Investigation of the Compact LEBT Design Prerequisites

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A new injection line [1,2,3] is proposed as a part of the upgrade and further development of the high current heavy ion linac UNILAC for the FAIR requirements. The final design of this straight line should be based on precise and complete information about beam current and emittance coming from ion source. An intense experimental campaign was carried out in June-November 2013 at the North Terminal of the UNILAC. Full and self-consistent data for uranium beam including detailed knoweledge about the beam current phase density in the transverse phase space has been obtained [4].

As the new LEBT (Low Energy Beam Transport) has no separation by bending magnets, the full spectra of different uranium charge states (2+, 3+, 4+, 5+, ...) will be transported through the line. Then the beam emittance of only design ions U4+ should be matched to the HSI-RFQ acceptance. Although the neighboring charge states could be partly separated at the LEBT, a significant portion of mainly U3+ ions will be also injected into the RFQ. This leads to an increased space charge effects and makes a strong influence on particle motion. Therefore an information about ratio U4+ / U3+ is important for proper beam transport and matching. Measurements of beam parameters have been performed at existing UNILAC beam line, directly behind North ion source terminal. Obviously a beam current and beam emittance could be measured only for all charge states together. The standard diagnostics is not able to distinguish ions with different charge states. To solve this problem, a set of measurements behind the first quadrupole triplet (UL4QT1) of the North LEBT was insistently proposed. As it is shown on Fig.1 (left), a different focusing efficiency for the different charge states leads to a complicate shape of a composite beam emittance.

To distinguish between different charge states a dedicated algorithm was proposed, developed and realized. A macroparticle distribution was generated from the raw data of measured (with slit-grid device) emittance. The density of macroparticles is proportional to the measured intensity in each bin. Beam dynamics simulations with DYNAMION code have been firstly done backward (upstream beam direction) through the measured magnetic field of the triplet. Two identical distributions, but with different charge state of macroparticles (U3+ and U4+) have been transported separately. In assumption that the beam parameters behind an ion source terminal are the same for every charge state, only a phase space overlapping of resulted particle distributions has been treated as an emittance formed by the complete beam. The obtained "realistic" particle ensemble has been simulated forward (downstream a beam), again separately as U3+ and as U4+. The transported particles at the position of measurements form separately beam emittances for different charge states which perfectly cover the originally measured phase space distribution (Fig. 1, right).

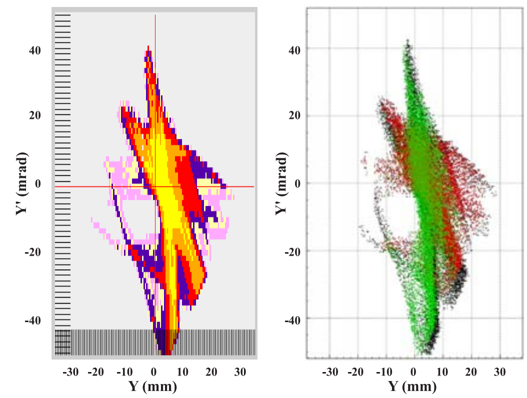

Figure 1: Measured beam emittance (left) and macroparticle distributions (right): generated from measurements (black), reconstructed U4+ fraction (green), reconstructed U3+ fraction (red)

Additionally a dedicated algorithm, based on least squares calculations, provides for an estimated U4+ intensity inside the measured one for all charge states together. With use of this algorithm one can extract from the recent measurements for the mixed beam (U3+ and U4+ mainly) the beam parameters for the design ion U4+ only. The beam current and emittance obtained with different settings of the ion source terminal are in the range of 20-35 mA inside 300-450 mm*mrad respectively. For comparison, the HSI-RFQ high current acceptance with these beam parameters is in the frame of 250-300 mm*mrad.

Generally the proposed coupling of detailed measurements and precise simulations acts as a virtual charge state separator. Being implemented simultaneously for both transverse phase planes, it provides for a better beam transport, refined matching with an RFQ acceptance, as well as for an improved UNILAC performance.

References

[1] L. Dahl et al, Proceedings LINAC 2002

[2] S. Yaramyshev et al, GSI internal Report 2009

[3] H. Vormann et al, these Proceedings

[4] S. Yaramyshev et al, GSI internal Report 2013