

# SPACE-CHARGE NEUTRALIZATION OF 750-keV PROTON BEAM IN LANSCE INJECTOR LINE\*

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## Abstract

The 750-keV low-energy beam transport of the Los Alamos Neutron Science Center (LANSCE) linac consists of two independent beam lines for simultaneous injection of  $H^+$  and  $H^-$  beams into the linear accelerator. Space charge effects play an important role in the beam transport therein. A series of experiments were performed to determine the level of proton beam space charge neutralization by residual gas ionization, and time required for neutralization. Study was performed as emittance scans between pairs of emittance measurement stations. The value of compensated space charge was determined through comparison of results of measurements and simulations using macroparticle method and envelope code. Obtained results provide new setup for beam tuning in transport beamline.

## 750 keV $H^+$ LANSCE BEAM TRANSPORT

The  $H^+$  beam injector includes a duoplasmatron proton source mounted at 750 keV Cockroft-Walton accelerating column and low-energy beam transport line (LEBT). The 750 keV LEBT (see Fig. 1) consists of a quadrupole lattice,  $81^\circ$  and  $9^\circ$  bending magnets, RF prebuncher, 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 three locations: 1) TAEM1 (just after the Cockroft - Walton column), 2) TAEM2 after pre-buncher, and 3) 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. Typical pressure measured by ion gauges along the transport channel is  $9 \times 10^{-7}$  Torr. A series of beam emittance scans along 750 keV proton 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 TAEM1-TAEM2, TAEM2-TDEM1. Measurements were performed with an ion source pulse length of 825  $\mu s$ . The emittance was sampled within 50  $\mu s$  of the ion source pulse being delayed at  $\tau = 10 - 400 \mu s$  after beginning of beam pulse. The value of proton beam current at 750 keV was 15.2 mA.

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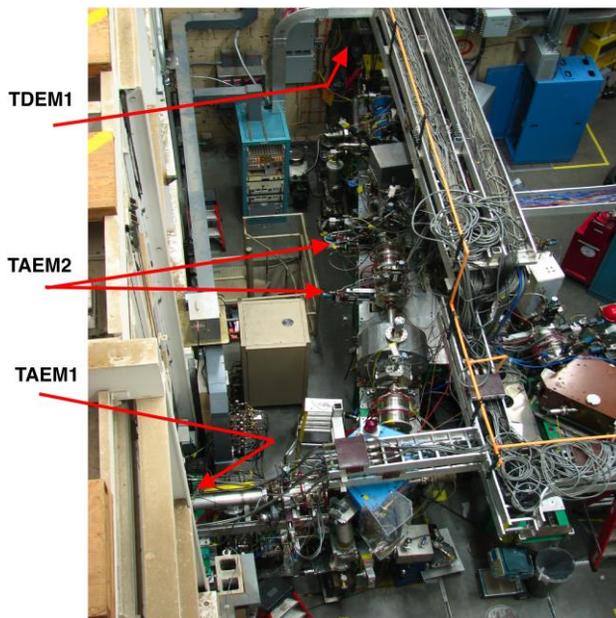
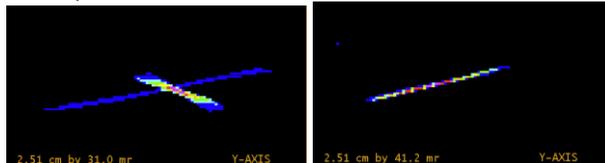
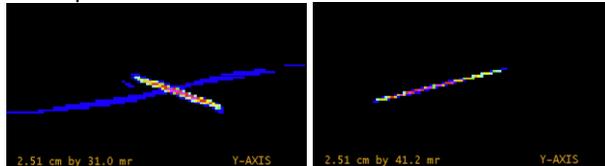


Figure 1: Layout of 750-keV proton Low Energy Beam Transport of LANSCE linear accelerator.

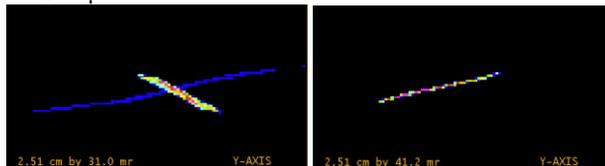
$\tau = 10 \mu s$



$\tau = 50 \mu s$



$\tau = 200 \mu s$



$\tau = 375 \mu s$

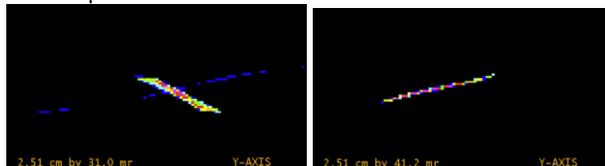


Figure 2: Variation of vertical beam emittance along the beam pulse: (left) TAEM1, (right) TAEM2.

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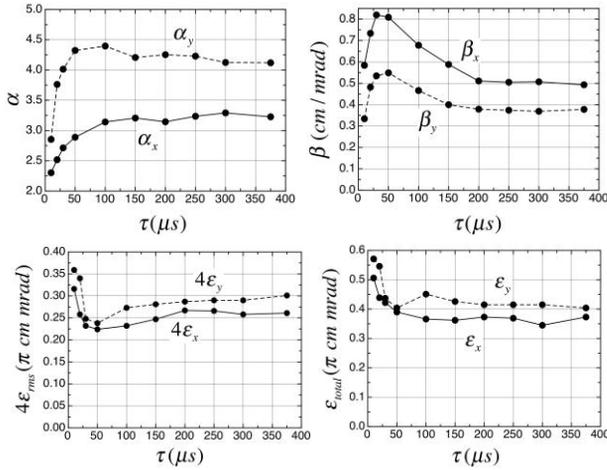


Figure 3: Parameters of 750 keV proton beam at TAEM1.

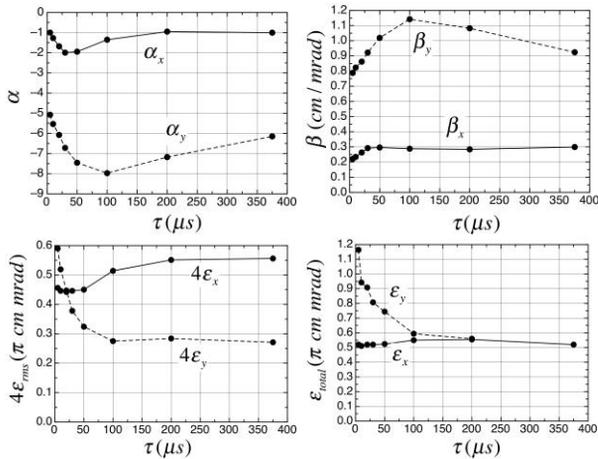


Figure 4: Parameters of 750 keV proton beam at TAEM2.

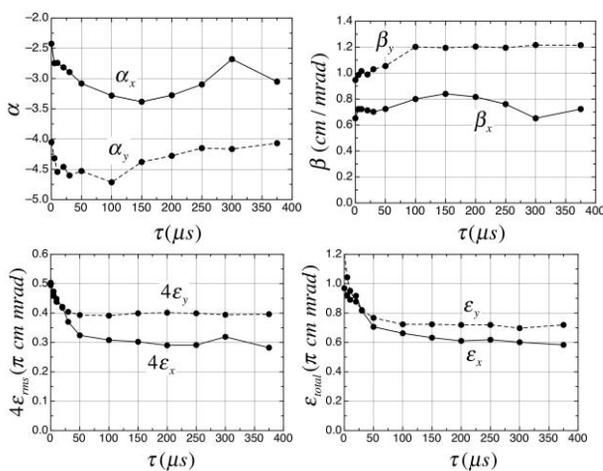


Figure 5: Parameters of 750 keV proton beam at TDEM1.

Emittance scans indicate a weak variation of beam parameters versus beam pulse length. Figure 2 illustrates the variation of beam emittance between TAEM1 and TAEM2 versus beam pulse length ( $\tau$ ). Additional tails at

TAEM1 beam emittance scans are due to presence of  $H_2^+$ / $H_3^+$  components in the extracted beam. Figs. 3-5 illustrate dependencies of Twiss parameters ( $\alpha, \beta$ ), four-rms unnormalized emittance ( $4\epsilon_{rms}$ ), and total emittance ( $\epsilon_{total}$ ) versus beam pulse length ( $\tau$ ) measured at emittance stations. Values of beam parameters are observed to be stabilized after 100  $\mu s$ .

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 [1] and envelope code TRACE [2] similarly to previous measurements of the same effect in 750 keV  $H^-$  LANSCE beamline [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

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

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  $\alpha_s, \beta_s, \gamma_s$ , 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,  $\eta$ , is defined by

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

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 6 - 9 illustrate results from the space-charge neutralization study between TAEM1 - TAEM2, and TAEM2-TDEM1 utilizing the described method. Figure 6 shows the value of mismatch factor  $F$ , Eq. (1), as a function of beam current in BEAMPATH simulations. In the region TAEM1-TAEM2, the minimum values of mismatching factor  $F$  are observed at effective current  $I_{eff} = 8...10 mA$ , while in the region TAEM2-TDEM2 the factor  $F$  has minimum at  $I_{eff} = 2...4 mA$ . Equation (2)

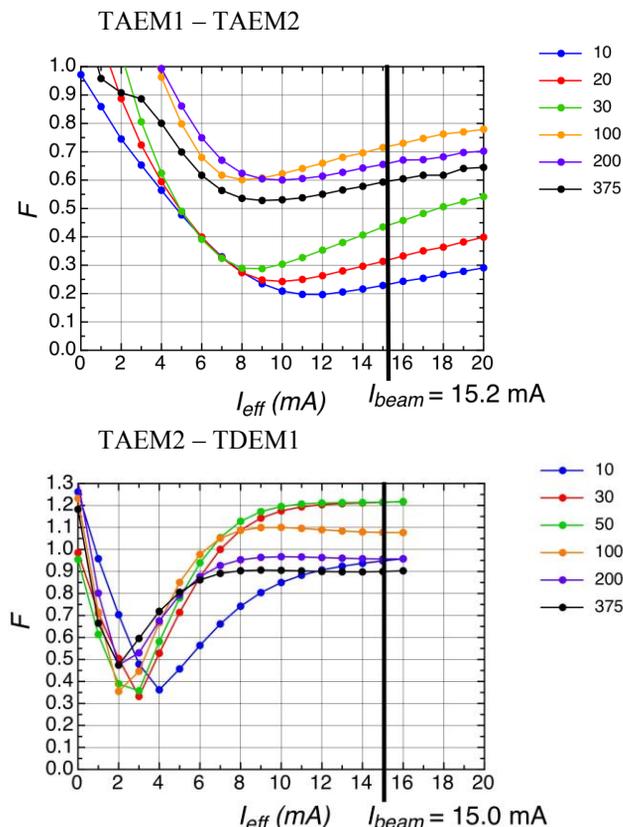


Figure 6: Mismatch factor  $F$  as a function of effective beam current in BEAMPATH simulations (numbers indicate pulse length in  $\mu\text{s}$ ).

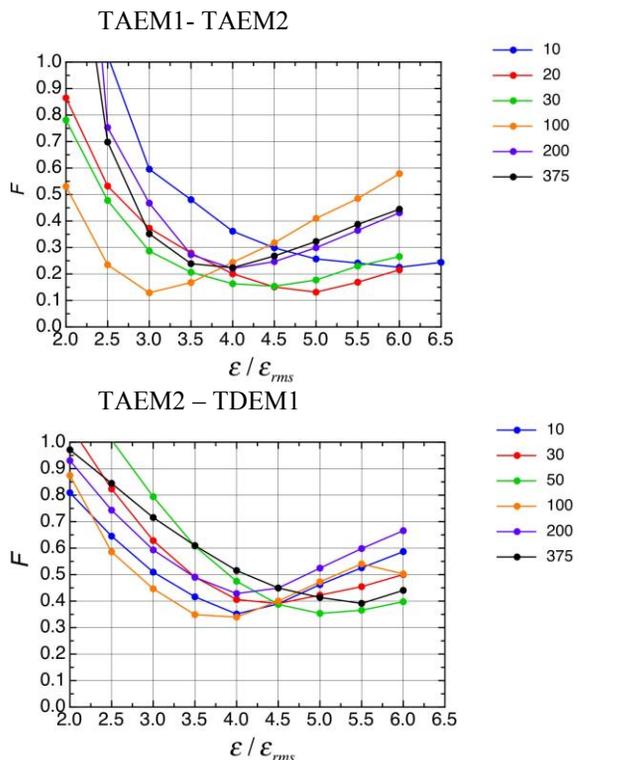


Figure 7: Mismatch factor  $F$  as a function of effective beam emittance in TRACE simulations (numbers indicate pulse length in  $\mu\text{s}$ ).

## 5: Beam Dynamics and EM Fields

### D08 - High Intensity Linear Accelerators - Space Charge, Halos

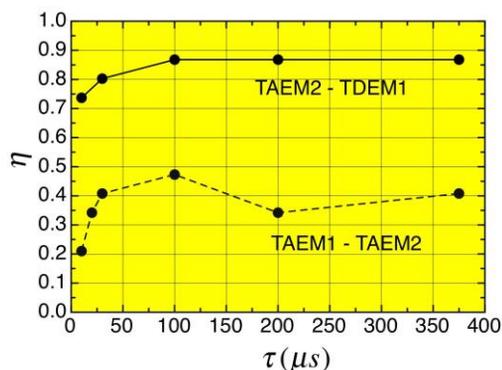


Figure 8: Space charge neutralization as a function of pulse length along the channel.

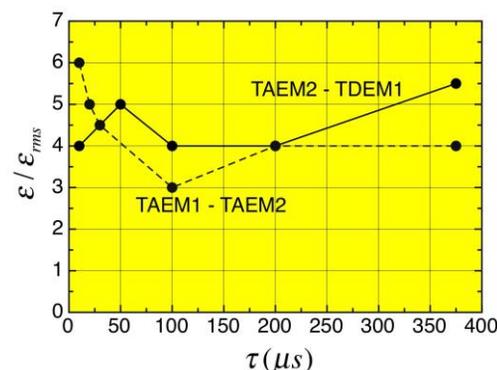


Figure 9: Effective beam emittance as a function of pulse length along the channel.

indicates that space charge neutralization reaches the value of 40% between TAEM1-TAEM2, and 87% in the region between TAEM2-TDEM1. In both cases, at the beginning of beam pulse, the minimum of mismatch factor is observed at the largest value of beam current. With longer beam pulses, the minimum of mismatch factor is moving towards smaller effective current. It indicates the small degree of space-charge neutralization in the beginning of the pulse, and development of neutralization during the beam pulse.

Obtained values of effective beam current for each pulse length were used in TRACE code with different values of beam emittance (see Fig. 7). Minimum mismatch indicates the most appropriate combination of effective beam current and effective beam emittance in the envelope model. Analysis of beam emittance (see Fig. 9) indicates that effective beam emittance in beam transport is close to the value of  $\varepsilon_{\text{eff}} = 4.46\varepsilon_{\text{rms}}$ . The analysis performed, creates a basis for more precise beam tuning in the structure.

## REFERENCES

- [1] Y.K. Batygin, NIM-A 539 (2005), p. 455.
- [2] K.R.Crandall and D.P.Rusthoi, "Documentation for TRACE: An Interactive Beam-Transport Code", LA-10235-MS.
- [3] Y.K.Batygin, C.Pillai, L.J.Rybarcyk, "Space Charge Neutralization of 750-keV  $\text{H}^-$  Beam at LANSCE," Proceedings of IPAC 2014, Dresden, Germany, June 15-20, 2015, p. 3116.