ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRO097

SPACE-CHARGE NEUTRALIZATION OF 750-KEV H$^-$ BEAM AT LANSCE*

Y.K. Batygin#, C.Pillai, L.J. Rybarcyk, LANL, Los Alamos, NM 87545, USA

Abstract

The injector part of Los Alamos Neutron Science Center (LANSCE) includes a 750-keV H- beam transport located upstream of the Drift Tube Linac. Space charge effects play an important role in the beam transport therein [1]. A series of experiments were performed to determine the level of beam space charge neutralization, and time required for neutralization. Measurements performed at different places along the structure indicate significant variation of neutralized space charge beam dynamics along the beamline. Results of measurements were compared with numerical simulations using macroparticle method and envelope equations to determine values of the effective beam current after neutralization, and effective beam emittance, required for beam tuning.

750 KEV LANSCE BEAM TRANSPORT

The H$^-$ beam injector includes a cesiated, multicusp-field, surface –production ion source and two-stage low-energy beam transport line. In the first stage, extracted beam is accelerated up to 80 keV, and then is transported through a solenoid, electrostatic deflector, a 4.5^o bending magnet, and a second solenoid. The 670 kV Cockroft-Walton column accelerates beam up to an energy of 750 keV. The 750 keV LEBT (see Fig. 1) consists of a quadrupole lattice, 81^o and 9^o bending magnets, slow-wave chopper, RF bunchers, an electrostatic deflector, diagnostics and steering magnets to prepare beam for injection into the Drift Tube Linac (DTL). Slit-collector beam emittance measurements at 750 keV are performed at five locations: 1) TBEM1 (just after the Cockroft - Walton column), 2) TBEM2 (downstream of the chopper), 3) TBEM3 (downstream of the 81^o bend before RF pre-buncher), 4) TBEM4 (between the first RF (pre)-buncher and second (main) buncher), and 5) TDEM1 (before the entrance to the DTL).

BEAM EMITTANCE SCANS

Ionization of residual gas by transported particles is an important factor of low-energy beam transport. Fig. 2 illustrates a typical spectrum of residual gas in the 750 keV H$^-$ transport channel obtained from a Residual Gas Analyzer installed in the middle of the channel. Main components are H_2 (48%), H_2O (38%) and N_2 (9%). Fractions of other components are significantly smaller. Typical total pressure measured by ion gauges along the transport channel range from $5 \cdot 10^{-7}$ Torr to 10^{-6} Torr.

*Work supported by US DOE under contract DE-AC52-06NA25396
#batygin@lanl.gov

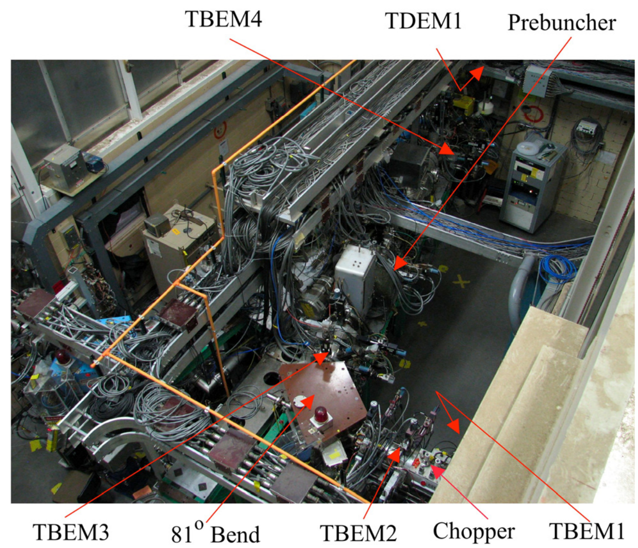

Figure 1: Layout of 750-keV H$^-$ Low Energy Beam Transport of LANSCE.

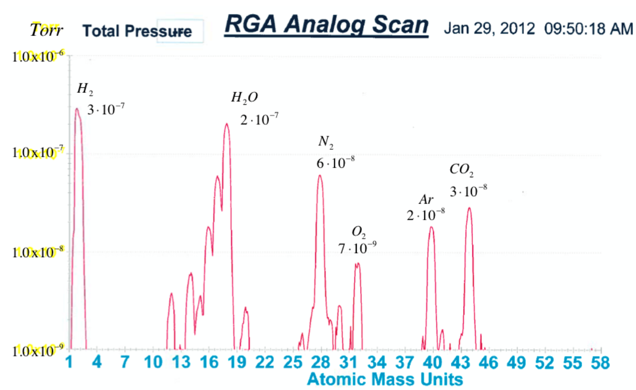

Figure 2: Residual gas analyzer scan.

A series of beam emittance scans along 750 keV H$^-$ beam transport were performed to determine time and level of space charge neutralization of the beam, value of effective beam current under space–charge neutralization, and the value of effective beam emittance. Measurements were done as pair measurements between each pair of emittance stations TBEM1–TBEM2, TBEM2-TBEM3, TBEM3–TBEM4, TBEM4–TDEM1. Measurements were performed with an ion source pulse length of 825 µs. The emittance was sampled within the last 50 μs of the ion source pulse. The beam pulse start time was varied between τ = 10 – 575 µs before the emittance sampling through delay in the 80 kV electrostatic deflector. Typical value of H$^-$ beam current at 750 keV was 14 – 17 mA.

5th International Particle Accelerator Conference IPAC2014, Dresden, Germany JACoW Publishing
ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRO097

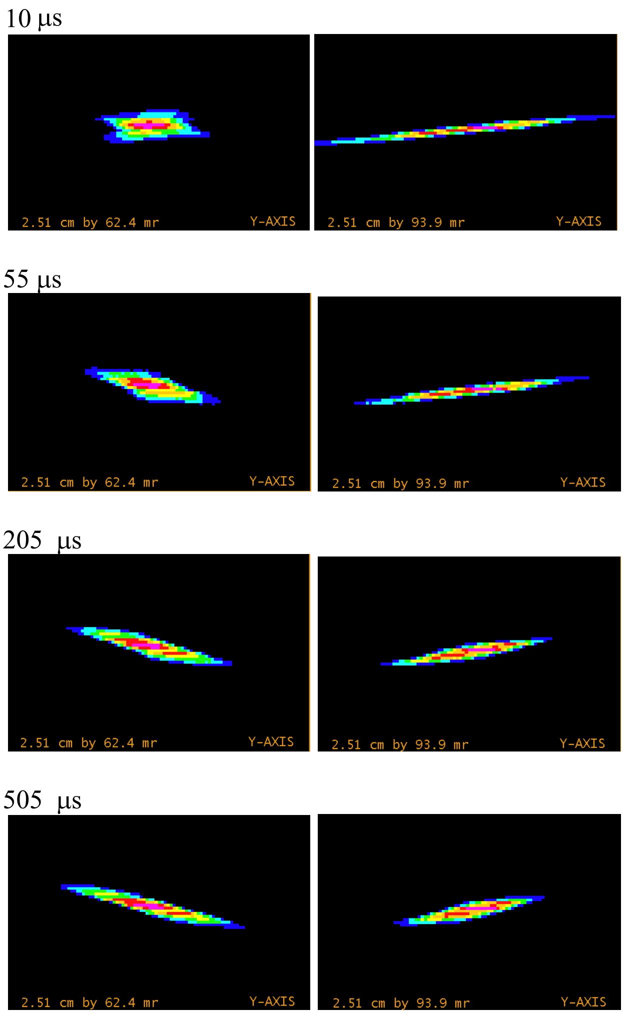

Figure 3: Variation of vertical beam emittance along the beam pulse: (left) TBEM1, (right) TBEM2.

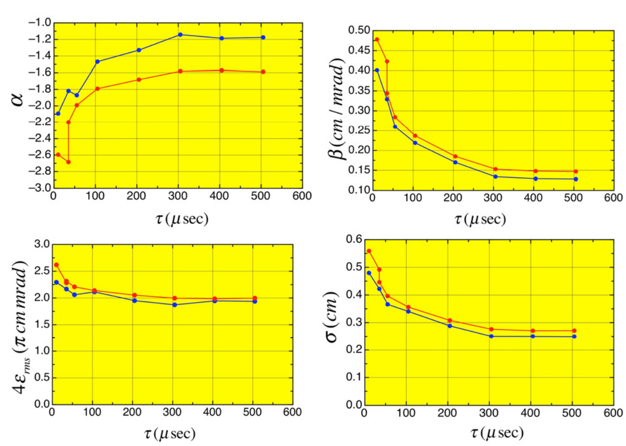

Figure 4: Parameters of 750 keV beam at TBEM2: (blue) horizontal, (red) vertical.

Emittance scans indicate a variation of beam parameters versus beam pulse length. Fig. 3 illustrates the variation of beam emittance between TBEM1 and TBEM2 versus beam pulse length (τ). Figs. 4 illustrate dependencies of Twiss parameters (α, β), four - rms unnormalized emittance ($4\varepsilon_{rms}$), and rms beam sizes (σ) versus beam pulse length (τ) at TBEM2. Values of beam parameters are observed to be stabilized after 250 µs.

Determination of the value of compensated space charge by residual gas ionization was done through comparison of results of measurements and simulations using macroparticle code BEAMPATH [2] and envelope code TRACE [3]. At the first stage of simulations, measured beam distributions at the starting station were reproduced in a BEAMPATH macroparticle model as the initial distribution for subsequent beam simulations. After that, simulations were performed between two emittance stations with variable beam current. At subsequent measurement station we compared equivalent beam ellipses obtained from measurement and from simulation, and calculated the mismatch factor between them $F = 0.5(F_x + F_y)$, where

$$F_x = \sqrt{\frac{1}{2}(R_x + \sqrt{R_x^{\,2} - 4})} - 1\,, \qquad (1)$$

and $R_x = \beta_{\exp}\gamma_s + \beta_s\gamma_{\exp} - 2\alpha_{\exp}\alpha_s$ is the parameter indicating overlapping of x - beam ellipses with Twiss parameters obtained from experiment, $\alpha_{\exp}$, $\beta_{\exp}$, $\gamma_{\exp}$, and from simulations α_s, β_s, γ_s, and similarly for F_y. The smallest value of the mismatch factor F determines the value of effective beam current under space-charge neutralization, I_{eff} (F_{min}). The value of space charge neutralization, η, is defined by

$$\eta = 1 - \frac{I_{eff}(F_{\min})}{I_{beam}}\,, \qquad (2)$$

where I_{beam} is the value of measured beam current.

At the second stage of analysis, the same procedure was repeated with the envelope code TRACE using different beam emittances with the value of effective beam current obtained from the macroparticle model. A minimum value of the mismatch parameter indicates an effective value of beam emittance representing beam in the envelope model.

Figures 5 - 6 illustrate results from the space-charge neutralization study between TBEM1 – TBEM2 utilizing the described method. Fig. 5 shows the value of mismatch factor F, Eq. (1), as a function of beam current in BEAMPATH simulations. At the beginning of beam pulse, the minimum of mismatch factor is observed at the largest value of beam current. It indicates the absence of space-charge neutralization. With longer beam pulses, the minimum of mismatch factor is moving towards smaller effective current, which corresponds to 50 – 60 % space charge neutralization (see Fig. 7, blue line). Obtained values of effective beam current for each pulse length were used in TRACE code with different values of beam emittance (see Fig. 6). Minimum mismatch indicates the

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRO097

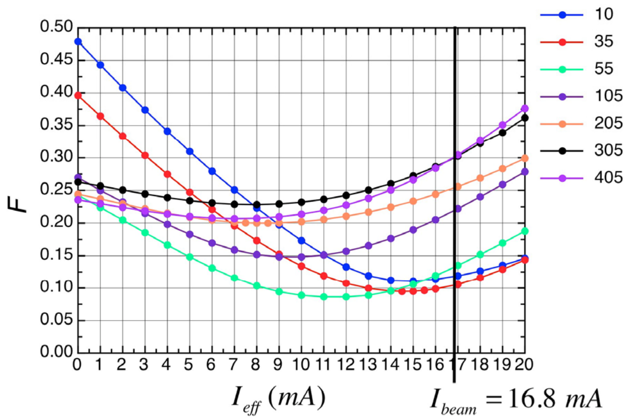

Figure 5: Mismatch factor F as a function of effective beam current in BEAMPATH simulations between TBEM1 and TBEM2 (numbers indicate pulse length in μs).

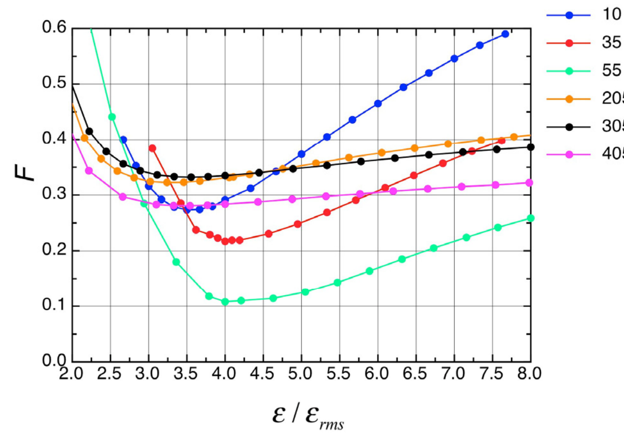

Figure 6: Mismatch factor F as a function of effective beam emittance in TRACE simulations between TBEM1-TBEM2 (numbers indicate pulse length in μs).

most appropriate combination of effective beam current and effective beam emittance in the envelope model (see Fig. 8, blue line).

The described method was used for space charge neutralization study of H$^-$ beam along the whole transport channel. Fig. 7 illustrates the value of space charge neutralization, η, versus beam pulse length for the rest of the beamline. Space charge neutralization reaches the value of 100% between TBEM2-TBEM3. In the region between TBEM3-TBEM4, neutralization starts with certain value of 60 – 80%, then drops to zero for the rest of beam pulse. The possible reason for this is a residual voltage present at the 750-keV beam deflector which is located between TBEM3 – TBEM4. At the final stage of beam transport, between TBEM4-TDEM1, space charge neutralization reaches 50-60%.

Analysis of beam emittance (see Fig. 8) indicate that effective beam emittance in beam transport is close to the value of $\varepsilon_{eff} = 3.5\ \varepsilon_{rms}$. In the region TBEM2-TBEM3 the value of beam emittance could be determined only when space charge neutralization is below 100%, which corresponds to a beam pulse length of τ < 150 μs. Otherwise, when the effective current is close to zero, transformation of beam ellipse from one point to another is independent on the value of beam emittance.

The analysis performed, creates a basis for more precise beam tuning in the structure.

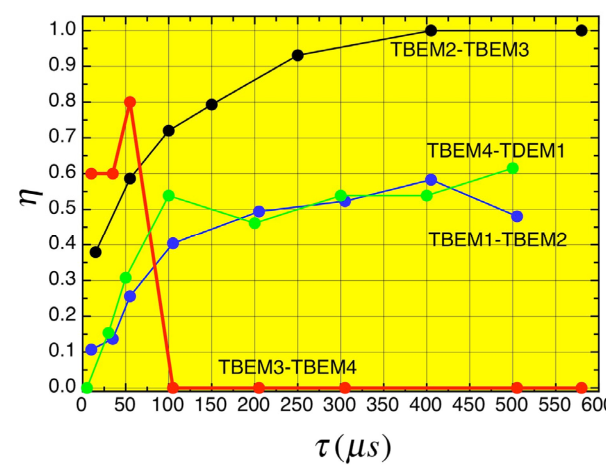

Figure 7: Space charge neutralization as a function of pulse length along the channel.

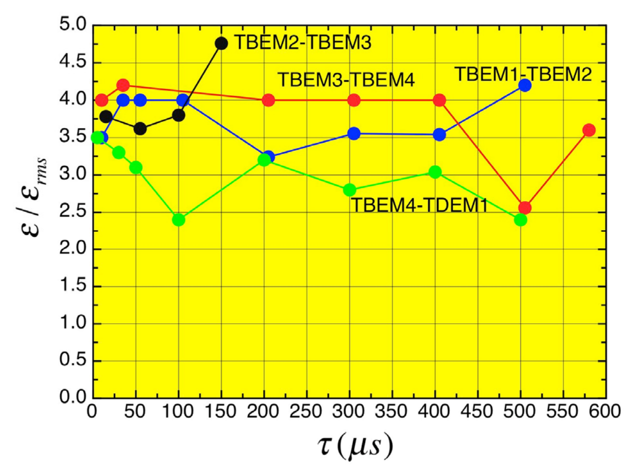

Figure 8: Effective beam emittance as a function of pulse length along the channel.

REFERENCES

[1] Y.K.Batygin, C.Pillai, L.J.Rybarcyk, "Beam Performance in H$^-$ Injector of LANSCE," Proceedings of IPAC 2011, San Sebastian, Spain, September 4 – 9, 2011, p. 697.

[2] Y.K. Batygin, NIM-A 539, p.455, (2005).

[3] K.R.Crandall and D.P.Rusthoi, "Documentation for TRACE: An Interactive Beam-Transport Code", LA-10235-MS.