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INJECTION AND EXTRACTION SYSTEMS OF THE SIS100 HEAVY ION SYNCHROTRON AT FAIR

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Abstract

The "Facility for Antiproton and Ion Research" (FAIR) is a new international accelerator complex, which is currently built in Darmstadt, Germany. Part of this complex is the SIS100 heavy ion synchrotron with a circumference of ~1086 m. To inject ions into the SIS100, an injection kicker system will we required. For fast extraction of the particle beam from the SIS100, an extraction kicker is used. This extraction kicker will be a bipolar system, to be capable of normal extraction or emergency extraction depending on the requirements. The fast kicker systems have to produce a current pulse >6 kA. To achieve this, energy storages are charged up to voltages >70 kV and are quickly discharged. The pulse durations vary from 0.5 µs to 7 µs, depending on the kicker type and the operation mode. Slow extraction of the ion beam will include an electrostatic septum, operating with voltages up to 160 kV. The requirements of these injection/extraction devices will be described in detail and the status of the projects will be presented.

INJECTION / EXTRACTION DEVICES

The injection and extraction devices described here will all be installed in the SIS100 heavy ion synchrotron at FAIR. Therefore all of them have to meet stringent vacuum requirements, operating at pressures in the very low 10^{-11} mbar range. To reach this vacuum level, the devices have to be baked out. This leads to a significant increase of complexity, because of the different expansion coefficients of all the materials in the vacuum chamber.

All systems have to be designed to be very reliable and allow easy maintenance. Since malfunctions can cause downtime of the complete SIS100, reasonable repair times are important.

Due to space restrictions, all designs have to be a compromise between compact design and reasonable operation voltages/currents.

INJECTION KICKER

The injection kicker system consists of 6 separate kicker magnets situated in one common vacuum chamber. To reach the required kick strength, each magnet must be supplied with a current of > 6 kA. The duration of the current pulse is between 0.5 µs and 2 µs. The rise time of the current has to be significantly below 180 ns.

The simplified electrical circuit for one injection kicker module is shown in Fig. 1.

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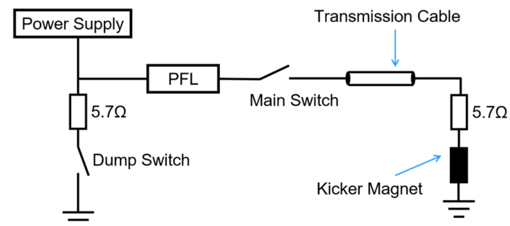

Figure 1: Simplified electrical circuit injection kicker.

As energy storage (pulse forming line - PFL), cables are used. Each cable is ~ 200 m long to reach the required pulse duration. As high voltage switches, 4 gap hollow cathode thyratrons, type CX2593X, made by Teledyne e2v [1] are used. To vary the pulse duration, the storage cables are connected on both ends to switches. On one end, the cables are connected via the switch to transmission cables and the magnet, on the other end, they are connected to ground via a termination resistance. The relative timing of the two switches defines the pulse duration.

While thyratrons may seem a bit old-school, the experience at GSI with these switches is quite positive, having some of them in operation for more than 20 years without a replacement.

As energy storage and transmission cables, Draka CPP20 [2] is used. It is a high voltage cable with a characteristic impedance of 17 ohms. By using 3 cables in parallel, an impedance of ~ 5.7 ohms is reached, corresponding to a current of > 6 kA at a voltage of 70 kV in the energy storage.

The system is built by the companies Research Instruments (RI) [3] in Dortmund, Germany and Danfysik [4] in Taastrup, Denmark. The set-up of the first of series module is shown in the picture below.

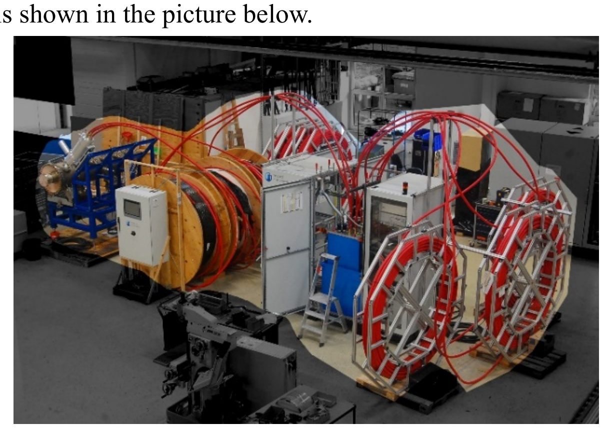

Figure 2: First-of-Series Injection kicker system.

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On the right front side of Fig. 2 the energy storage cables can be seen. Next to it is the pulsed power rack. It is connected via the transmission cables (in this picture on the wooden drums) to the kicker magnet in the vacuum chamber (left hand side of the picture, only one module installed). The pulsed power rack is shown in Fig. 3 and consists of 3 different areas. In the middle of the rack, 2 oil tanks with the thyratrons are situated (blue). On the right hand side, the controls, the supplies for the thyratrons and the HV power supply are situated. On the left hand side of the rack (behind the door) is a discharge circuit to safely discharge the whole system and isolating transformers to supply the main thyratron (floating on high potential).

Figure 3: Pulsed power unit - Injection Kicker SIS100.

ELECTROSTATIC SEPTUM

While the kicker magnets are used for fast injection/extraction of the particle beam into/out of the synchrotron, the electrostatic septum is used for « slow extraction ». During this extraction mode, not all the accelerated ions are extracted at once.

Basically, it consists of a high voltage cathode, charged to up to -160 kV and a series of very thin (100 µm), grounded wires that separate an area for the circulating beam and an area where particles are deflected to be extracted. This way, a certain amount of ions is taken out of the circulating beam and extracted out of the ring.

A clearing electrode system is used to reduce the effect of the penetration of the high electric field into the anode area. This penetration cannot be fully suppressed due to the distance of the grounded wires. The clearing electrodes can also be used as a kind of « pump » for stray electrons and ions in the area of the circulating beam.

The concept is sketched in Fig. 4 and an existing electrostatic septum is shown in Fig. 5.

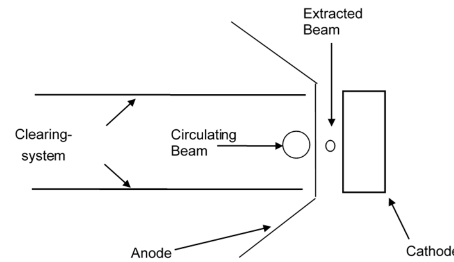

Figure 4: Concept of electrostatic septum.

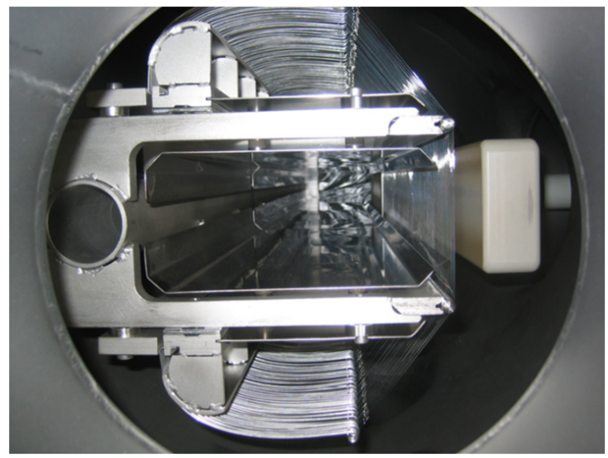

Figure 5: Existing electrostatic septum at GSI (SIS18).

Since the wires are rather fragile, springs are used to pull them out of the system if a wire breaks. The force of the spring has to be optimized, strong enough to ensure that the wires are straight also in the high electric field but are not ripped apart by the force. If a wire breaks, the spring will touch a contact that allows detection of broken wires. To keep the complexity of this detection reasonable, not each spring has its own detection, but there are a number of segments that are checked. While it is not possible to detect whether one or more wires in an area are broken, the information that there is a problem is usually sufficient.

The new septum will be significantly longer than the ones we are using at the moment. Therefore two sets of electrodes and wires will be used. They are situated in two vacuum vessels that are put on a common stand. All electrodes can be moved with stepper motors to optimize their angles and distances.

The system is currently built by Danfysik [4].

The two vacuum chambers on their stand with heating jackets are shown in Fig. 6 below. The total length of the system is ~5.7 m.

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Figure 6: Vacuum chambers of the septum.

EXTRACTION/EMERGENCY KICKER

A combined extraction/emergency kicker magnet system (EE Kicker) will be used to kick the beam either out of the ring to the experiments or, in case of an emergency, into a beam dump with a kick in the opposite direction. The required current is ~6.1 kA. The pulse duration has to be 7 µs to empty the SIS100 synchrotron. Such a pulse duration would be quite difficult with cables as energy storage, mainly due to the expected droop of the pulse. Therefore pulse-forming networks will be used. The magnet will be situated between two PFNs that are charged synchronous with the beam energy in the accelerator. This way, there is always the right amount of energy stored to perform a correct emergency kick. A simplified sketch of the electrical setup can be found in Fig. 7 below.

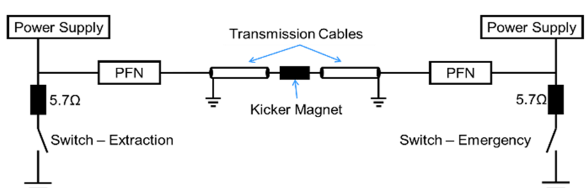

Figure 7: Simplified electrical circuit of the EE Kicker.

Depending on the required kick direction, either one of the thyratrons is triggered. The energy stored in the PFN next to the switch is wasted and the energy of the other PFN is used for the kick. This means, that the switches have to withstand 14 µs pulses.

The thyratrons and the transmission cables are of the same types as those of the injection kicker.

To achieve the required kick strength, a total of 8 separate magnet modules will be used. They are situated in 3 different vacuum chambers. Since the magnets are at high voltage for a long time, careful design is required to prevent electrical breakdown. Therefore, the whole magnet is supposed to be mounted in an isolating frame which achieves a floating potential of the magnet with respect to the vacuum chamber.

The design, that is sketched in Fig. 8, is at the moment finalized at Research Instruments [3].

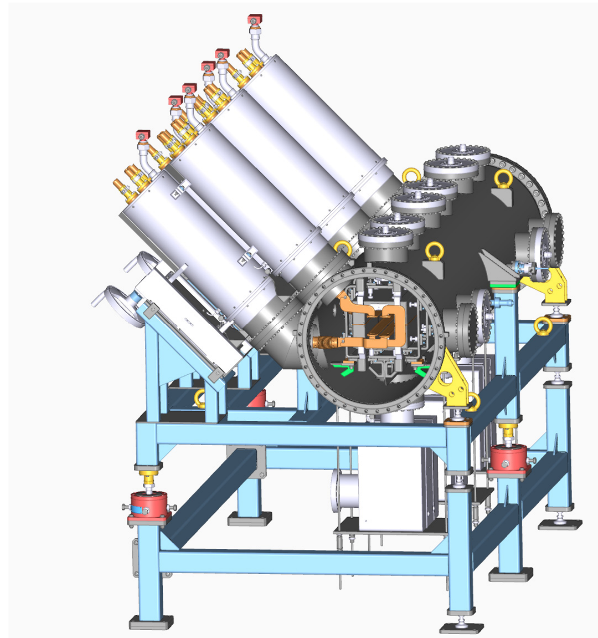

Figure 8: Design of one vacuum chamber with 3 kicker magnets.

SUMMARY

The described injection/extraction systems are being designed respectively built at the moment. While the basics of the systems are quite straightforward, the detailed design requires a significant research and development effort. This process is partly finalized but still ongoing for different aspects of the three projects.

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