DEVELOPMENT OF THE INJECTION- AND EXTRACTION SYSTEMS FOR THE UPGRADE OF SIS18*

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Abstract

SIS18 will serve as booster synchrotron for the proposed International Accelerator Facility FAIR [1] at GSI. The aim is to provide high intensity proton and heavy ion beams of e.g. U^{28+}-ions with a repetition rate of 2.7 – 4 cycles per second for injection into SIS100. The operation with low charge state heavy ions requires modifications of the injection and extraction systems. The goal is to minimize beam loss and thereby ion induced gas desorption during the injection and extraction processes. In order to increase the acceptance and for an injection at the reference energy it is necessary to build and install a new electrostatic inflector septum and a new inflector magnet.

INTRODUCTION

The existing inflector magnet and the electrostatic septum in SIS18 will be replaced completely by the end of the year. For these upgrades both components have been re-designed. The existing inflector magnet consists of two straight 4.5°- magnets, while the new inflector is built as a 9° sector magnet. The beam acceptance has been increased by a factor of 3. The vacuum chamber is bent and allows a bake-out temperature of up to 300° C by means of a permanent installed heating seal. Thereby the yoke must not be movable as in the existing inflector magnet. The existing high current power supply of the inflector magnet will also be replaced by a new supply unit with the same electrical parameters based on modern technical standards.

The electrostatic septum provides the final deflection of 43 mrad of the beam before injection into SIS18. The present electrostatic septum is designed and equipped with a 160 kV power supply. The new electrostatic septum has a larger aperture and will be operated with a higher electrical field strength. This demands a 300 kV deflection voltage with major consequences for the design. It is also equipped with a beam profile monitor and a moveable beam scraper to protect the electrodes. The operation at high field strength and bake-out temperatures of up to 300° C are achieved by means of new cathode surface treatment procedures, e.g. with pulsed high intensity electron beams. Alternative techniques like coating of alumina by a plasma spray technique have also been considered.

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DESIGN OF THE INFLECTOR MAGNET

The limitation of beam acceptance is given by the present inflector magnet in front of the electrostatic injection septum. The re-design has led to an optimised beam transport within the limited space between the transfer channel and SIS18 beam pipe. A further design goal was the permanent installation of the heating seal in the inflector magnet. To minimize the required aperture of the inflector magnet the heating seal consists of a very thin material (< 1.0 cm). Thereby, the mechanical design of the inflector magnet becomes simpler and the service time for the bake-out procedure can be shorted.

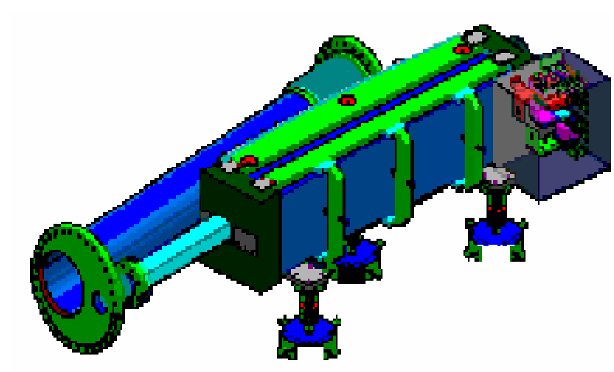

Figure 1: Sketch of the new inflector magnet (right) next to the SIS18 beam pipe (left).

Figure 1 shows a sketch of the new inflector magnet design connected with the SIS18 beam line. The required yoke length is 0.9 m with a magnet aperture of 78 x 60 mm. Due to the fact that the magnet is situated very close to the SIS18 beam pipe the magnetic shielding had to be carried out very effectively. The water cooled coils consist of 18 windings with a square cross section of 8 x 8 mm. The required current for the maximum magnetic rigidity of 4.5 Tm is 2200 A, which means a power consumption at DC-operation of about 79 kW. The maximal power for pulsed operation is 94 kW for a current rise of 22 kA/s. Completion of all mechanical parts, including vacuum chamber, as well as the high current power supply is scheduled for the end of the third quarter of 2007.

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Table 1: Main parameters of the new inflector magnet

Parameter	
# of Windings	18
Coil resister	18.87 mΩ
Inductance	0.635 mH
Current	2050 A
Field strength	0.75 T
Power consumption (pulsed)	94 kW

DESIGN AND IMPROVEMENTS OF THE ELECTROSTATIC INJECTION SEPTUM

At present, the maximum field strength of the electrostatic septum is not sufficient for injection of U^{28+}-beams at the standard energy of 11.4 MeV/u (today 7.1 MeV/u). In order to reach the required deflection angle, the electrical field strength must be increased from 50 kV/cm to 80 kV/cm at an extended horizontal channel width from 3.0 cm to 3.5 cm. In order to achieve the required field strength, the present 160 kV high voltage power supply needs to be replaced by a commercially available 300 kV DC power supply. The power supply unit is voltage controlled with automatic crossover current limiting. The 5 MΩ resistor is housed in an oil tank and able to support 300 kV. The resistor is connected with a 15 m long HV-cable to the septum tank. An additional 1 kΩ resistor is installed in front of the cathode inside the vacuum tank, which consist of a polished tungsten-rhenium wire with 0.1 mm diameter.

The design of the plug and 300 kV feed through must ensure that no pockets of air in the isolating liquid FC77 remain after filling. A further goal for the plug design was to minimize the electrical field strength.

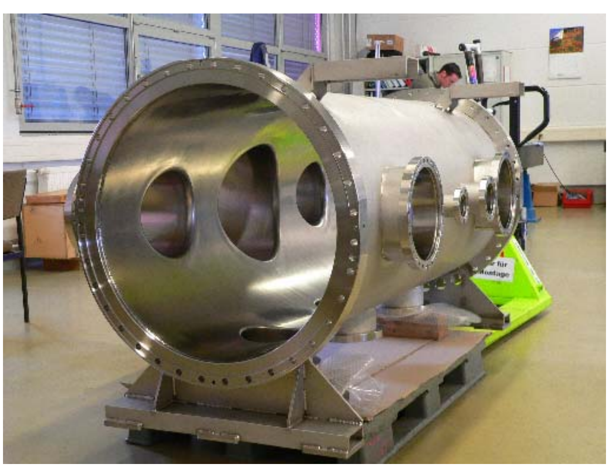


Figure 2: Electrostatic septum tank after manufacturing.

The cylindrical UHV chamber of 2000 mm length and 700 mm diameter is made of stainless steel 1.4301 [Fig. 2]. The material is annealed at 950° C for 3 hours under vacuum. The completely cleaned and assembled septum unit will be baked out at 300°C and pumped down to the design pressure 10^{-11} mbar by two Ti-sublimation pumps and an ion sputter triode.

At the typical injection energy of 11.4 MeV/u, heavy ions have a high specific energy deposition in matter, and thereby a high potential to damage the septum. The first 1/3 of the anode consists of thin tungsten-rhenium wires which are tightened by 290 springs. In case of a damage, the springs also have to pull out destroyed wires of the electrical deflection field.

Currently the electrostatic septum is not protected against beam loss in the injection channel. Additionally beam loss may occur inside the synchrotron if the deflection voltage is not stable over the injected beam pulse. These effects could be observed during operation with uranium beams with at the presently available peak intensities of $3x10^9$. In order to minimize the injection loss the horizontal beam position and profile shall be controlled directly in front of the injection septum. Therefore, a new horizontal beam profile monitor will be installed in front of the injection septum, as well a moveable scraper to protect the septum.

The septum is also equipped with clearing electrodes. They are mounted on insulators inside the anode hole and will be supplied with a maximum voltage of –10 kV. Clearing electrodes prevent secondary ions from diffusion into the high electrical field, where they may be accelerated to the cathode and initiate flashovers

Table 2: Comparison of the existing and new e-septum

	Existing	New
Max. Voltage	160 kV	300 kV
Field strength	50 kV / cm	80 kV / cm
Gap width max.	3.0 cm	4.0 cm
Back-able	Up to 150° C	Up to 300° C
Diagnostics	None	Profile monitor
Protection	None	Scraper

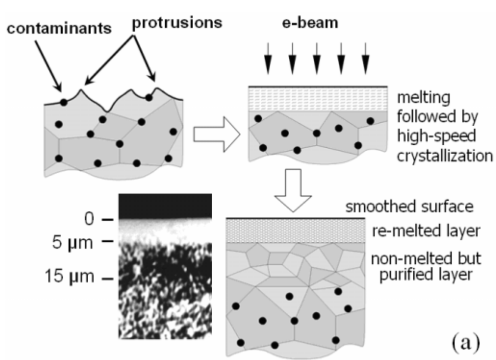
Table 2 summarizes the main distinctions between the existing and the new electrostatic septum.

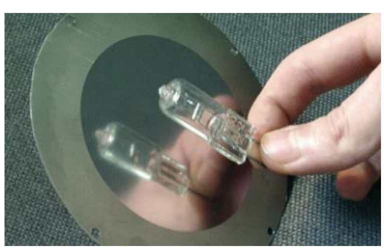
The new electrostatic injection septum has a cathode length of 1.5 m with an adjustable anode and cathode which enables a maximum horizontal channel width of 4 cm. The present cathode consists of stainless steel, coated with aluminium oxide which allows a maximum electrical field strength of 100 kV/cm at a gap width of 2 cm without significant flashovers during beam operation. Due to the kind of coating, the maximum temperature for the bake out process was limited to 150° C. However, this temperature is not sufficient to achieve the desired XHV vacuum conditions in the range of less than 10^{-11} mbar. Two different coating techniques, to achieve the requested bake-out temperature of 300° C, were under investigation. First a plasma spray procedure was used to treat a heated (500° C) aluminium cathode.

Thereby the cathode has been coated with an additional thin alumina layer. The maximum bake-out temperature could be reached, however the coating was damaged during HV conditioning. The application of pulsed electron-beams to smooth the cathode surface was substantially more successfully.

ELECTRON BEAM SURFACE TREATMENT

Electron-beam surface treatment (EBEST) has been investigated to suppress surface emission activity from the septum cathode, which may lead to electrical breakdowns. The method is based on melting a thin surface layer in vacuum by means of a pulsed electron beam [1]. This process is repeated in a series until most impurities are evaporated and the surface layer is purified. Short beam pulses result in further fast solidification of a thin melt above rather cold bulk. Resulting in a fine crystalline structure which distributes residual contaminants over much broader grain boundary and reduces the local concentration of impurities. Finally, beam shots in a series smoothes the treated surface and provides the polishing effect (Fig. 3).





(b)

Figure 3: (a) Sequence of processes under surface treatment by pulsed electron beam and (b) a beam mark on a titanium foil after a single beam shot.

An electron beam has to meet certain requirements to provide the treatment regime presented above. A beam should be of low accelerating energy to avoid deep penetration of electrons into bulk material and high-current at the same time to provide required energy surface density e.g. about 10 J/cm^2 for stainless steel. Furthermore, beam duration should not be too short to avoid the ablation treatment mode and too long to avoid loss of heat on account of thermal conductivity. All the above parameters were met eventually with use of low-energy high-current electron beams generated in plasma-filled vacuum diodes [2]. Electron beam polishing was proved to be an affective method for improving of vacuum insulation at short-pulsed (100 ns) [3] and pulsed microwave (50 ns wavetrains at several GHz) [4] electric fields. This gave sufficient reason to try that method for DC electric fields at septum. Preliminary experiments were performed with small-sized stainless steel electrodes (14 cm × 11 cm plane) and low voltage (up to 80 kV) to test the applicability of the method to DC vacuum insulation. Two EBEST gaps and a reference gap polished mechanically up to Ra = 0.05 µm were tested. Results are plotted in Fig. 4. EBEST gap points meet the fitting curve corresponding to the total voltage effect [5] when $E \times V$ = const. Extrapolation of the curve gives the hold-off level higher than 8 MV/m required for septum upgrade. The reference gap meets the above condition also, however, electron beam polishing has a better hold-off level and it is less expensive treatment when used on a series of cathodes.

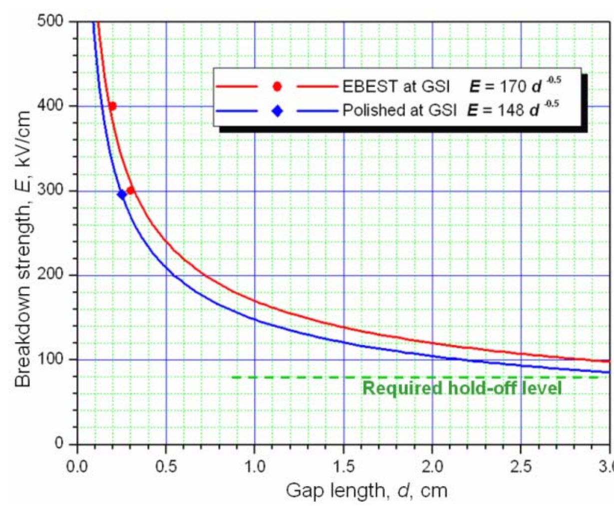


Figure 4: Results of DC breakdown tests for small-sized HV-gaps treated with different polishing techniques.

ACKNOWLEDGMENT

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