first picture (Fig. 4)) is the important one. By using a kicker system, all ions which come to this point will be injected. Additionally a monitor in the center of the second toroid was positioned in this simulations. This one shows the acceptance of the injection system without a kicker system. These results will be used during the first experiments. At this time, no kicker system is available and two independent beams will be monitored. Later the ExB kicker will be implemented to combine the beams to get one final beam.

Using bender and the different analysis methods, a final geometry for the injection system was found and the necessary parts were developed. This final geometry will be used in future simulations. It has nearly the same dimensions (few millimeters longer injection channel) than the geometry used in the shown simulations. The main difference is that the height-adjustability of the injection tank can be used now.

THE EXPERIMENT

The injection experiment is under construction at the moment. The two injectors, the two filter channels [2], the two toroids, the end tank and the whole periphery (power supplies, high voltage terminals, etc.) are ready for use now [3]. The height-adjustable vacuum tank is under construction and the injection magnet was ordered and will be delivered at the end of the year. The detectors were built and will be tested during the next months. The construction of the experiment will be finished at the beginning of next year. In Fig. 5 the final layout of the injection experiment is shown.

THE NEW DETECTORS

For the measurement of the positions and the dynamics of the two ion beams, two new detector systems were developed and built. Detector Number One is a non-destructive detector using phototransistors to detect the fluorescence generated by the reaction of the beams with the residual gas. The phototransistors are positioned around the beams at the tube walls and look at the beams radially. The 92 signals are measured using an electronic system connected to a PC. The PC is used to calculate the beam positions and diameters. This type of detector will be positioned at different spots in the experiment and will also be built moveable to detect the beams at different positions. By comparison of the different results at different positions, the beam dynamics can be investigated.

The disadvantage of this detector is that it is not possible to detect beams near the wall of the tube. Such beams will hit the detector structure and can not be measured. For this situation a second detector was developed and built.

Detector Number Two is a destructive detector and was designed to measure the beams at each position in the vacuum tube, for example in front of the other detector. It can be positioned in front of the first detector if a beam near the wall is expected. The detector consists of 64 single Faraday cups (FDCs) with a suppression for secondary electrons.

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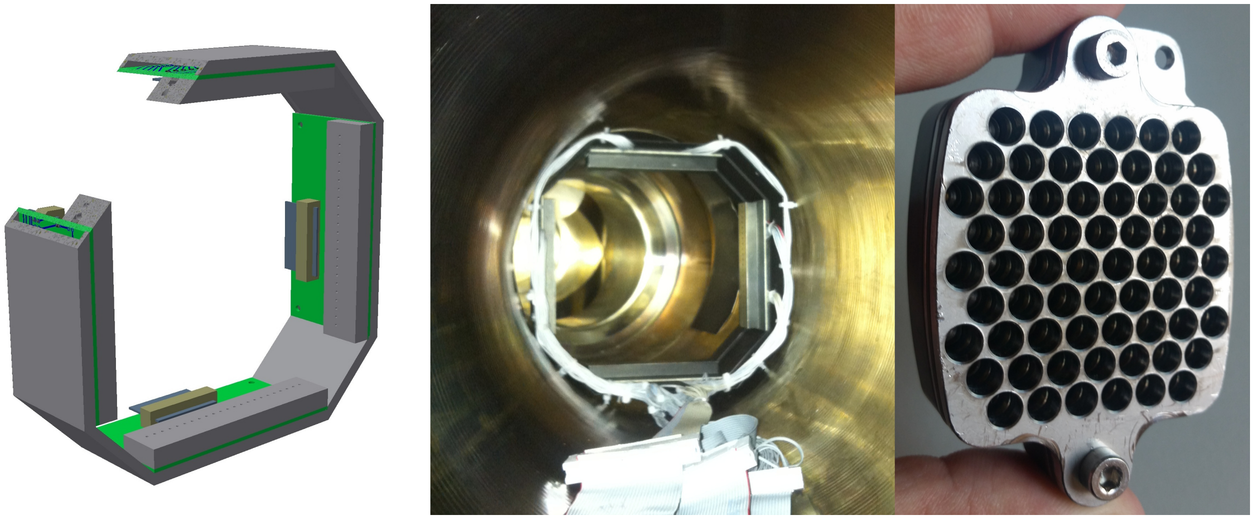

Figure 6: The left picture shows the layout of the non-destructive detector using phototransistors (Detector Number One). The middle one shows the non-destructive detector inside the first toroid. The right picture shows the destructive Faraday cup detector (Detector Number Two).

Each of the 64 signals will be measured independently by the same electronic system mentioned before.

Pictures of the detectors and the layout of the first one are shown in Fig. 6.

OUTLOOK

The scaled down injection experiment of the F8SR project is under construction at the moment. This step should be finished at the end of the year. After the setup of the injection system will be finished, the first experiments can take place. The offset of the injection channel, the magnetic fields of the magnets and the transverse positions at the beam injection are the main parameters which will be varied.

Future simulations will include the final geometry and the height-adjustablility of the injection system. Further analysis methods will be applied and different beam distributions will be used. Finally, a comparison with the measurements will be done.

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