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Construction and Initial Tests of the Electrostatic Septa for MedAustron

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Abstract

For the MedAustron facility under construction in Wiener Neustadt/Austria, two electrostatic septa are built in collaboration with CERN. These septa will be used for the multi-turn injection of protons and ions, as well as for the slow extraction from the synchrotron. The power supplies are designed to combine the required precision with the capability to cycle sufficiently fast to keep up with the machine cycle. The septa are being assembled at CERN. Initial tests have been done on the remote displacement system to validate its precision and communication protocol with the MedAustron control system. Subsequently the septa are tested for vacuum performance and then HV conditioned. The construction of the septa, the requirements of the power supplies and the high voltage circuit will be described. Results of the initial laboratory tests, prior to installation in the accelerator, will be given.

INJECTION AND EXTRACTION CONCEPTS

The synchrotron is filled with protons or fully stripped Carbon ions at 7 MeV/u (Bρ = 0.383 Tm for protons, Bρ = 0.763 Tm for Carbon ions) with a multi-turn injection in the horizontal plane [1]. As the treatment of one patient is performed with one ion species only, it is expected that the particle type is changed only a few times per day. Hence there are no firm constraints on the dynamic behaviour of the electrostatic injection septum (ESI).

The extraction from the synchrotron is achieved with a betatron-core driven third order slow resonant extraction [2]. The extraction energy is given by the treatment plan, or experimental area needs, ranging between 60 – 800 MeV for protons and 120 – 400 MeV/u for Carbon ions ($B\rho_{max}$= 6.4 Tm). The treatment energy will change from cycle to cycle by up to 20 %, imposing a maximum rise and fall time on the electrostatic extraction septum (ESE).

SEPTA DESIGN

The principal parameters of the septa are shown in Table 1. The basic mechanical design of both septa is identical. The position of the septum foil (anode) and the cathode can be remotely adjusted. The septum is grounded electrically, while the cathode is connected to the High Voltage (HV) power supply.

Septum and Cathode

As described in [3], the ESI septum foil (and subsequently the cathode) is angled at 60 mrad, while the septum of the ESE is straight. The ESE septum is 30 % longer than the ESI. Both devices use the same HV feedthrough and mechanical supports for the septum and insulating rods for the cathode. The septa are made of Molybdenum foils, which are tightened on a stainless steel support frame (in which the circulating beam passes). By tightening the foils in successive steps, allowing the foils to settle (typically 1 day pauses between steps), an overall flatness of ± 70 μm was achieved. This means that the apparent thickness of the septum is smaller than 170 μm. The cathodes are made of solid Titanium to improve robustness and good vacuum compatibility.

Figure 1: Electrostatic extraction septum (ESE).

Remote Displacement System

The remote displacement system mechanics of both the septum as well as the cathode are located on one side of the vacuum vessel (Fig. 1) to provide sufficient space for the extraction line adjacent to the ESI. To reduce the design cost, the same layout is also used for the ESE.

The support of the septum is attached via 2 push-rods (up- and downstream) to screw jacks outside the vacuum vessel. These are driven by 3-phase motors via reduction gears to obtain precise positioning, without the need for motor drive regulation or additional brakes. By displacing both sides simultaneously a radial displacement of the septum is achieved. By displacing the upstream side only (for the ESI) the angle of the foil w.r.t. the orbiting beam is adjusted.

The mechanical displacement system of the cathode is mounted onto the septum displacement system. This implies that when the foil is displaced the gap width remains constant and there is no need for anti-collision electronics. A motor displaces via drive shafts 2 screw jacks acting on the insulating cathode supports to adjust the gap width. Since the remote displacement systems as well as the anode support guides are all mounted close to the same base plate, the alignment of the septum foil is far less influenced by deformation of the vacuum vessel when being pumped down.

Table 1: Principal Electrostatic Septa Parameters

	Injection (ESI)	**Extraction (ESE)**
Deflection angle [mrad]	60	2.5
Septum thickness [µm]	100	100
Gap width (min., max.) [mm]	25 (15, 35)	15 (10, 25)
Septum position w.r.t. orbiting beam centre (min., max.) [mm]	41 (31, 51)	35 (25, 40)
Cathode length [mm]	555	770
Septum length [mm]	660	860
V_{nom} [kV]	69.7	63.7

ELECTRONICS

Remote Displacement and Interlocking

The remote displacement electronics uses a SIEMENS® SIMATIC S7-300 "Failsafe" programmable logic controller (PLC) communicating to decentralised stations with safety modules via an integrated PROFINET and PROFIBUS-DP interface. The system has been developed to allow the safe treatment of end stop switches, the emergency management and the motor displacement. The motor is monitored and controlled by a SIEMENS® SIMOCODE module with integrated safety and standard functions.

In local mode the motors can be controlled via a touch panel, monitored, calibrated, the safety parameters can be adjusted as well. A local control box is available to allow control from the synchrotron hall (e.g. for maintenance). In remote mode, the system allows a SCADA application (PVSS) to control and monitor all functions.

Acceptance tests were done in the laboratory and showing the positioning system achieves a displacement accuracy of ± 50 µm and allows a synchronous movement of both, upstream and downstream, motors.

Power Supply

Both septa are powered by individual off-the-shelf primary switched power converters (PCOs) (Heinzinger PNC series) which provide (negative) voltages of up to 80 kV. An additional 150 kV PCO can be connected to each circuit for conditioning purposes. All PCOs are located in a dedicated area one floor above the synchrotron from where 40 m primary transmission lines lead to each septum. Both the PCOs and the septa side of the circuits are decoupled by 150 kΩ resistors to protect septa and PCOs in case of flash-overs. A short secondary transmission line (4 m) connects the decoupling resistor to the septum feedthrough. All PCOs, HV cables and resistors use industrial HV connectors (R24) and are designed for the full conditioning voltage of up to 150 kV. Electrostatic septa are generally DC devices, but this application requires adapting the field to change with the extraction energy on a cycle-to-cycle basis (1500 ms). The capacitance of the circuit plays an important role, as it mainly determines the system rise and fall times. By minimising the HV cable length to 40 m and customizing the PCO (incorporating a drain resistor) the 1500 ms fall time requirement is met without the need of any actively cooled PCO system or additional HV switches.

The PCO voltage accuracy, reproducibility and stability depend on the PCO nominal output voltage. For normal operation the used PCOs have a maximum voltage rating (80 kV) close to the operational voltage (Table 1) of the septa. In case of malfunction on these operational PCOs the conditioning PCO can be used as a spare with reduced performance. A PLC is used to control the PCOs via the analogue interface, while for conditioning purposes the PCO can be operated from its front panel in local mode.

Spark Detection System

Occasional sparking of the ESE/ESI can cause potentially poor injection or extraction stability or move the beam off orbit. Additionally, spark bursts (sparks at a high rate) can even damage the HV components under vacuum.

To detect a HV breakdown, a current transformer is installed near the HV feedthrough on the HV cable connector. Compared to OTS spark detection systems for HV power supplies, this design has the clear advantage of picking up spark signals without distortion due to HV cable and connector capacitances. The interlock logic is based on the acceptance of several sparks during a set time window to allow the ESE/ESI tanks vacuum to recover. The PLC based SDS interlock logic uses a moving average spark rate count to determine if the ESE/ESI performance is acceptable. Below a certain spark rate it is probable that the ESE/ESI septa tank vacuum can recover, thus avoiding transition into a state where rapid degradation would occur. Above this level an interlock is raised and the high voltage is automatically cut off. At the present, the interlock is used in monitoring mode, but after commissioning with beam it can be implemented into the system for machine protection purposes.

HIGH VOLTAGE CONDITIONING

To determine the high voltage performance before installation, the septa were conditioned in the laboratory. The aim was to determine the HV limits, locate the weak points prone to sparking and get an idea of the deconditioning after venting.

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ESI

Once the vacuum arrived in the 10^{-8} mbar region, conditioning was started. The septum foil was put in the position closest to the orbiting beam (furthest from the feedthrough), and the gap was opened to its maximum value. By limiting the current to 40 µA 130 kV was reached after some time. Subsequently the gap was closed to its minimum value and the device was conditioned with max. 60 µA. The first DC current was measured at 75 kV whilst sparking commenced at 95 kV. Finally 110 kV was reached; the vacuum had meanwhile degraded to 10^{-7} mbar. Subsequently the gap was increased to its nominal value and the first DC current showed up around 95 kV, and sparking above 115 kV. Finally, by increasing the maximum current for a short period to 300 µA, 130 kV was obtained; the DC current decreased to 4 µA at this voltage. The DC current totally vanished when the voltage returned below 120 kV. Finally the gap was increased to its maximum value again and 135 kV could be obtained without DC current. Allowing 400 µA for a short period provoked that the DC voltage fell to only 45 kV and even increasing the current to 800 µA didn't allow the situation to improve. At this point the gap was reduced to minimum and only 32 kV could be achieved at 200 µA. Conditioning was stopped until the next day for cool down.

The next day, with the HV components cooled down and vacuum recovered to 10^{-8} mbar, 120 kV was reached where conditioning started with current peaks of 400 µA. Swiftly 135 kV was obtained with 10 µA DC current, while 130 kV was maintained without any DC current. Vacuum has increased to 7×10^{-8} mbar. Finally the DC current as a function of the DC voltage was measured for different gap widths (Fig. 2).

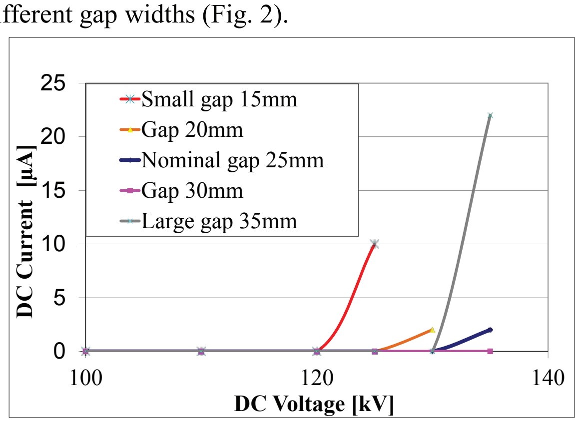

Figure 2: I = f(U) of ESI after conditioning.

What essentially can be retained from this process is that a current of 40 – 60 µA is needed to start conditioning. Although starting with a large gap is useful to decouple the different areas (around feedthrough and cathode supports vs. cathode/anode assembly), alternating between the areas is required to condition the whole device. When conditioning with this current range does not produce a voltage hold-off increase, a 10 times higher current limit may be used to burn off an electron emitting point, but at the risk of overheating the material, which needs several hours to cool down (more than 12 hrs in case of Titanium).

ESE

The ESE was conditioned in a similar fashion as the ESI. Since this device uses a straight cathode/anode assembly, the limits of the main gap field were tested as well for different anode/cathode gaps. With a 10 mm gap 7 MV/m can be achieved without DC current. Increasing the gap to 15 mm, a voltage of 100 kV can be achieved without current, as well as for a 25 mm gap. (Fig 3). This indicates that above 100 kV the limit is dominated by the feedthrough - cathode support assembly.

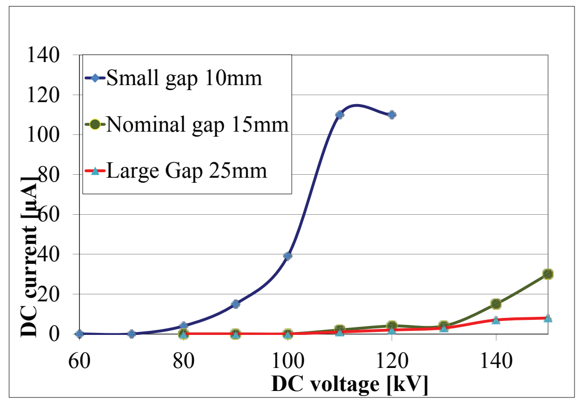

Figure 3: I = f(U) of ESE after conditioning.

After dismantling, the ESE showed effectively that most of the spark impact craters were located on the cathode facing the septum foil, but also at the cathode edges facing the vacuum vessel cover, in particular the race-track shaped opening for the beam inlet and exit.

CONCLUSIONS

The electrostatic injection and extraction septa have been designed and built. Subsequently both devices were conditioned successfully in the laboratory. The dedicated power supply for conditioning has proven to be specified with a sufficiently high output of 150 kV to condition devices such that the operational voltages can be achieved without any leak current. The re-conditioning after venting was rather straight-forward, indicating that temporary exposure to atmospheric pressure does not decondition the devices significantly.

Installation in the MedAustron accelerator and commissioning are planned for the second half of 2013.

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