

COMMISSIONING OF THE NEW GSI-CHARGE STATE SEPARATOR SYSTEM FOR HIGH CURRENT HEAVY ION BEAMS

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Abstract

A dedicated charge separator system has been installed in the transfer line to the GSI synchrotron SIS18, replacing charge separation with a single 11 degree dipole magnet after a 25 m beam transport section. This was not adequate to meet the requirements during high current operation for FAIR: it only allows for charge state separation of low intensity and low emittance beams. With the new compact charge separator system emittance blow up and undesired beam losses for high intensity beam operation will be avoided. Additionally, a new beam diagnostics test bench is integrated to measure beam parameters (ion current, beam profile, beam position, transversal emittance, bunch structure and beam energy) for the injection into the SIS 18 in parallel to the routine operation in the transfer line. Results of commissioning with high intensity argon beams as well as with an uranium beam will be reported. We acknowledge the support of the EU-Research Infrastructure Activity under the FP6 "Construction of infrastructure for the FAIR-project" (co.-number 515876).

INTRODUCTION

In the transfer line (TK) to the GSI synchrotron SIS 18 the beam is stripped to higher charge states in a carbon foil, if high final energies from the SIS 18 are required. The TK is operated at 3 Hz pulse to pulse mode at maximum, with beams of different ion species and intensities, with or without stripping. A high current U^{28+} -beam of 15 emA (FAIR requirement) has a power of 1.5 MW ($\leq 300\mu s$ pulse length). After stripping, undesired charge states with 85 % of the beam power must be separated and dumped. A newly developed stripper foil (with enlarged width) is loaded with 3 % of the beam power. To avoid evaporation in a single beam pulse, the beam is rapidly swept over its width of 55 mm. The UNILAC delivers beam emittances in the range of 5 to 20 μm , depending on the beam current. Emittance growth in the TK is caused by small angle scattering in the stripper foil, and by space charge forces, mainly in the

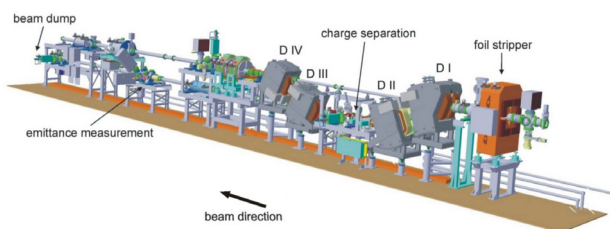


Figure 1: New charge state separator system integrated in the TK comprising the foil stripper, the four 35°-Dipole magnets (DI - DIV), and a beam diagnostics bench.

section between the stripper and the charge separator (see Fig. 1). To minimize emittance growth, a narrow, vertically elongated beam spot (4 mm · 20 mm) is prepared, and the distance to the separator is kept as short as possible. [1]

THE NEW CHARGE STATE SEPARATOR SETUP

The vertical magnetic bending system of the new charge state separator system consists of four 1.6 T-dipole magnets providing high resolution and a field homogeneity $\geq 99.97\%$. Each of the four 35° H-type dipole magnets (D I - D IV) has a bending radius of 1.1 m. The first two dipoles have the same vertical and horizontal aperture, as well as D III and D IV. Rogowski profiles at the beam entrance and the beam exit assure independence of the magnetic flux density (up to 1.6 T) from the effective magnetic length. The gyration number of each coil is chosen to make use of three equal power supplies (650 A/380 V); the last two dipole magnets (with reduced gap height) are operated in a serial mode. All coils are equipped with correction coils to compensate remaining fields. [2] With a beam diagnostic bench behind D III high current beam measurements are accomplished to prepare for the injection of high intensity heavy ion beams into the synchrotron. Besides ion current the beam profile and position, the emittance, the beam energy and the bunch structure can be measured. Additionally, beam focusing using a quadrupole duplet and the correction of beam positions is provided in the 12 m diagnostic line. [3]

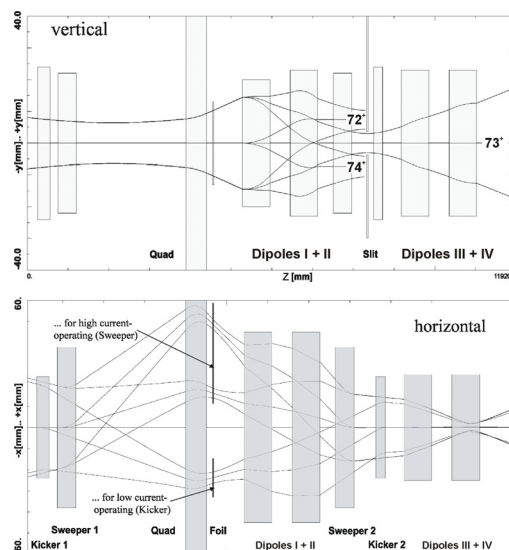


Figure 2: Beam dynamics layout of the new charge state separator system.

BEAM DYNAMICS LAYOUT

Beam envelopes [3] are shown in Fig. 2. Well focused beams, passing the stripper in horizontal off-axis positions, are bend back by a quadrupole magnet into the horizontally 90 mm wide gaps of the first two dipoles of the analysing system. The beams are realigned to the ion optical axis in a sweeper or a kicker magnet, respectively. In the vertical plane, the rather wide, divergent beam striking the stripper is charge states separated by the first magnet. Simultaneously, it is focused by the magnets upstream pole face rotation angle of -20° onto the analysing slit. Ions from neighbouring charge states hit the jaws of the slit and even the magnet chambers. These components were designed for a high thermal surface load and low radiation activation. The charge resolution $q/\Delta q$ is about 100. The slot width is 10 mm; the dispersion in this point is 7.5 mm/%. The dispersion of the complete system is zero.

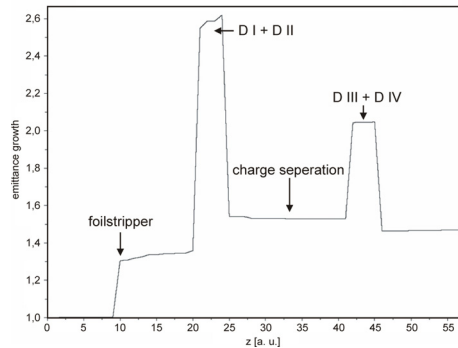


Figure 3: Vertical emittance growth in the charge separator.

PARMILA Transport simulations were performed to investigate the influence of space charge effects on the beam dynamics layout. As shown in Fig. 3 the vertical rms emittance increases by 50 %. Besides small angle scattering in the stripper foil, the emittance growth in vertical as well as in horizontal plane is caused by coulomb interactions.

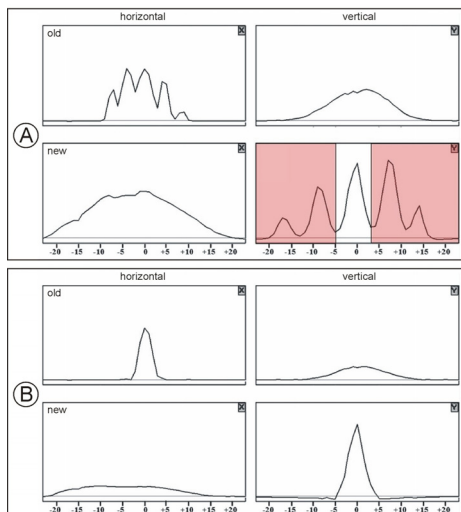


Figure 4: Measured uranium beam profiles with opened (A) and closed (B) separation slits.

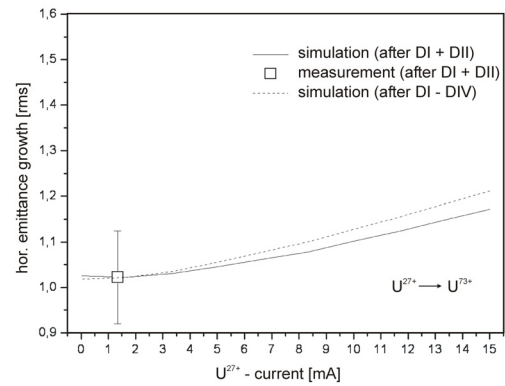


Figure 5: PARMILA Transport beam simulations for different uranium beam intensities; emittance growth measured for low and medium intensities.

COMMISSIONING RESULTS

After mounting the magnetic charge state separator and the beam diagnostics bench in the TK (December 2007), commissioning of all subsystems and components was performed until January 2008, followed by a three weeks period of beam commissioning with a high intensity $^{40}\text{Ar}^{11+}$ beam (7 emA) and a $^{238}\text{U}^{27+}$ beam with a beam intensity of up to 2 emA. The uranium beam was used to investigate the separation capabilities of the system. Fig. 4 shows the measured uranium beam profile inside the charge separator and at the position of former charge separation. For the new charge separator an improved charge resolution (factor of 2) is clearly visible, especially when the separation slits are closed.

The simulated horizontal rms emittance growth is presented in Fig. 5. Behind D II as well as behind the whole charge separator system the maximum growth factor is less than 20 % (for 15 emA). Emittance growth for low intensities is confirmed by measurements with a 1.5 emA U^{27+} -beam. High and low current argon beam emittance measurements were performed along the whole transfer line. As an example Fig. 6 shows measured transverse beam emittances behind D II. For the high current case the emittance is significantly increased in both transverse planes (65 % horizontally, 30 % vertically). When the beam is passing D III and D IV the dispersion becomes zero – the measured transverse emittance decreases significantly.

The space charge induced emittance growth is reduced to less than 10 % horizontally and less than 20 % vertically. The total horizontal normalized rms emittance was measured with 0.22 mm*mrad, meeting the FAIR-requirements. The beam transmission in the charge state separator system and the adjacent beam transport lines to the emittance measurement devices is close to 100 %.

Table 1: Measured $^{40}\text{Ar}^{18+}$ -beam Emittances (90 %)

$(4 \cdot \epsilon_{\text{rms}} [\mu\text{m}])$	high current		low current	
	hor.	vert.	hor.	vert.
behind D II	9,0	17,6	6,9	7,1
SIS injection	5,5	8,1	5,9	5,6

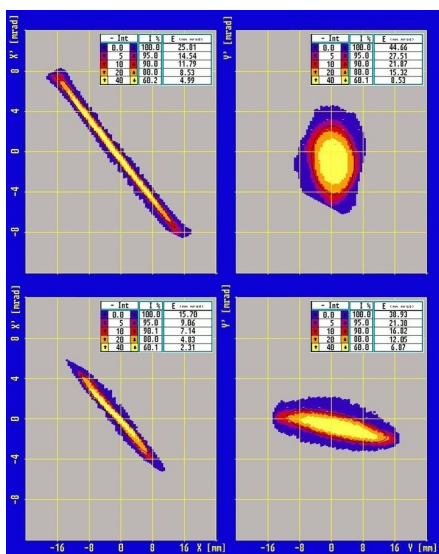


Figure 6: High (top) and low (bottom) current argon beam emittance behind D II.

Emittance measurements for low and high intensity argon beams were also performed for different stripper foil thicknesses. The equilibrium charge state distribution is reached for $400 \mu\text{g}/\text{cm}^2$. For this reason space charge induced emittance growth for high current argon beams hitting thicker targets is much higher as for the $200 \mu\text{g}/\text{cm}^2$ stripper foil. The $600 \mu\text{g}/\text{cm}^2$ foil is sufficient for the operation with heavy ions; e.g. U^{73+} is stripped

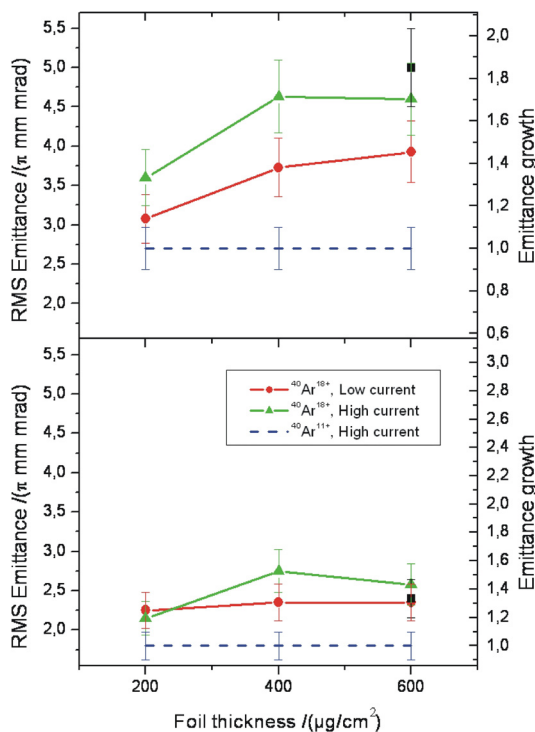


Figure 7: High and low intensity argon emittance measurements for different stripper foil thicknesses in horizontal (bottom) and vertical (top) plane; additionally measurements with U^{73+} ($600 \mu\text{g}/\text{cm}^2$) are shown in black.

with high efficiency (15%). For the argon beam additional emittance growth is measured, while the stripping efficiency stays constant. As simulated with the PARMILA Transport code the horizontal emittance growth is below 50% for low and high current, while the vertical emittance increases by 70%. In both transverse planes the space charge dominated beam transport from the stripper foil downstream to the first dipole magnet (D I), where charge separation reduces the space charge forces, increases the emittance area significantly.

SUMMARY

The new charge separator system was installed in the transfer line to the GSI SIS 18 in December 2007. After commissioning of all components, beam commissioning was performed successfully with a medium intensity uranium beam and a high intensity argon beam. The measured beam transmission is close to 100% for low and high current operation. For the high current heavy ion beam operation newly developed stripper foils of extended size are in use. The sweeper operation was tested with a high intensity argon beam as well as with an uranium beam. In general emittance growth is not induced by the sweeper devices. The stripping efficiency measured with the charge separator as a spectrometer is as expected. The improved charge separation capability was confirmed for heavy ions as well as for high current operation. Simulated and measured emittance growth effects for low current operation are caused by small angle straggling. Additionally, the vertical emittance inside the charge state separator is increased by dispersion. Space charge forces act in the short drift length between stripper foil and charge separation in D I only – the space charge influenced emittance growth is 10% (hor.) resp. 20% (vert.). The measured high current emittance potentially meets the requirement defined by the FAIR project [4]. We acknowledge the support of GSI expert divisions involved in the charge separator project.

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