SPACE CHARGE DOMINATED BEAM TRANSPORT IN THE 1.4 MeV/u-UNILAC-STRIPPER SECTION

W. Barth, J. Glatz, J. Klabunde and U. Ratzinger
GSI, Planckstraße 1, 64291 Darmstadt, Germany

Abstract

The intensity upgrading program for the GSI accelerator facility comprises major modifications of the UNILAC for its operation as a high current injector into the heavy-ion synchrotron SIS. This paper focuses on space charge effects arising in the stripper section at 1.4 MeV/u between a new 36 MHz preaccelerator (under construction) and the existing Alvarez structures.

In this section the charge states of incoming ions, having a mass-to-charge ratio of $A/q \leq 65$, are increased by stripping in a nitrogen jet to allow further acceleration at $A/q \leq 8.5$. The anticipated high current beam of e.g. 4 pmA uranium will experience considerable space charge forces, most severely after the charge state jump in the stripper (from 4^+ to an average charge state of 28^+ for uranium).

The associated emittance growth has been studied for the present transport section, it was found to depend strongly on the underlaying particle density distribution. The amount of ‚useful' beam remaining within given emittance limits will be discussed.

Introduction

The goal to fill the SIS up to the space charge limit requires beam intensities of up to 15 emA ($^{238}U^{4+}$) in the UNILAC prestripper section. [1] The necessary replacement of the present Wideröe accelerator by a high current RFQ and two IH-type cavities will be realized in 1998. The beam transport at 1.4 MeV/u and matching from the exit of the IH-tank to the gas stripper, charge state separation after stripping and matching to the existing Alvarez poststripper linac, all under space charge conditions, have been studied.

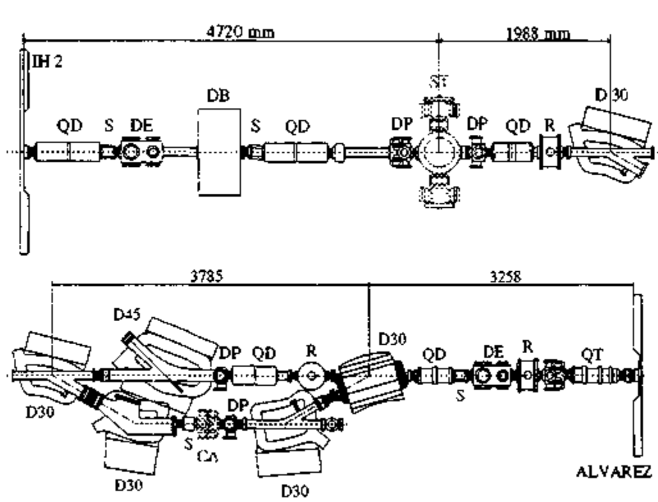
Table 1: Parameters of stripper section for uranium

	Exit of IH	Stripper to charge separation	Entrance of Alvarez
Mass	238		
Charge state	4	28 (mean)	28
Current	15 emA	105 ... 12.5 emA	12.5 emA
Energy (v/c)	1.4 MeV/u (β=0.054)		
Bunch frequency	36 MHz	36 MHz	36 MHz
Phase width	±6° (a)	±25° (b)	±6° (c)
Energy spread	±0.2% (a)	±1.7%	±1.8% (c)
Horizontal emittance	11 π·mm·mrad (90%) (a)		15 π·mm·mrad (c)
Vertical emittance	11 π·mm·mrad (90%) (a)		22.5 π·mm·mrad (c)
Relative space charge force (d)	1	50	6

(a) Present result of particle dynamics calculations in RFQ and IH
(b) Chosen for low emittance growth
(c) Upper limit, defined by the acceptance of SIS
(d) For identical bunch dimensions

As the present length of the stripper section may be maintained in the future, the study has to resolve if the existing installation, modified as shown in Fig. 1, is capable of high current operation. Emphasis is given to the study of emittance growth as the SIS poses limits; the acceptance of the poststripper Alvarez section is uncritical. Table 1 summarizes the beam parameters at the IH exit, at the gas stripper and at the entrance of the Alvarez structure.

UNILAC stripper section as studied for high current beam transport



D30	30° bending magnet	QD	Quadrupole doublet
D45	45° bending magnet	QT	Quadrupole triplet
DB	Six gap debuncher (108 MHz)	R	Rebuncher (36 MHz)
DE	Emittance measurement device	S	Steerer
DP	Diagnostics	ST	Gas stripper
CA	Charge analysis		

Fig. 1. Optical elements and beam diagnostic devices in the stripper section between IH2 exit and the Alvarez accelerator, including the gas stripper ST and the charge analysing system of four dipoles D30.

The mechanical layout of the stripper section is shown in Fig. 1. Two quadrupole doublets and a six gap rebuncher (operating frequency 108 MHz) are provided to match the beam to the gas stripper. The charge separator is composed of four 30° bending magnets, charge separation is required between the second and third dipole at maximum dispersion. Transverse and longitudinal matching to the poststripper linac is done with a quadrupole doublet, a triplet and two 36 MHz rebunching cavities.

Matching to the gas stripper

Due to the beam current jump in the stripper (e.g. 12 mA to 105 mA) the downstream section up to the charge analysis is heavely space charge loaded (see Table 1). By iterative calculations reasonable beam properties at the gas stripper were found, which allow the beam passage through a 9 mm aperture, minimize emittance growth and account a larger growth value to the vertical plane as allowed by the SIS acceptances (Table 1). As a consequence a bunch width of ±25° (36 MHz) at the stripper is demanded and beam waists are to be located before resp. after the stripper in the vertical resp. horizontal plane.

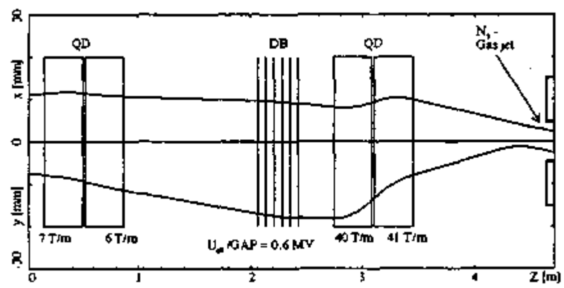


Fig. 2. Transverse matching to the gas stripper, calculated with the code MIRKO. [2] Notations see Fig. 1.

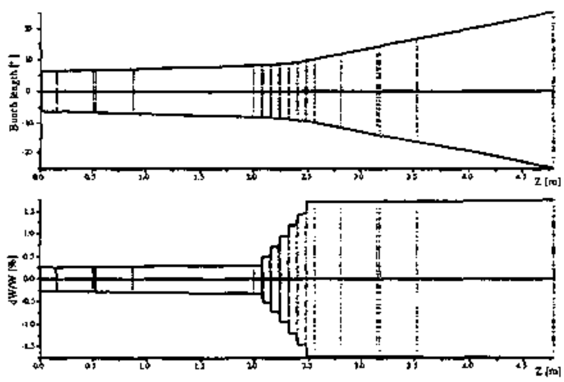


Fig. 3. Long. matching to the gas stripper, calculated for a KV-distribution with PARMT.

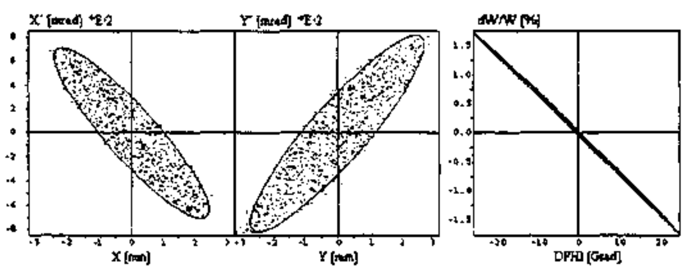


Fig. 4. Transverse KV- and longitudinal homogenous phase space distribution at the stripper position corresponding to the in- and output beam parameters of Table 1.

The envelope matching to the gas stripper including space charge forces is shown in Fig. 2. The required bunch length is obtained by transforming the beam to an energy spread of ±1.7% in the six gap structure with gap voltages of 0.6 MV. Quadrupole strength up to 12 T are required due to the magnetic rigidity of the beam of 10 Tm.

Emittance growth in this section is below 10 % for all planes and different particle distributions. A KV distribution remains virtually undistorted (Fig. 4).

Charge separation and matching to the poststripper linac

In the section from the stripper to the entrance of the Alvarez accelerator the electrical beam current is reduced by the charge state separation (from 105 mA ^{238}U of average charge state 28 to 12.5 mA $^{238}U^{28+}$). An exact modeling of the space charge effect in the separation process, not yet possible with existing tools, was approximated by a current jump before the second dipole magnet. The transverse and longitudinal beam envelopes are given in Fig. 5 and Fig. 6.

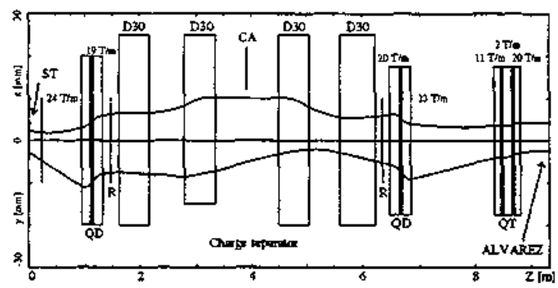


Fig. 5. Transverse beam dynamics between the stripper and the entrance of the poststripper linac (notations as in Fig. 1).

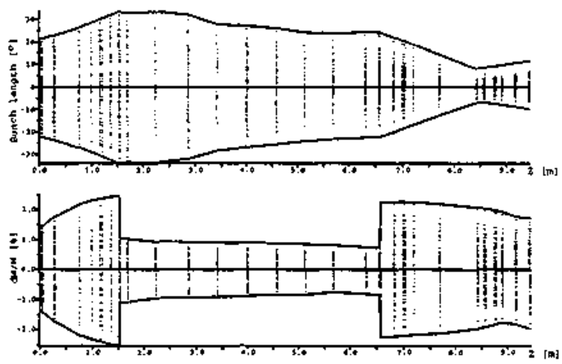


Fig. 6. Longitudinal beam dynamics between the stripper and the entrance of the poststripper linac.

Growth of energy spread by space charge force after the stripper is obvious in the plot of the particle dynamics calculation. The bunchers are required to limit the initially large phase width growth and to produce short bunches at the Alvarez entrance.

Emittance growth effects

The charge separator is an achromatic system and the stripper gas jet density of 4µg/cm^2 is too low to induce significant energy or angular straggling. Therefore the emittance growth is dominated by space charge forces.

As an example the horizontal rms-emittance growth along the beamline is shown in Fig. 7, calculated with a KV-distribution and a more peaked distribution (homogenous in a six dimensional hyperellipsoid folded with a Gaussian and cut at 3σ) on the basis of particle-particle interaction. The apparent emittance growth by dispersion is compensated behind the magnet system, leaving the current and distribution dependent space charge effect. For low intensities the net emittance growth is zero.

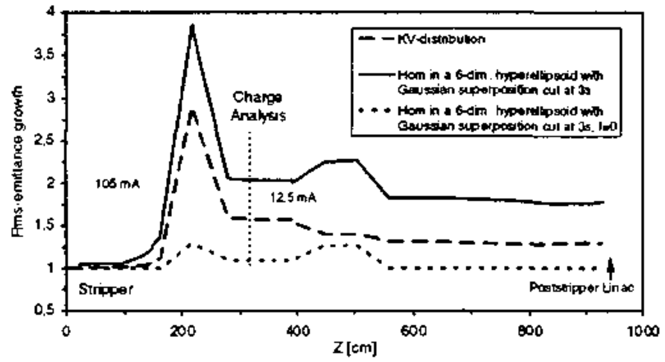


Fig. 7 The rms-emittance growth after stripping for three different distributions calculated by PARMT.

Starting with different particle distributions, which all hold 90 % of the intensity in emittance areas as given in Table 1, the rms emittance values at the end of the stripper section have been calculated for the three phase planes.

Fig. 8 is a summary of the results. Type 2 is a homogenous distribution in a six dimensional hyperellipsoid. The distributions 12 to 42 have increasingly intensified cores, which result in increasing emittance growths by up to a factor of 2 compared to the homogenous distribution.

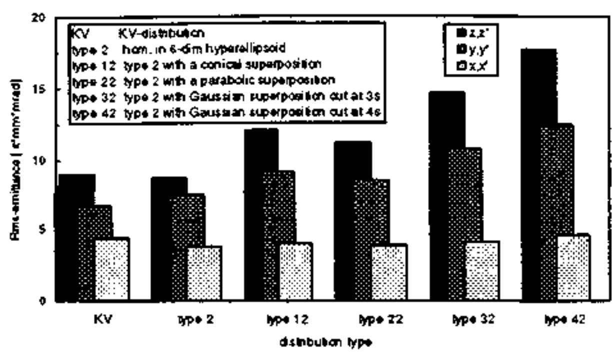


Fig. 8. Rms-emittance for different input particle distributions.

In such a „peaked" distribution the electric field rises more steeply near the center than at the edge; this deviation from linearity causes „ears" of the distribution (Fig. 9), which increase the emittance areas.

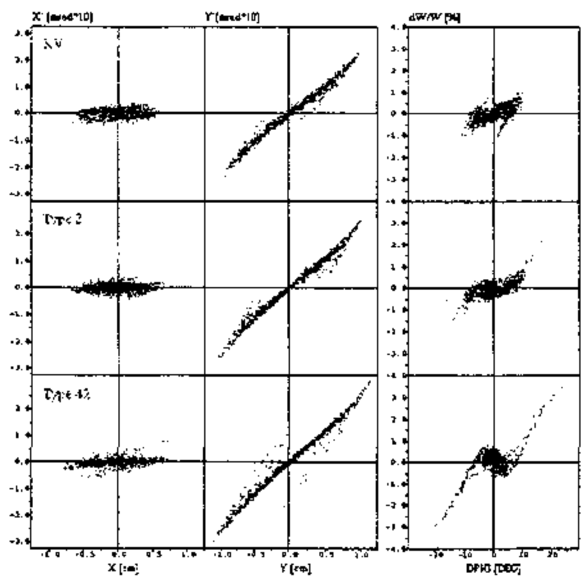


Fig. 9. Results of multiparticle calculations for three different input distributions.

More relevant for the injection into the SIS than the rms emittances is the intensity fraction remaining within the acceptances of the SIS listed in Table 1. Table 2 shows the fraction of beam intensities matching the requirements in the three phase space planes. For the not unrealistic distributions of type 42 the more prominent peaking of the particle density leads to less acceptability; however the loss of useful intensity is less than might be expected from the rms-emittance growth.

Table 2 Fraction of beam intensities corresponding to the design emittances (see Table 1)

Distribution	KV	Type 2	Type 42
Horizontal	0.81	0.90	0.80
Vertical	0.82	0.78	0.72
Longitudinal	1.00	1.00	0.96

Conclusion

With respect to emittance growth a rather homogenous particle density in the bunch is favourable. Aside from attempting to achieve flatter distributions from the IH-accelerator the activities concerning emittance growth will also cover a rigorous shortening of the very-high-current section, an increase of transverse beam size at the stripper position, analysis and optimization of the charge separation process and beam neutralisation in drift spaces.

References

[1] U. Ratzinger, The new GSI Injector linac for high current heavy ion beams, these proceedings.

[2] B. Franczak, MIRKO, Proc. of the Europhysics Conf. Computing in Accelerator Design and Operation, Berlin, 1983