SPACE CHARGE NEUTRALIZATION OF LOW ENERGY H⁻ BEAM

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Abstract

The LANSCE ion source test stand is used for systematic studies of H^- source performance and details of low energy beam transport. It includes a cesiated surface – production H^- ion source with a multicusp magnetic field, focusing solenoids, slit-collector emittance stations, a 4.5° bending magnet, and an electrostatic deflector. A series of experiments were performed to determine space charge neutralization of a low energy H^- beam. Measurements were done for 80 keV and 35 keV H^- beams. Measurements are compared with beam dynamics simulations to determine level of space charge neutralization. Experimentally determined beam neutralization time is compared with theoretical estimations.

ION SOURCE TEST STAND

The ion source test stand (ISTS, see Fig. 1) was developed to perform H^- beam studies in support of H^- source operations for the LANSCE facility [1]. It replicates the 80 keV H^- beamline of LANSCE which is used as an injector for the 670 keV Cockcroft-Walton column. Focusing structure of beamline includes two solenoids separated by 1.9 m to accommodate an emittance measurement station IDEM2, an electrostatic beam deflector, and a bending magnet to separate H^- beam from electrons. A second beam emittance measurement station, IDEM3, is located at the end of the structure. Beam current is measured by both a current monitor and Faraday cup. The beamline is also equipped with a residual gas analyzer (RGA).

BEAM EMITTANCE SCANS

A series of beam emittance scans were performed at IDEM2 and IDEM3 at beam energies of 80 keV and 35 keV. The purpose of the experiment was to determine the time and level of space charge neutralization of the beam. During the measurements, the electrostatic deflector pulse was kept constant at 4 Hz x 625 μs. Emittance measurements were sampled at both stations over 50 μs with variable delay of $\tau = 10$ - 580 μs with respect to the beginning of the deflector pulse as a means of producing variable pulse lengths. Emittance scans were performed at ionization gauge pressure readings of $1.6 \cdot 10^{-6}$ Torr. Measured beam current was 9.3 mA for the 80 keV beam, and 5.5 mA for the 35 keV beam. Emittance scans indicate variation of beam parameters versus beam pulse length. Figs. 2 - 4 illustrate dependencies of Twiss parameters (α, β), four - rms emittances ($4\varepsilon_{rms}$), and rms beam sizes (σ) versus beam pulse length (τ) for the 80 keV beam. Similar dependencies were observed for the 35 keV beam. Values of beam parameters are observed to be stabilized after 100 - 150 μs.

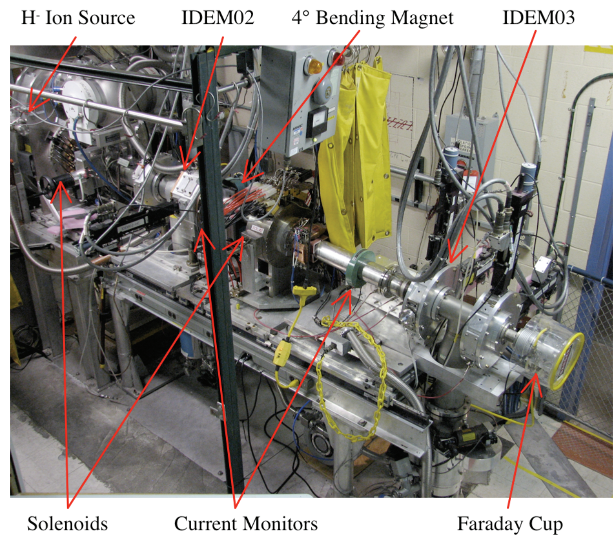

Figure 1. The ion source test stand.

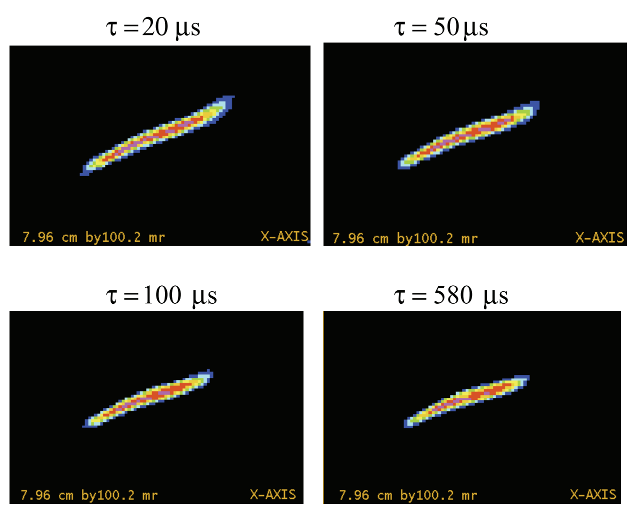

Figure 2. IDEM2 horizontal emittance scans of 80 keV beam at different values of pulse length.

Determination of the value of compensated space charge by residual gas ionization was done through comparison of results of measurements and simulations using the computer code TRACE. Simulations were performed between emittance stations IDEM2 and IDEM3 with beam current as the independent variable (see Fig. 5). Beam emittance data at IDEM2 for each value of beam pulse length were used as the initial conditions for the simulation. Beam ellipses obtained from simulations and from measurements at IDEM3 were

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compared using 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 $R_x = \beta_{\exp}\gamma_s + \beta_s\gamma_{\exp} - 2\alpha_{\exp}\alpha_s$. F_x quantifies the overlap of x - beam ellipses using the 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. Fig. 6 shows the mismatch factor F as a function of beam current for different values of beam pulse length. The minimum value of mismatch parameter F for each pulse length is a measurement of the effective beam current under space-charge neutralization, $I_{eff}(F_{\min})$. The value of space charge neutralization, η, is defined by

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

where I_o is the value of measured beam current. Figs. 7 and 8 illustrate the value of space charge neutralization as a function of beam pulse length for different beam energies. The 80 keV beam reaches 100% neutralization after 120 μs, while the 35 keV beam achieves the same level of neutralization after 200 μs.

SPACE-CHARGE NEUTRALIZATION TIME

Time required for ionization of residual gas by the incoming beam with velocity of βc is estimated from the well-known formula:

$$\tau_N = \frac{1}{n_s \sigma_i \beta c} \quad (3)$$

where n_s is the density of scattering gas centers, βc is the beam velocity, and σ_i is the ionization cross section. Measurements with the RGA indicate that residual gas is dominated by H_2, while concentrations of other components are at least two orders of magnitude smaller (see Fig. 9). Density of scattering centers for H_2 residual gas is $n_s = 2n_g$, where n_g is the number of molecules per unit volume at pressure p and temperature T determined from the ideal gas law:

$$n_g = \frac{p}{kT} \quad (4)$$

where k = 1.38 × 10^{-23} J·K^{-1} is the Boltzman constant. Taking into account the value of sensitivity of ionization gauge for H_2 gas as $S = p_{gauge} / p_{actual}$ = 0.46, the actual pressure is estimated to be p = $3.5 \cdot 10^{-6}$ Torr ($4.6 \cdot 10^{-4}$ Pascal). The cross-section values for ionization of different gases by H$^-$ ions with energy of

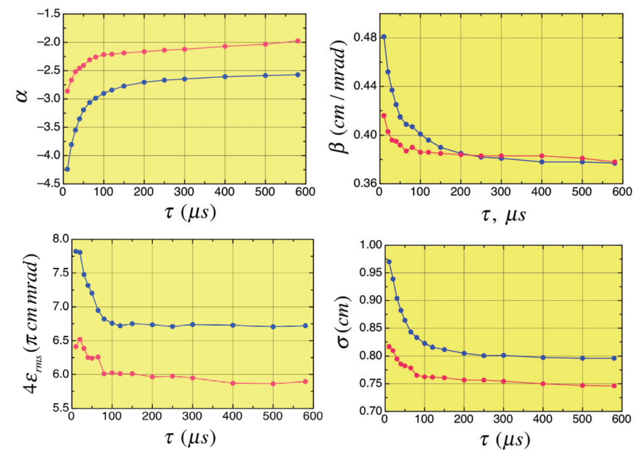

Figure 3. Parameters of 80 keV beam at IDEM2: (blue) horizontal, (red) vertical.

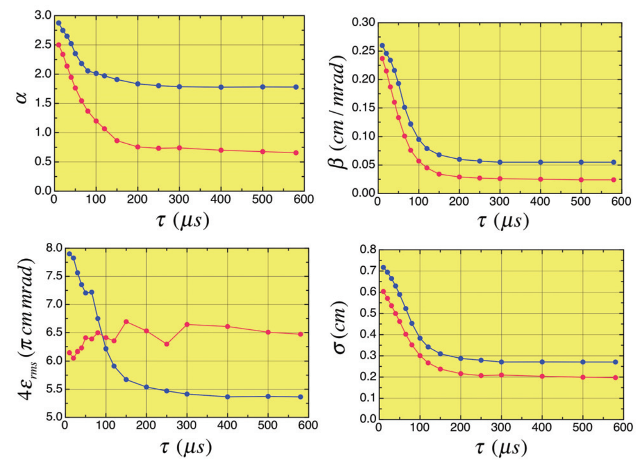

Figure 4. Parameters of 80 keV beam at IDEM3: (blue) horizontal, (red) vertical.

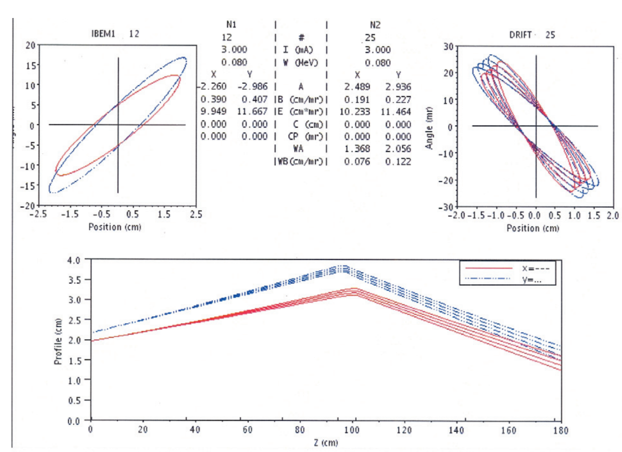

Figure 5. TRACE run between beam emittance stations with different values of beam current.

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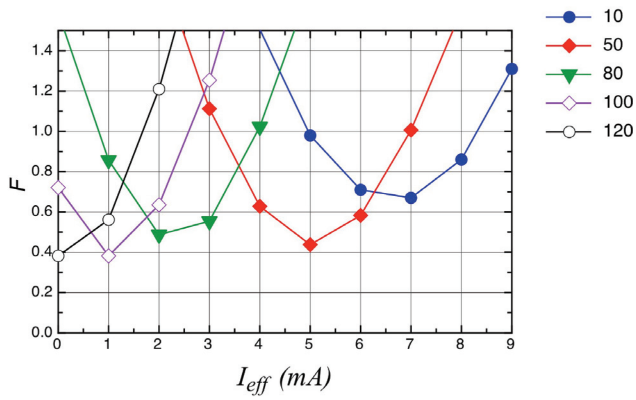

Figure 6. Mismatching factor F as a function of effective beam current in TRACE simulation (numbers indicate pulse length in μs).

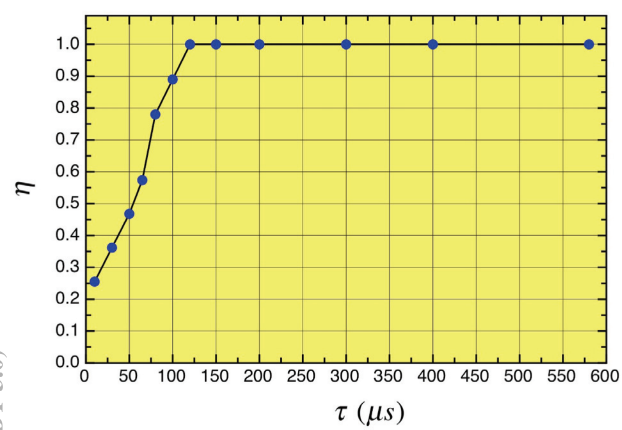

Figure 7. Space charge neutralization of 80 keV beam as a function of beam pulse length.

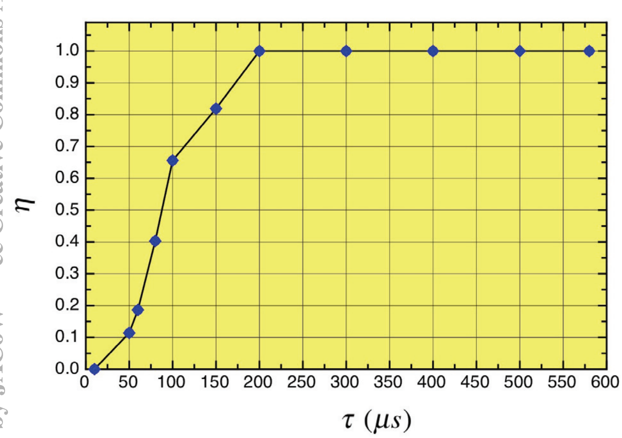

Figure 8. Space charge neutralization of 35 keV beam as a function of beam pulse length.

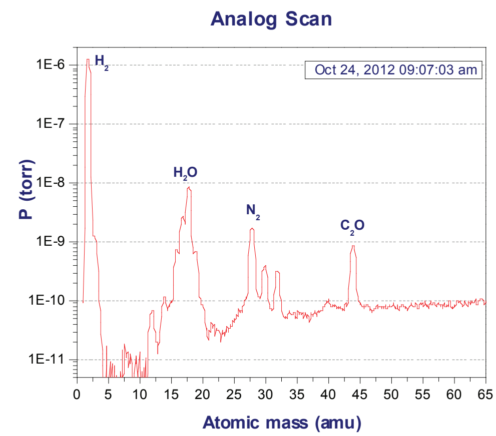

Figure 9. Residual gas analyzer scan.

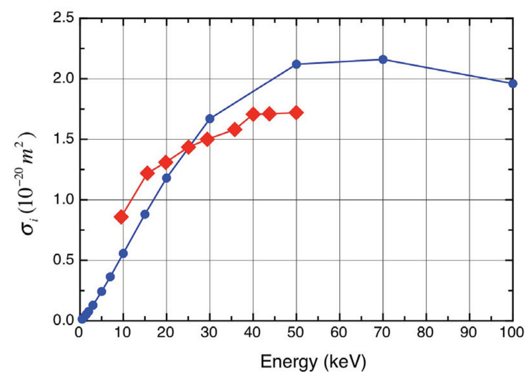

Figure 10. Ionization cross-section of H_2 by H^- (red, Ref. [2]) and H^+ (blue, Ref [3]) collisions.

10 - 50 keV were determined experimentally in Ref. [2]. For higher energies, the values of ionization cross-section can be taken as that of protons [3]. The ionization cross-section for 80 keV beam is $\sigma_i = 2.1 \cdot 10^{-20} m^2$, while that for a 35 keV beam is $\sigma_i = 1.6 \cdot 10^{-20} m^2$ (see Fig. 10). Substitution of these corresponding values into Eq. (3) gives neutralization times for the 80 keV beam $\tau_N = 56\,\mu s$ and for the 35 keV beam $\tau_N = 112\,\mu s$. These time constants are close to the experimentally observed values of $\tau_N = 75\,\mu s$ and $\tau_N = 100\,\mu s$ as illustrated by Figs. 7 and 8, where neutralization $\eta = 1 - \exp(-t/\tau_N)$ reaches the value of $\eta(t = \tau_N) = 0.63$.

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REFERENCES

[1] J.Sherman et al., AIP Conf. Proc. 763, American Institute of Physics, Melville, NY, 254 (2005).
[2] Ya.M.Fogel, A.G.Koval, Y.Z.Levchenko, Zh. Eksp. Teor. Fiz., 38, 1053 (1960) [Sov. Phys. JETP 11, 760 (1960)].
[3] M.E.Rudd, Y-K.Kim, D.H.Madison, J.W.Gallagher, Reviews of Modern Physics, 57, No.4, 965 (1985).