CONCEPT FOR CONTROLLED TRANSVERSE EMITTANCE TRANSFER WITHIN A LINAC ION BEAM

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Abstract

Generally the two transverse emittances of a linac beam are quite similar in size (round beam). However, injection into subsequent rings often imposes stronger limits for the upper allowed value of one of these emittances. Provision of flat linac beams (different transverse emittances) thus can considerable inrease the injection efficiency into rings. Round-to-flat transformation has been already demonstrated for electron beams. It was also proposed for angular momentum dominated beams from Electron-Cyclotron-Resonance sources. We introduce a concept to extend the transformation to ion beams that underwent charge state stripping without requiring their extraction from an ECR source. The concept is of special interest for beams from low-charge-state / high-particle-current sources. It can be also applied to stripping of H^- to proton beams. These proceedings are a compressed version of [1].

INTRODUCTION

Emittance transfer was proposed for electrons [2] and has been demonstrated experimentally [3]. Rms-emittances are defined through the beam second moment matrix

$$C = \begin{bmatrix} <xx> & <xx'> & <xy> & <xy'> \\ <x'x> & <x'x'> & <x'y> & <x'y'> \\ <yx> & <yx'> & <yy> & <yy'> \\ <y'x> & <y'x'> & <y'y> & <y'y'> \end{bmatrix}, \tag{1}$$

where the full 4d-emittance is defined by $\epsilon_{4d}^2 = det\,C$ and $\epsilon_{x,y}$ are defined by the corresponding sub phase space determinants. If for a given 4d-distribution with vanishing inter-plane correlations moments, the horizontal and vertical emittances are equal, they will remain equal and may be just increased by symplectic transformations M [4], being defined through

$$M^T J M = J \tag{2}$$

with

$$J := \begin{bmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{bmatrix}. \tag{3}$$

Drifts, solenoids, quadrupoles, and dipoles are symplectic, the later even if they are tilted, that do preserve ϵ_{4d}, however. Accordingly, to transfer emittance between the transverse planes, a non-symplectic transformation must be applied. This transformation nevertheless should preserve ϵ_{4d}. A transformation through a fringe field of a solenoid

$$M_{SolFringe} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & +K & 0 \\ 0 & 0 & 1 & 0 \\ -K & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

with

$$K := \frac{B}{2(B\rho)}, \tag{5}$$

B as the solenoid on-axis magnetic field strength, and $(B\rho)$ as the beam rigidity is such a transformation.
The issue can be addressed also through the concept of the eigen-emittances $\pm E_x$ and $\pm E_y$ of a 4d-distribution [5]. They solve the complex equation

$$det\,(JC - iEI) = 0 \tag{6}$$

where I is the identity matrix. The eigen-emittances do not change with symplectic transformations. But they do change by transformation through a solenoid fringe field. Their product is equal to ϵ_{4d} and for vanishing inter-plane coupling moments they are equal to the rms-emittances.

BEAMS FROM AN ECR SOURCE

For beams from an ECR source emittance transfer has been proposed already in [6] assuming a beam second moment matrix (Eq. 1) with nonzero elements just along the two diagonals. But generally all coupling moments are different from zero. Extraction of the ions from an ECR source is through the fringe of the plasma-confining longitudinal magnetic field. Accordingly, the source itself inhabits intrinsically the non-symplectic transformation which changes the eigen-emittances. The fringe creates inter-plane coupling moments as seen in the projections of the transverse distribution after extraction (Fig. 1) [7]. Horizontal and vertical rms-emittance are equal. In the figures coupling moments are quantified through the corresponding α-parameter. The 120° symmetry in the inter-plane projections is due to the non-linear inter-plane coupling hexapolar field inside the ECR source. Along the beamline following the extraction only symplectic elements are applied, thus preserving the eigen-emittances. This beamline needs to remove the inter-plane correlations, i.e. equalizing the final rms-emittances to these eigen-emittances. For typical beam parameters obtained after the GSI ECR source, a beamline comprising a sequence of two solenoids, two

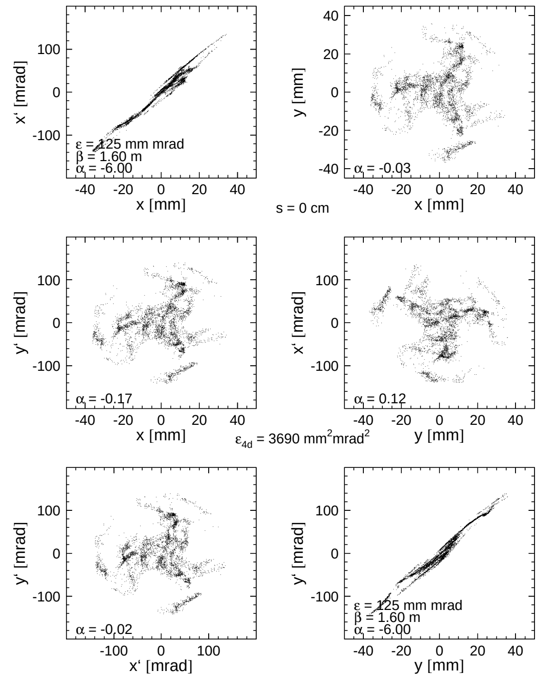

Figure 1: Two dimensional projections of the initial ECR transverse phase space distribution.

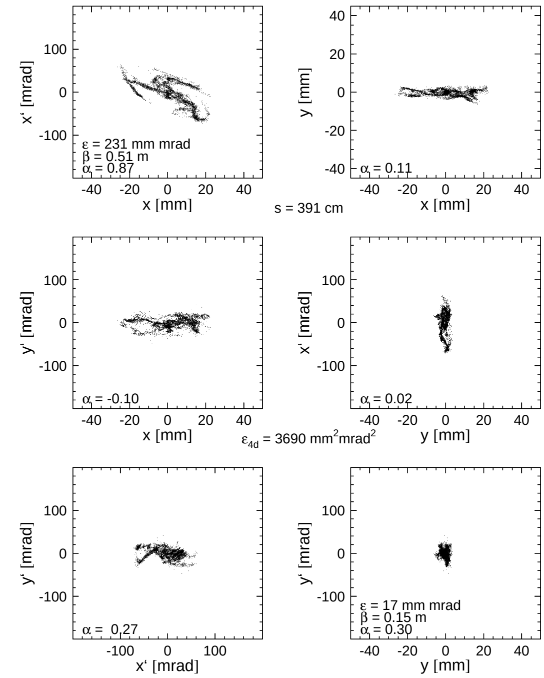

Figure 2: Two dimensional projections of the final ECR transverse phase space distribution.

quadrupoles, another solenoid, and two skew-quadrupoles can do this task within reasonable appperture and field limits. The total length of this beamline is four meters. Figure 2 shows the distribution at the exit of this beamline. The inter-plane correlations are zero, final rms-emittances are equal to the eigen-emittances, and their ratio is about 16.

BEAMS TO BE STRIPPED

Beams from sources different from an ECR, pre-accelerated to some MeV/u along a linac, do generally have similar rms-emittances, zero inter-plane correlations, and thus their eigen-emittances are equal to the rms-emittances. The required solenoid fringe field to vary the eigen-emittances cannot be provided in a straight forward way, since any entrance fringe intrisically causes an exit fringe field. Both fringe effects just cancel out, making the overal transformation symplectic again. This cancellation can be bypassed through placing a charge state stripping foil between both fringes as displayed in Fig. 3. Such a solenoidal stripper is proposed to be integrated into the existing charge state stripping & separating beam line of the GSI UNILAC [8]. Simulations have been done using an H_3^+ beam stripped to a proton beam in a 20 $\mu g/cm^2$ carbon foil placed between to pancake coils. Figure 4 shows the transverse distribution at the beginning of the beamline. Its rms- and eigen-emittances are equal to each other and are equal in each plane.

Figure 5 shows the beamline itself together with the corresponding beam envelopes and rms-emittances. The entrance fringe creates inter-plane correlations which in

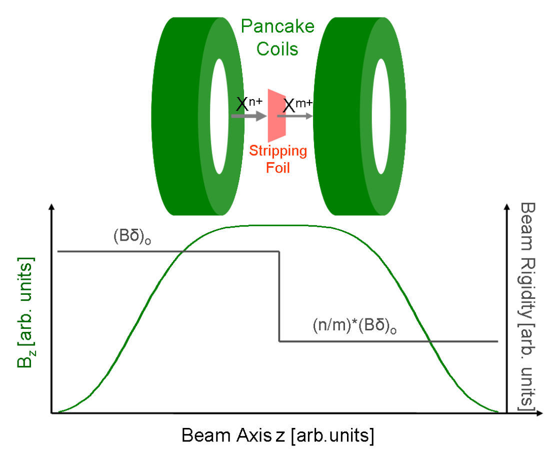

Figure 3: Conceptual layout of an ion stripper set-up providing a non-symplectic transformation for transverse emittance transfer. The stripping foil is placed between two pancake coils, i.e. inside a region with a longitudinal magnetic field of few Tesla in strength.

turn increase both transverse rms-emittances. After the non-symplectic entrance fringe the horizontal and vertical eigen-emittances are different. Since the exit fringe is passed by the beam with reduced rigidity w.r.t. the entrance fringe, there is no cancellation of the two non-symplectic fringes. The exit fringe separates the two eigen-emittances even more. Along the subsequent vertical four-bend chicane the rms-emittances and correlations are preserved until the entrance to the skewed quadrupole triplet (vertical rms-emittance growth is due to dispersion). The skewed

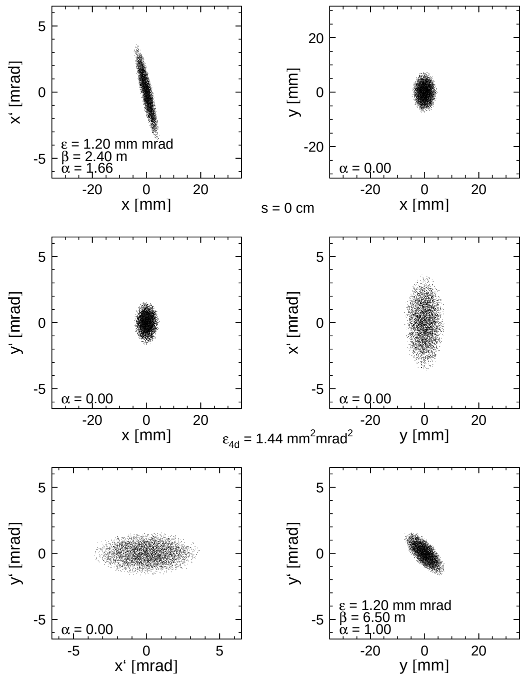

Figure 4: Two dimensional projections of the initial UNILAC transverse phase space distribution.

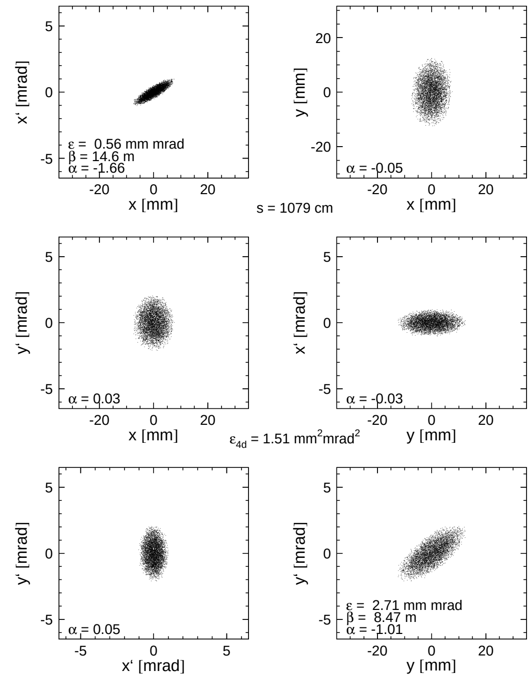

Figure 6: Two dimensional projections of the final UNILAC transverse phase space distribution.

triplet removes all inter-plane correlations and another regular quadrupole provides matching to the following beam

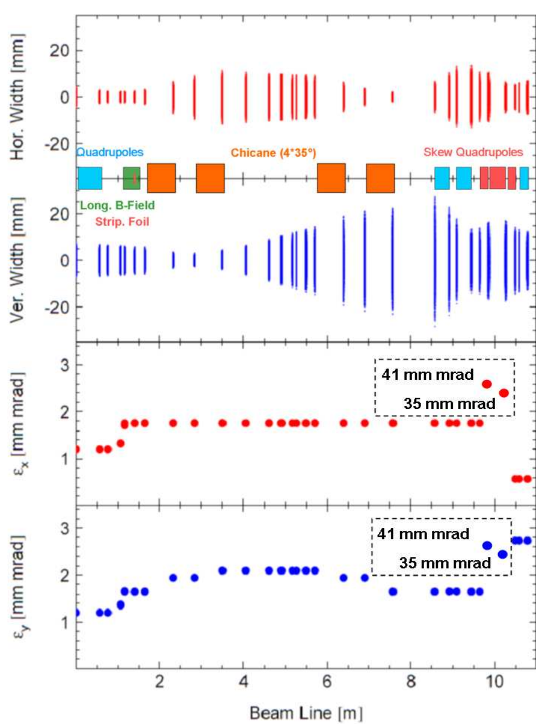

Figure 5: From top to bottom: horizontal beam envelope, vertical beam envelope, horizontal rms-emittance, and vertical rms-emittance along the proposed emittance transfer section along the UNILAC.

transport section. Figure 6 displays the distribution at the exit of this quadrupole. The final rms-emittance ratio is 4.8. The rms-emittance values are equal to the eigen-emittances behind the exit fringe, being the last non-symplectic element of the beamline.

The solenoidal stripper is of special interest for beams from low-charge-state high-particle-current sources. It was tentativley applied to heavy ions. First simulations indicated horizontal emittance reduction of about 40% for intense beams of $^{238}U^{27+}$ stripped to $^{238}U^{73+}$ based on the existing foil stripping section at the GSI UNILAC. Further optimization of the layout for an emittance transfer section for intense beams of heavy ions is needed.

REFERENCES

[1] L. Groening, PRST-AB **14**, 064201 (2011).

[2] R. Brinkmann et. al., PRST-AB **4**, 053501 (2001).

[3] D. Edwards et al., Proc. XX Linac Conf., p. 122, (2000).

[4] K.L. Brown et al. SLAC-Rep. No. slac-pub-4679, (1989).

[5] B.E. Carlsten et al., PRST-AB **14**, 050706, (2011).

[6] P. Bertrand et al., Proc. 10th EPAC Conf., p. 1687, (2006).

[7] P. Spädtke et al., Proc. 1st IPAC Conf., p. 4029, (2010).

[8] W. Barth et al., Proc. XXIV Linac Conf., p. 175, (2008).