HIGH CURRENT BEAM TRANSPORT TO SIS18

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Abstract

The optimized transversal and longitudinal matching of space charged dominated ion beams to the heavy ion synchrotron SIS18 is essential for minimizing injection losses. This paper focuses on the beam dynamics in the transfer line (TK) from the post-stripper accelerator of the Unilac to the SIS18. Transverse beam emittance measurements at different positions along the TK were done. In particular, the different foil stripping modes were investigated. A longitudinal emittance measurement set-up was commissioned at the entry to the TK. It is used extensively to tune all the rebunchers along the Unilac. In addition, a test bench is in use for measurements of longitudinal bunch profiles, enabling the monitoring of the final debunching to SIS18. Multi particle simulations by means of PARMILA allow a detailed analysis of experimental results for different ion currents.

INTRODUCTION

For the FAIR project the Unilac and SIS18 combination is foreseen to serve as an injector for the SIS100 [1]. To gain the envisaged intensities, up to 10^{12} U^{28+} particles/s must be injected from the Unilac into the synchrotron. To reach this number, different measures must be undertaken to achieve this goal.

Since the successful commissioning of the Unilac High Current Injector (HSI) the particle numbers for the heaviest ions have steadily increased due to constant machine improvement [2].

The high current within the 100 µs pulses offered by the HSI/poststripper accelerators must be transported via the 130 m transfer line (TK) to SIS18. The TK is divided into nine sections (TK1-TK9). A foil stripper in section three allows stripping to higher charge states for SIS18 injection, the charge state analysis is done by using dipole magnets in section 4; the beam is inserted during 20 turns. Typically the ions are stripped at a foil stripper in the TK for SIS18 operation. The ion beam may either be kicked, or in order to reduce the thermal stress, be swept over the foil. For the design ion uranium the charge state equilibrium changes from U^{28+} to U^{73+}. The beam can be manipulated longitudinally after the poststripper by two bunchers.

Table 1: Beam parameters required for SIS18 injection at 11.4 MeV/u.

$\varepsilon_{n,x}$ [mm mrad]	0.8
$\varepsilon_{n,y}$ [mm mrad]	2.5
$\Delta W/W$	$\pm 2\cdot 10^{-3}$

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For an optimum SIS injection both the transversal and longitudinal matching conditions have to be met (see table 1).

Until the end of 2003 the only available longitudinal diagnosis in the Unilac were the phase probe signals, and after a successful injection into SIS18 the Schottky analysis of the circulating beam on the injection plateau.

The TK is currently equipped with two transverse emittance measurement devices and one longitudinal emittance measurement device which was recently commissioned.

PARMILA SIMULATIONS

The multi particle simulations indicate different regions where further experimental investigations should be carried out and additional beam diagnosis elements should be installed. A full description of the beam transport line from the Alvarez accelerator section to the SIS18 injection point at the end of the transfer channel was compiled for PARMILA simulations [3]. After the Alvarez a single gap resonator is used as a rebuncher.

As an outcome of the simulations, the region after the foil stripper is identified as a beam transport line where strong space charge influences are expected. This is due to the approx. 25 m drift of the not yet analyzed multi-charge beam to the charge state separator. Thus, a comparison between the theoretically determined emittances at the exit of the Alvarez section, the stripper section and before SIS injection (see Fig. 1) can be performed. The installed beam diagnostic elements allow a comparison of simulations and measurement.

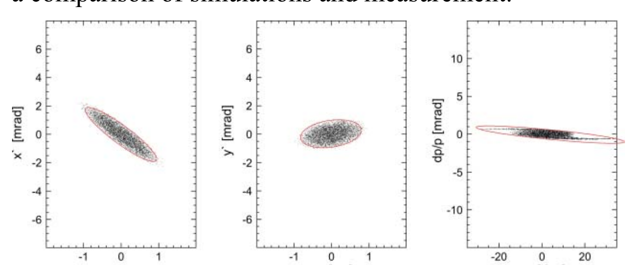

Figure 1: Calculated transversal and longitudinal emittances at the end of the TK.

TRANSVERSE EMITTANCE MEASUREMENTS

Machine development strongly focused on the systematic investigation of emittance growth along the whole Unilac. The results from the last campaigns during 2003 and 2004 are presented here [4]. Two ion species – uranium and argon - delivered by the HSI were investigated. The uranium beam was produced in a MEVVA ion source, whereas argon beam was delivered by the MUCIS. The transverse emittance measurements were carried out behind the Alvarez exit, the foil stripper where the two different modes (kicked - TK5-Ki - and sweeped - TK5-Sw) were analyzed, and in TK8 (for sweeper mode) before the SIS18 injection.

To determine the emittance growth due to the space charge effects, measurements were done with full and reduced intensity. The attenuation was done by reducing the gas stripper pressure behind the HSI. This method ensures that there is no influence on the emittance size before the Alvarez entrance. The conditions for the beam envelope at the TK-foil-stripper are a waist in the horizontal plane and a broad beam in the vertical one.

In high current uranium operation the kicker mode cannot be used as the foil would be destroyed due to the thermal stress, no measurement was performed in the TK8 region.

The 90 % normalized emittances for low and high current argon and of uranium beams respectively are shown in Fig. 2. The upper part displays the results for the horizontal plane and those for the vertical plane are shown in the lower part.

For comparison the green line indicates the acceptance of the SIS18.

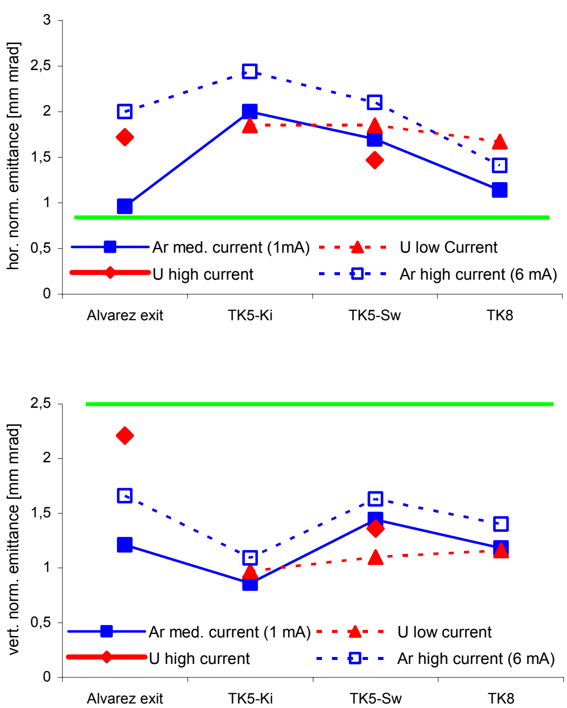

Figure 2: 90 % normalized transverse emittances along the TK. All measurements were performed at an energy of 11.4 MeV/u. Intensities are given for Alvarez exit.

For the horizontal plane an emittance growth is visible between the Alvarez exit and stripping region, whereas a slight size reduction in the vertical plane is detected. This observation can be explained by the strong space charge forces after the foil stripper, where the separation has not yet taken place. Thus a strong coupling between the horizontal and vertical phase space is established.

If the emittances for the two argon intensities are compared a much stronger influence of the space charge forces can be detected for the 6 mA case.

The emittance decrease in TK8 is explained by losses between TK5 and TK8.

LONGITUDINAL EMITTANCE MEASUREMENTS

Next to the transverse emittances the knowledge and tuning of the longitudinal beam parameters is crucial for an optimisation of the matching to the SIS. The phase probe signals have proved not to deliver sufficient information to tune the two bunchers after the Alvarez exit. To gain the necessary information at the entrance of the TK, a longitudinal emittance measurement was installed at the end of 2003.

The schematic layout of the configuration is shown in fig. 3.

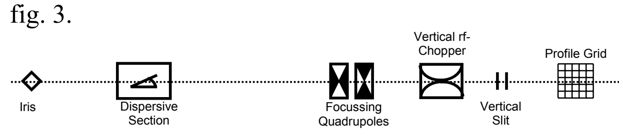

Figure 3: Schematic layout of the longitudinal emittance measurement. For explanation see text.

The insertion region in the transfer channel with its three dipole magnets provides the dispersion needed to monitor the energy spread of the beam. To get a sufficiently small focus in the transversal analysis plane, a rhomb aperture with a typical radius of 1 mm transversally trims the beam which then drifts through the dispersive section and is focussed with a quadrupole doublet. To gain information about the phase distribution a 108 MHz rf-chopper was installed behind the third dipole at the beginning of the focussing drift section. The chopper is used to deflect the beam vertically, corresponding to its phase dispersion.

Simulations (see Fig. 4) for the theoretically achievable resolution ($\Delta p/p = 2.7 \cdot 10^{-4}$, phase dispersion 1°) were done with MIRKO [5] and could be confirmed during the commissioning of the device.

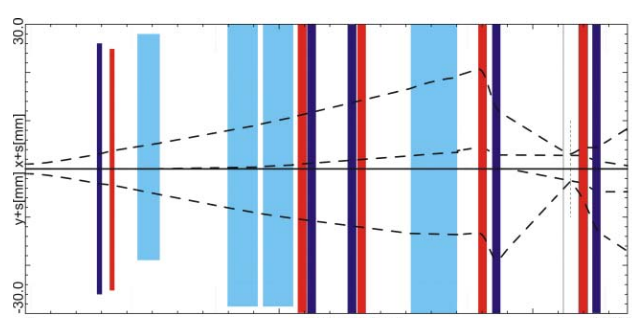

Figure 4: Theoretical simulation of transversal beam envelopes for longitudinal emittance measurement. (Colour scheme red/dark blue: focussing/defocussing

quadrupole, light blue: dipole, dotted line: envelope in x and y)

The analysis of the horizontal plane of the profile grid gives the information about the momentum spread, bunch length, and orientation of the longitudinal phase ellipse. So far only one measurement of the ellipse was possible, but the calibration of rf-chopper amplitude has not been done yet, so that a full evaluation of the emittance size could not be performed.

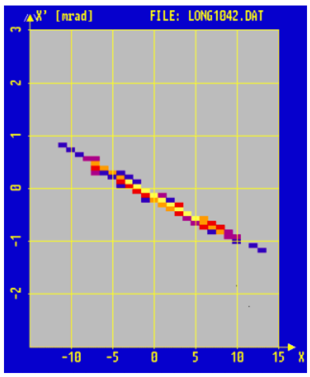

Figure 5: Result of a longitudinal emittance measurement.

Thus Fig. 5 shows in arbitrary units the phase width on the abscissa and the momentum spread on the ordinate. The theoretical limit for the resolution could not be reached in that case, as the opening diameter of the iris was 2 mm. Thus more than one wire on the profile grid was hit. To transform the measured data into values to determine the emittance size, the calibration of the buncher has still to be done.

First commissioning experiments promised that even without measuring the full emittance, this measurement device is a very helpful tool to set up the rebuncher correctly. The information gained at this point (after the first rebuncher) can be used to be fed into a simulation that gives the correct setting for the second buncher.

A viewing screen is planned to substitute the profile grid, to have an instantaneous picture of the longitudinal emittance and to tune online the beam properties with the rebuncher after the Alvarez exit.

LONGITUDINAL BUNCH PROFILE MEASUREMENT

To gain further longitudinal information just before the injection into SIS18 a bunch shape measurement [6,7] will be installed in the TK8 region. This detector is capable of determining non-destructively the bunch structure in the range of 0.1 to 5 ns as it uses the time spectra of secondary electrons created by residual gas interaction. The time spectrum is transformed into a spatial separation by an rf-deflector driven by the main acceleration frequency. A multi-channel plate equipped with a phosphor screen is observed by a CCD camera. The achievable time resolution is 50 ps, which corresponds to 2° for the 108 MHz acceleration frequency.

To reconstruct the longitudinal emittance, the voltage amplitude of the buncher cavity is varied and the bunch length is measured correspondingly. A parabola is fitted through the square of the bunch width and gives then an estimate for the emittance.

First successful test measurements in the Experimental Hall of the Unilac were performed for different ion beams at 11.4 MeV/u.

CONCLUSION AND OUTLOOK

The multi particle simulations indicate the critical regions for the beam transport in the transfer line to SIS18. These regions are already or will be equipped in the near future with additional beam diagnosis devices. To overcome the strong space charge forces after the foil stripper, a new compact charge state separator [8] with the separation directly behind the foil is foreseen.

The determination of the transverse beam emittances along the TK is sufficient. The measured transversal normalized emittances for space charge dominated beams are in the region of 1.5 mm·mrad for both planes. For zero current beams the emittances fit very well to the SIS18 acceptance.

To obtain full benefit from the transversal and longitudinal emittance measurement devices, a concept for an operating instruction will be developed. The transverse emittance measurements are applied to an online MIRKO simulation of the TK (after the foil-stripper) which should allow a good matching to the required parameters for SIS18 injection. The longitudinal properties of the beam will be tuned independently of the Schottky diagnosis in the SIS18, by especially setting up the beam line automatically for the measurement of the longitudinal emittance at the entrance of the transfer line. The result of this measurement will then be used to tune the second buncher.

There is strong expectation to improve significantly the matching to SIS18 and prepare the Unilac operation for the FAIR facility.

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