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# CHALLENGES OF THE TECHNICAL LAYOUT OF THE SIS100 EXTRACTION SYSTEM

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## *Abstract*

The FAIR synchrotron SIS100 which is under construction will provide heavy ion and proton beams of high intensity with fast and slow extraction. All extraction devices, including an internal emergency beam dump system, are installed within one straight section. This way, expected systematic beam loss is kept in a relatively small area of the synchrotron. In this area, it is rather challenging to protect components against high radiation fields, to keep XHV conditions, and to allow for maintenance of highly activated components to assure reliable beam operation. In this contribution, the technical measures to fulfill the requirements for the extraction straight section of SIS100 will be presented. These include remote controlled devices to move apart magnet yokes for the purpose of placing beam pipe heater; dedicated star-shaped vacuum chambers with integrated collimators and NEG-panels to reduce pressure bumps due to lost particles behind the electrostatic septa; a high-power multi-stage vertical extraction septum including a variable horizontal deflection.

## ADJUSTMENT AND MOVING DEVICES

A part of the extraction area of SIS100 is exposed to unavoidable particle loss during beam operation [1, 2]. The origin may be due to ion beam halo or due to ion beam losses during slow extraction. These losses will mainly be deposited into a dedicated radiation resistant quadrupole magnet doublet [3]. These magnets will be highly activated. Hence, hands-on maintenance will be extremely difficult if not impossible. A particular challenge would be the handling of heating devices to re-establish the necessary XHV conditions inside the beam pipe after a vacuum break. For this reason an automatic device has been designed to drive apart the magnet and to position a heater box around the vacuum chamber, see Fig. 1. After the heating process has been finished, the heater box is removed and the magnets are automatically repositioned properly again. This special quadrupole doublet is located in cell2 of sector5 of SIS100.

The adjustment and moving device for these quadrupole magnets is rather challenging. It has to be very stable since each side of the magnet weights several tons. High rigidity is demanded since neither deformation nor torque is acceptable in order to assure reproducible movements and to withstand magnetic forces during operation. Lastly, in the final phase of closure the iron yoke and the coils have to match into the fits. Beyond that, the available space for this device is restricted to all sides by other installed equipment in the SIS100 tunnel.

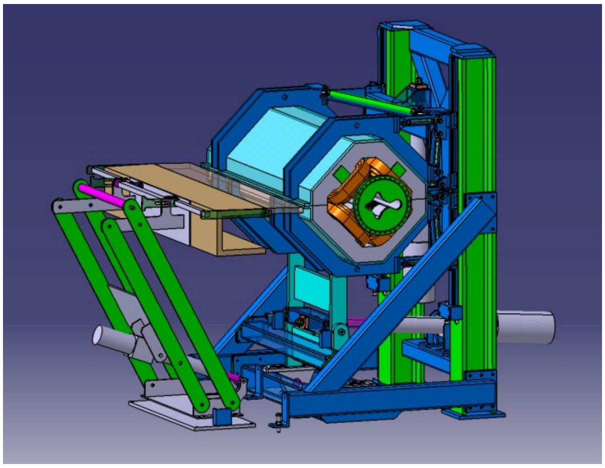

Figure 1: One radiation resistant quadrupole magnet in normal position hold by its adjustment and moving device; heater box on the left hand side in standby position. The vacuum chamber -beam pipe- is located between the coils.

The quadrupole magnet is symmetrically divided into an upper and lower part with a support structure around to absorb the forces during operation at high current, see Fig. 2. Each coil has to be installed separately in advance into one quarter of the iron yoke. The coil is mechanically fixed inside the mould of the yoke. Afterwards, two quarter of yoke and coil are mounted together via a thick sheet plate which itself is stabilized and held by reinforcement stirrups. The latter are connected to the main holding structure via suspension bars.

On the basis of the existing design, the final design and manufacturing of the adjustment and moving devices will be tendered. A careful adjustment and test phase of the whole assembly including the magnet has to follow the delivery before a fully automated routine operation can start.

Other radiation-activated devices which comprise special mechanics for baking out the vacuum chamber, either automatically or manually driven, are the injection and extraction septa, and the Lambertson septum.

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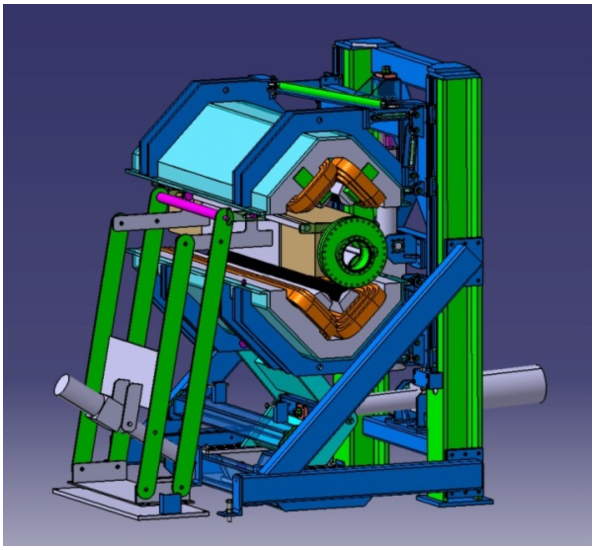

Figure 2: The quadrupole magnet opened with the beam pipe heater box in heating position.

## STAR-SHAPED VACUUM CHAMBERS

The vacuum system of SIS100 comprises in general either elliptical or round vacuum chambers. Along the extraction straight section, vacuum chambers with star-shaped cross-section are indispensable inside the first three quadrupole doublets. This special design, see Fig. 3, is necessary because the beam has to be deflected vertically over four cells in case of fast extraction or with a combined horizontal-vertical deflection over three cells in the case of slow extraction to achieve sufficient deflection strength [4]. During this beam manipulation particles largely leave the area of the circulating beam.

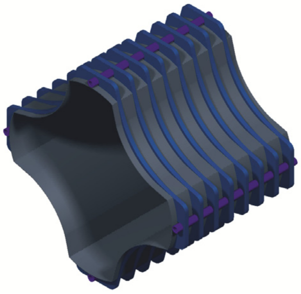

Figure 3: Star-shaped vacuum chamber.

Inside the radiation resistant quadrupole magnets discussed in the last chapter, the regular star-shaped cross section is modified on one side in horizontal plane. This distinguished side is downstream the electrostatic septum wires. Particles which hit the electrostatic septum wires during slow extraction are electron-stripped and scattered such that the following quadrupole magnets strongly deflect them out of the orbit, see Fig. 4.

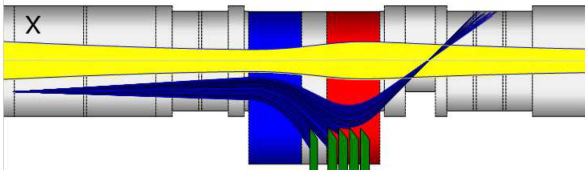

Figure 4: Deflection of lost particles inside the radiation resistant quadrupole doublet (blue, red) in horizontal plane. Trajectories of the circulating beam (yellow), particles (dark blue) which have interacted with the electrostatic septum wires and the subsequent collimation system (green).

These lost particles would mainly hit the vacuum chamber inside the quadrupole magnets leading to a cascade of secondary particles. This would cause pressure bumps degrading the lifetime of the beam and the achievable maximum beam intensity.

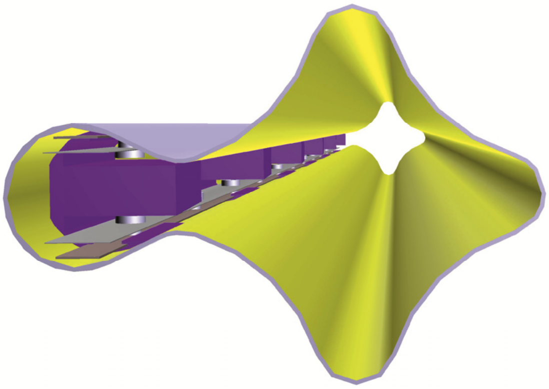

Figure 5: Star-shaped vacuum chamber of the radiation resistant quadrupole doublet with the anti-chamber at the left, comprising collimators (purple) and NEG panels (grey).

In order to minimize the creation of secondary particles, collimators are placed in series inside the vacuum chamber to assure a perpendicular impact of particles, see Fig. 5. In addition, they are coated with low desorption yield material. Both measures minimize pressure bumps, see e.g. [5]. NEG panels on top and bottom of the collimators add an effective pumping capacity [6] and may be re-activated thermally.

The efficiency of the collimation system with respect to lost particles is rather high, in the order of 80% for the reference ion $U^{28+}$. It is a function of the relative charge change of the lost particles and the collimator-to-orbit distance of the collimators. However, this distance cannot be chosen too small since the slowly extracted beam is close by.

It was a challenging task to stabilize the complex vacuum chamber geometry. The chamber wall has to be non-magnetic and thin to keep the high magnetic field homogeneous and suppress eddy currents. In order to further stabilize the vacuum chamber mechanically the outer part of the collimator is c-shaped.

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## INTEGRATION OF COMPONENTS

The integration of all technical subsystems of the extraction straight section in sector 5 of SIS100 has been performed by means of a 3D (CATIA) modelling. The following devices have been added recently and integrated successfully to complete all necessary components for beam operation: the knock-out-exciter, the BTF-exciter, the ion beam halo-scraper, the radiation resistant quadrupole doublet, and the internal emergency beam dump.

The extraction straight comprises many different components which are closely spaced. Figure 6 shows a part of cell 3 as example. Nearly all of the originally planned components have been revised to meet the requirements in position and in size, to allow for alignment purposes, for the connections inside and outside of the vacuum chambers, and to compensate the elongation during the bake-out of the vacuum chambers in order to achieve the necessary XHV conditions. Realistic solutions were implemented for all components at least up to a design stage which represents all technical requirements properly and therefore allows the completion of the final design by external contractors in a direct way.

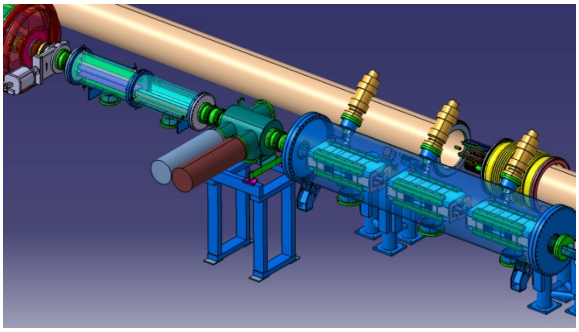

Figure 6: From left to right (part of cell 3): BTF-exciter, SEM grid and beam stopper, and triple kicker group. In the background the He-Bypass line can be seen.

Cell 4 of the extraction straight section comprises three extraction septa to apply the necessary vertical deflection strength to guide the beam into the high energy beam transport (HEBT) system. Special technical effort was devoted to septum 3, see Fig. 7. It will be operated at high magnetic field, up to 1.85 T for the vertically deflecting main field, and has a variable horizontal steering field in case of slow extraction of up to 0.5 T. If both fields are applied simultaneously, correction coils are indispensable to achieve a homogenous field distribution. The complex coil system is depicted in Fig. 7. The main coils, for the vertical deflection field, the steering coils for the horizontal deflection (green), and the correction coils (beige), are all guided in the necessary compact and independent way, maintaining the cooling water flow in the different coil sections.

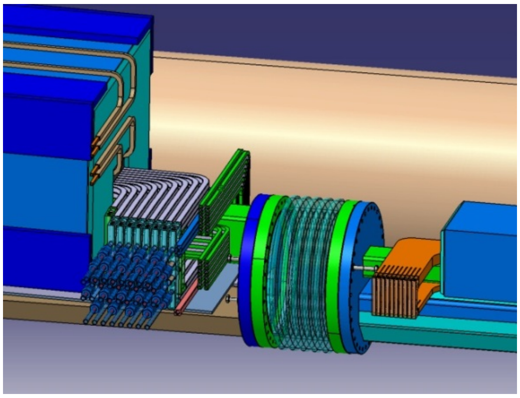

Figure 7: Detail of the crossover section between magnetic extraction septum-2 (right) and -3 (left). The bellow in the middle serves to compensate the elongation during the bake-out of the vacuum chamber and to adjust the septa in transverse direction.

An internal beam dump has been integrated in magnetic septum 3. It is placed on the bottom of the septum along a length of about 2 m to effectively dump the beam. It serves for emergency cases only. It is not meant for setting up the synchrotron. For this purpose a dedicated beam dump is foreseen in the HEBT system downstream of SIS100. A huge gate valve allows for the independent passage of the circulating and the extracted beam, see Fig. 8.

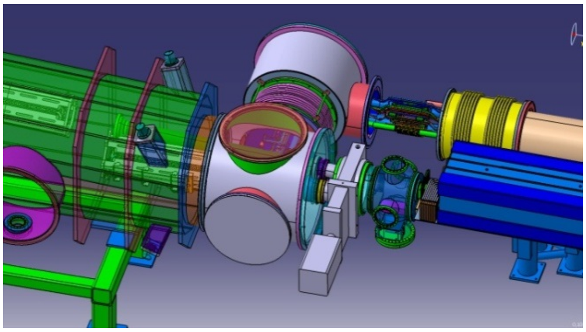

Figure 8: Crossover from septum-3 (right), via the vacuum gate valve into the feed-in-box (grey with flange) of the extractor cryostat (green, left).

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