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STUDYING X-RAY SPECTRA OF THE SIS18 ELECTROSTATIC SEPTA TO MEASURE THEIR ELECTRIC FIELD

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Abstract

The synchrotron SIS18 at GSI uses resonant extraction for slow beam extraction on the order of seconds. For some time, there has been an unexplained discrepancy of the slow extraction with a lower extraction efficiency than expected at the highest beam energies. Recent machine studies have indicated that the deflection by the electrostatic septum might be less than the nominal 2.5 mrad, leading to increased losses at the magnetic septum. In this paper we pursue an idea to directly measure the voltage of the electrode gap by utilizing the fact that dark current electrons accelerated in the gap of the electrostatic extraction septum generate Bremsstrahlung X-rays when hitting the anode. The high-energy cut-off of the X-ray spectra then corresponds to the voltage of the electrode gap. Measurements of the X-ray spectra at the extraction septum of SIS18 have been performed using a solid state CdTe detector. This technique provides an in-situ measurement of the voltage applied to the electrostatic extraction channel, and has proven to be a useful diagnostics tool.

INTRODUCTION

At the SIS18 synchrotron, at GSI, there are two electrostatic septa, one for injection and one for slow extraction, see Fig. 1. Both septa are of similar design, but are used with a different electrode distance and voltage [1]. The extraction septum at present has an 18 mm electrode gap and the injection septum a 35 mm gap. The electrostatic extraction septum is designed for a deflection angle of 2.5 mrad, which for particles with the maximum electric rigidity, 5.3 GV, is obtained at an electric field of 90 kV/cm. See Table 1 for a summary of the septa parameters.

For some time, it has been an open issue that the performance of the extraction electrostatic septum (ES) is not as expected, and higher voltage settings than nominal are required [2]. For particles close to maximum electric rigidity, high losses at the magnetic extraction septum have been observed, leading to low extraction efficiencies and high levels of activation.

Recent beam studies, presented below, also show that the deflection angle of the ES is about a factor of two smaller than expected theoretically. The question has therefore been raised whether the field in the ES-gap is correct, or if there is some other effect that has been overlooked.

Direct measurements of the voltage at the electrodes, in vacuum, under operating conditions, for example to monitor if there is a connection problem or a resistor is broken, is not trivial. In this study, we employ a method of measuring the voltage of the ES by analysing the energy distribution of the X-rays generated in the extraction electrode gap of the ES. This is a method which is used for voltage measurements in RF-cavities [3], but to our knowledge it has not been applied in the context of electrostatic septa so far.

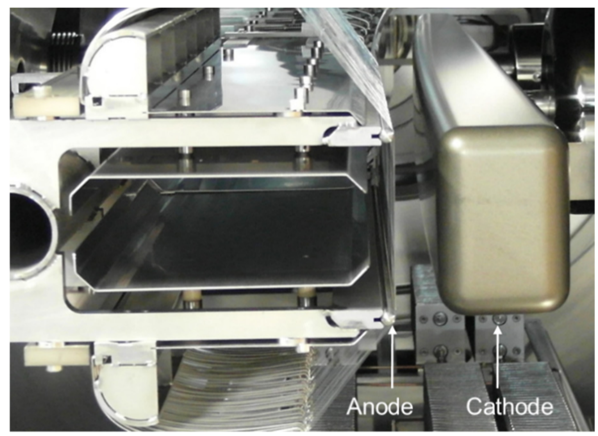

Figure 1: The electrostatic extraction septum in the beam direction with the anode wires and the cathode pointed out. The circulating beam area is to the left, and the extraction channel is to the right between the anode wires and the cathode.

Table 1: Parameters of the Electrostatic Septa

Cathode length	1.5	m	
Anode wire thickness	0.1	mm	W-Re
Electrode distance	10-40	mm	Horizontally
Max voltage	-160	kV	Extraction
Max voltage	-230	kV	Injection
Electric field, max	90	kV/cm	
Deflection angle	2.5	mrad	Extraction

X-RAY MEASUREMENT METHOD

X-rays are generated when electrons accelerated in the electrode gap hit the anode wires (or any other structures on ground potential). Electrons are generated at the cathode by field emission and then accelerated in the electrode gap.

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The main source of electrons is assumed to be field emission, but there may also be other sources such as ionization of rest gas molecules in the electrode gap or gas adsorbed at the electrode surfaces. The Bremsstrahlung X-ray spectrum is continuous with the maximum energy cut-off in the spectrum corresponding to the maximum electron energy, i.e. the voltage of the electrode gap.

The measurements of the X-ray spectra at the electrostatic septa were performed using a solid state detector, Amptek XR-100-CdTe [4]. Energy calibration was carried out using radioactive gamma sources, Am-241 and Eu-152, as reference.

The measurements were performed with the detector at the upstream flange of the electrostatic septum tank, where lower background due to activation is expected than at the downstream flange. The measurement set-up is shown schematically in Fig. 2, including the HV-supply and the protection resistors for dissipating the energy stored in the cable in case of discharges.

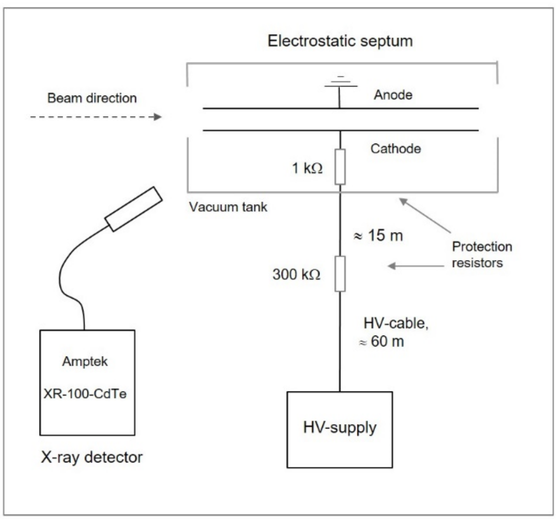

Figure 2: Schematic measurement set-up, with the X-ray detector at the upstream flange of the electrostatic septum.

RESULTS

Beam Studies of Extraction Septum

In this section we briefly present beam studies performed recently in order to quantify the deflection angle of the ES. In SIS18 the ES is situated in sector 4 and the magnetic extraction septum in sector 6, after about 240 degrees phase advance, and there is no diagnostics to directly measure the deflection of the electrostatic septum in the ring. Instead the beam position was measured at a viewing screen in the extraction channel after the magnetic septum. The voltage of the ES was changed in terms of the nominal, theoretically expected, deflection angle and the position at the screen observed, see Fig. 3. The expected value is 13 mm/mrad, and the measurements show a position change at the viewing screen of 7.4 mm/mrad, only about 55% of the expected value.

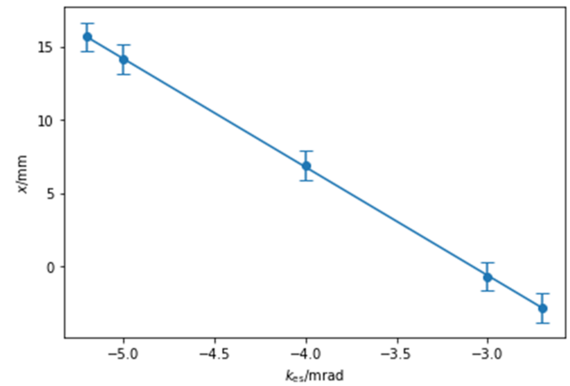

Figure 3: Deflection of beam by changing nominal extraction septum angle, as observed by beam position at a viewing screen after the magnetic extraction septum.

X-Ray Measurements

In this section the results of the X-ray measurements are summarised. Figure 4 shows the first measurement at the extraction septum for a setting of -160 kV of the HV-supply. As can be seen the high energy cut-off of the X-ray spectrum was about 98 keV, instead of the expected 160 keV. Figure 5 displays the spectrum at the injection septum, as a comparison. Here, the high energy cut-off was at 205 keV, well in correspondence with the HV-supply setting of -205 kV.

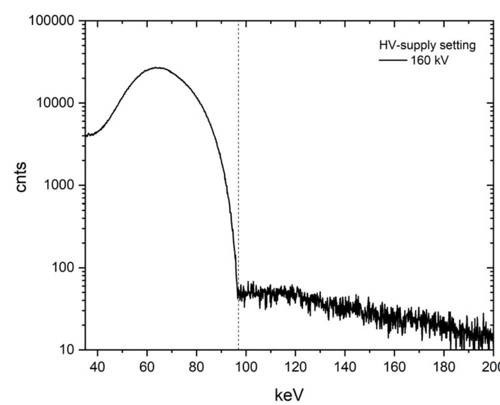

Figure 4: X-ray spectrum for the first measurement at the extraction septum. High-energy cut-off at about 98 keV.

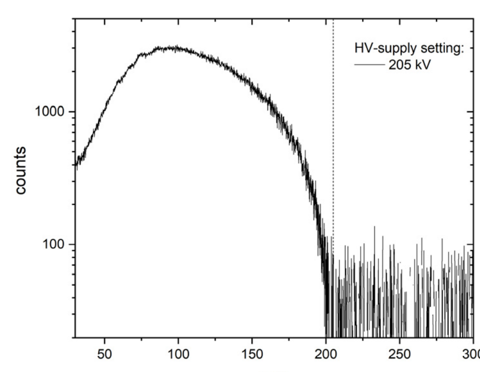

Figure 5: X-ray spectrum at the injection septum. The high-energy cut-off corresponds to the voltage setting.

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After the X-ray measurements, control measurements with a voltage probe off-line, revealed that the HV-supply for the extraction septum was defective and the supply was replaced. The measurements were repeated and it could be confirmed that the X-ray cut-off energy corresponded to the HV-supply voltage setting within 5%, see Fig. 6. A difference of 8 keV is observed, which will be investigated during the next beam shutdown period. The results of the X-ray measurements are summarised in Table 2. The table also shows the currents from the HV-supply and corresponding equivalent dose-rates at about 0.5 m distance from the upstream flange.

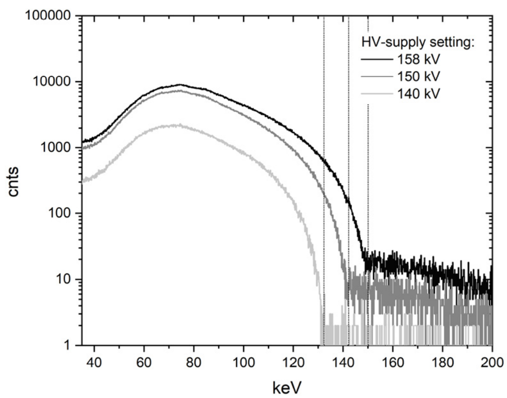

Figure 6: X-ray spectrum with new HV-supply, three different voltage settings.

Table 2: Measurement Results, Extraction Septum

HV readout (kV)	X-ray cut-off energy (keV)	Current (μA)	Dose rate (μSv/h)
140	132	20	25
150	142	30	70
158	150	60	150

Discussion

It is difficult to determine the cut-off energy exactly from the measured X-ray spectra, and we estimate the uncertainty to about ± 1 kV. Pile-up in the detector was one source of error, making background subtraction difficult. The adaptation of the measurement distance in relation to the X-ray intensity is important to reduce pile-up.

The main X-ray signal is due to Bremsstrahlung, but also some characteristic X-ray lines would be expected. Indications of characteristic X-ray emission can be seen at 59.5 keV in the spectra, which may be interpreted as characteristic X-ray emission from the anode wires (W Kα, 59.3 keV, Re Kα, 61.3 keV), but the low signal compared to the Bremsstrahlung level makes the interpretation ambiguous.

SUMMARY AND CONCLUSIONS

The measurements of X-ray Bremsstrahlung spectra from the electrostatic extraction septum showed that the voltage of the extraction septum was lower than expected, about 60 % of expected value (98 keV instead of 160 keV). This is consistent with recent beam studies, that the deflection angle of the ES is about 55% of what is expected theoretically. Measurements at the injection septum showed a good correspondence of the energy cut-off with the HV-supply voltage.

After the X-ray measurements indicated the problem, the error could be detected, and solved by replacing the defective high-voltage supply. Repeated X-ray measurements confirmed that the voltage of the ES was correct (within 5%, the discrepancy will be further investigated). It is not clear at the time of writing how long the HV-supply has been giving the incorrect voltage. The fact that the HV-supply of the extraction ES had already been fully replaced once during the lifetime of SIS18 led to the erroneous assumption that the HV-supply was not the problem, which triggered an extensive but ultimately unsuccessful investigation to find a possible other cause. With the new HV-supply, the extraction septum works correctly, resulting in significantly lower losses at the magnetic septum for nominal settings than before.

With the correct voltage delivered to the ES, the rate of high-voltage discharges in the extraction electrode gap has increased significantly, especially for operation with high intensities of heavy ions at maximum rigidity. While this did not come unexpected, it has been observed recently that conditioning as well as beam collimation are important components for reducing the discharge rate.

In conclusion, a long-term issue with the extraction septum seems to have found its solution and the X-ray method of measuring the voltage in-situ has proven to be a useful and relatively simple diagnostics tool for determining the gap voltage of the electrostatic septa.

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