BEAM PERFORMANCE IN H⁻ INJECTOR OF LANSCE

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Abstract

During beam development time in 2010 we performed a series of beam emittance and beam profile scans along 750-keV H- beam transport and 800-MeV linac. The purpose of the measurements was to determine the effects of space charge, slow-wave intensity modulation or chopping, and RF buncher fields on beam performance. As previously reported [1], from our observation and analysis we concluded that the 750 keV H- beam transport is affected by space-charge forces. This presentation will look at the relative importance of space-charge, chopping, and RF-buncher on the observed emittance growth for beam in the short and long pulse regime.

LANSCE LOW-ENERGY BEAM TRANSPORT

The H^- beam injector includes a cesiated, multicusp-field, surface-production ion source and two-stage low-energy beam transport line. Typical value of normalized rms beam emittance extracted from H^- sources is 0.2 π mm mrad. In the first stage, extracted beam is accelerated up to 80 keV, and then is transported through a solenoid, electrostatic deflector, a 4.5° bending magnet, and a second solenoid. The 670 kV Cockroft-Walton column accelerates beam up to energy of 750 keV. The 750 keV LEBT (see Fig. 1) consists of a quadrupole lattice, 81° and 9° bending magnets, a slow-wave chopper, RF bunchers, an electrostatic deflector, diagnostics and steering magnets to prepare beam before injection into Drift Tube Linac (DTL). The chopper is used to prepare different beam pulse structure depending on the application (see Figs. 2, 3).

Slit-collector beam emittance measurements at 750 keV are performed at five locations: 1) TBEM1 (just after the Cockcroft -Walton column), TBEM2 (downstream of the chopper), 3) TBEM3 (downstream of the 81° bend before RF pre-buncher), 4) TBEM4 (between the first RF (pre)-buncher and second (main) buncher), and TDEM1 (before the entrance to the DTL).

SPACE-CHARGE NEUTRALIZATION STUDY

During beam development time in 2010 we performed a series of beam emittance and beam profile scans along 750 keV H- beam transport. The purpose of the measurements was to determine the effect of space charge on beam emittance and the level of space charge neutralization of the beam. The estimated neutralization time of a 750 keV H^- beam in H_2 residual gas at the pressure of 10^{-6} Torr is around 250 μs, which is a significant part of a typical 625 μs beam pulse.

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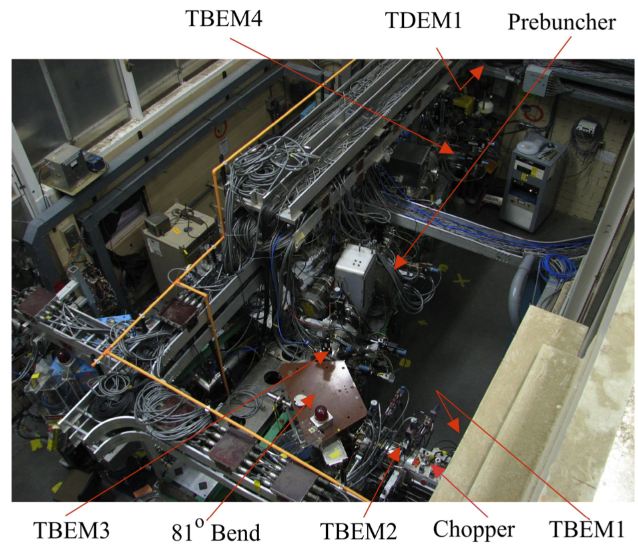
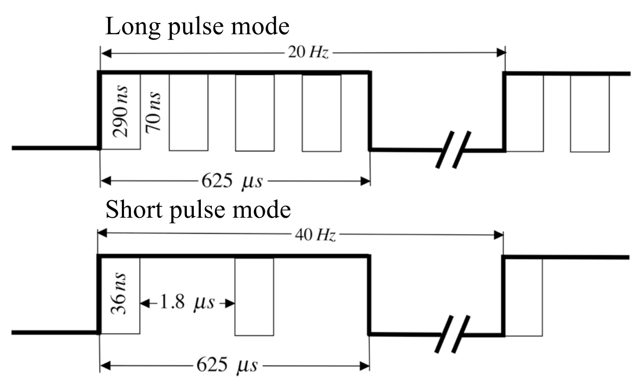


Figure 1. Layout of 750 keV H^- Low Energy Beam Transport of LANSCE.

Figure 2. Slow-wave chopper.



3. Figure 3. Pulse structure of the beam.

Measurements were performed at several pulse lengths in the range of 50 to 660 μs. The emittance was sampled within the last 30 to 50 μs of the pulse. Measurements were performed with an ion source pulse length of 825 μs, while the measured beam pulse was taken after first 200 μs of ion source pulse.

Results of measurements were compared with simulation results of TRACE, PARMILA, and BEAMPATH codes. Measured beam distributions at the starting station TBEM1 were reproduced in a macroparticle model as the initial distribution for subsequent beam simulations. At each 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, α_{exp}, β_{exp}, γ_{exp}, and from simulations α_s, β_s, γ_s, and similarly for F_y [2]. Smaller values of the mismatch factor F indicate better coincidence of results of measurements and simulations.

Table 1 contains the results of beam emittance measurements for different length beam pulses. Results of the measurements indicate that while the total emittance of the beam is close to constant, the rms beam emittance experiences growth up to 17% for τ = 50-100 µs and smaller growth for τ ≥ 150 µs. It is supported by calculation of mismatch factor for each case. The mismatch factor is smaller for simulations with current I = 15 mA at pulse length of τ = 50 μs, and gradually becomes larger for longer pulses. This suggests that during beginning of the pulse τ < 150 µs the beam is space-charge uncompensated, while for the rest of the pulse τ ≥ 150 µs certain compensation occurs.

Measured and simulated beam emittances used in this study are illustrated by Fig. 4. Measured beam emittance projections exhibit the presence of S-shaped distortions in the distributions, especially clear at the small value of beam pulse τ = 50 μs. The appearance of S-shaped beam distribution is attributed to the presence of uncompensated space charge forces. Simulations with full current of I = 15 mA are close to experimentally observed distributions at small values of beam pulses τ = 50-100 µs while simulations with negligible current of I = 0 reproduce beam more correctly for longer beam pulse of τ ≥ 150 µs.

EFFECT OF CHOPPER AND RF BUNCHING ON BEAM EMITANCE

The H^- chopper is located downstream of the Cockcroft-Walton column. It consists of two traveling-wave helix electrodes, see Fig. 2, which apply a vertical kick to the beam. The chopper is normally energized so that no beam gets through. An electrical pulse of length τ = 36 and 290 ns for short and long bunch, respectively, travels along the chopper allowing the unchopped part of the beam pulse to pass through. The minimum width of chopper pulse is determined by the chopper risetime, which is about 10 ns.

Table 1. Measured beam emittance growth from TBEM1 to TBEM3 (H = horizontal, V = vertical) and mismatch factor F between measurements and simulations.

τ, µs	Scan	$\frac{E_{\_total\_TBEM3}}{E_{\_total\_TBEM1}}$	$\frac{E_{\_rms\_TBEM3}}{E_{\_rms\_TBEM1}}$	F 0 mA	F 15 mA
50	H V	1.05 0.98	1.14 1.17	0.28	0.19
100	H V	0.99 1.027	1.08 1.16	0.23	0.26
150	H V	1.06 0.94	1.08 1.05	0.21	0.40
660	H V	0.92 0.82	0.91 1.05	0.17	0.60

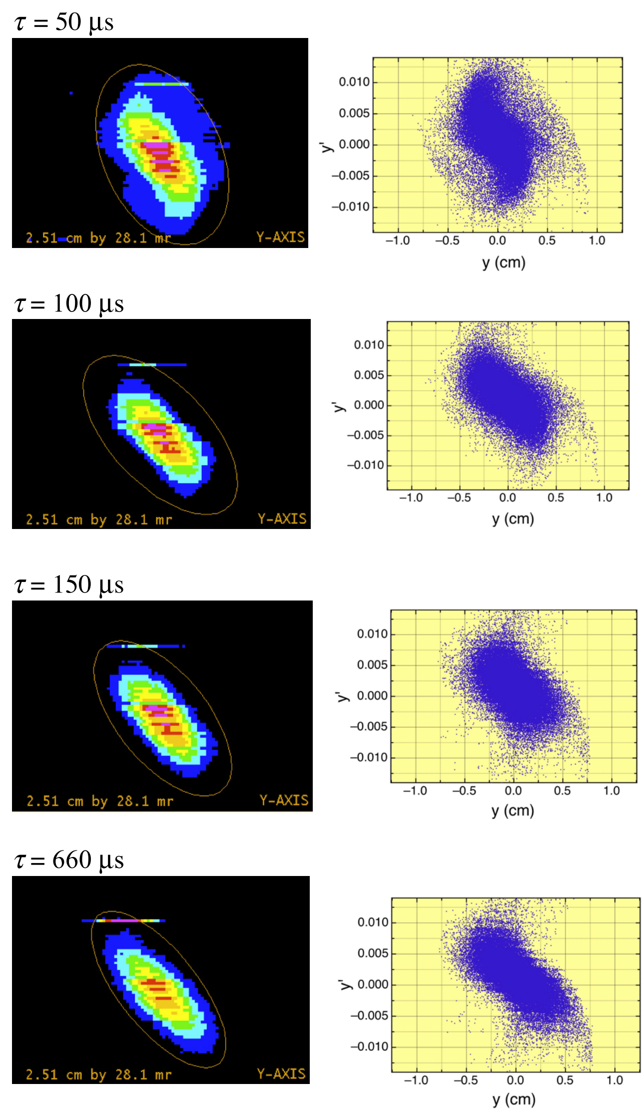


Figure 4. (Left) Measured vertical beam emittance at TBEM3 and (right) BEAMPATH simulations at different values of beam pulse length (simulations performed with current I = 15 mA for τ = 50-100 µs and with current I = 0 for τ ≥ 150 µs.)

The long bunch pulses feed the chopper at the rate of 2.8 MHz, which corresponds to one pulse every 358 ns, which is the revolution time for the Proton Storage Ring at the LANSCE Accelerator Facility. Following the chopper, the leading and trailing edges of the beam are bent vertically, which affects the beam emittance (see Fig. 5).

In order to study the effects of the chopper on beam emittance, a series of measurements were performed for the beam with different values of chopping pulse ranging from 36 to 290 ns. Table 2 contains comparable characteristics of beam emittance at the end of the transport as function of chopper pulse length. Fig. 6 shows the results of beam emittance scans versus chopper pulse length. It is clear that short pulse length of 36 ns affects the beam emittance more significantly than the long chopper pulse of 290 ns. Emittance growth due to short chopper pulse can be as high as 30% while for longer pulse it is of the order of 10%. This is explained by the fact that emittance distortion is caused by the edges of chopper pulse with rising-falling time of 10 ns. These edges are significant fraction of the 36 ns pulse length, but insignificant portion of the 290 ns pulse. The effect of RF bunching on beam emittance is smaller and estimated to contribute about 15% emitance growth.

SUMMARY

A study of 750 keV H^- beam transport was performed. Results of measurements show that with chopper and bunchers off, beam transport might be space-charge uncompensated at the initial part of beam pulse $\tau<150$ μs and space-charge compensated for $\tau \geq 150$ μs. Short chopper pulse (36 ns) together with bunchers significantly contribute to beam emittance growth (up to 65%), while effect of long chopper pulse (290 ns) is substantially smaller.

REFERENCES

[1] Y. Batygin, C.Pillai, L.J.Rybarcyk, "Space-charge Effects in H- Low-energy Beam Transport of LANSCE," 2011 Particle Accelerator Conference, March 28-April 1, 2011, New York, NY.
[2] K.R.Crandall and D.P.Rusthoi, TRACE 3-D Documentation, LA-UR-97-886 (1997).

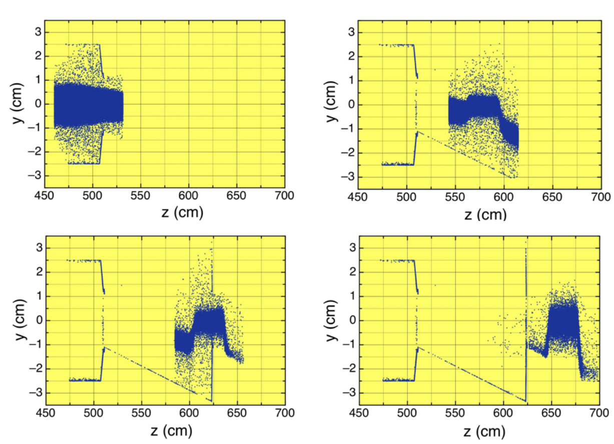


Figure 5. Dynamics of 36 ns beam pulse in chopper.

Table 2. Measured beam emittance growth (H = horizontal, V = vertical) at the end of beam transport (TDEM1) and mismatch factor *F* between simulations and measurements.

Scan	Chop per Pulse, ns	Bunch ers	$E_{total} / E_{total\_TBEM1}$	*F* 0 mA	*F* 15 mA
H V	290	On	1.097 1.091	0.23	0.12
H V	290	Off	1.017 1.019	0.27	0.24
H V	36	On	1.194 1.649	1.17	0.14
H V	36	Off	1.283 1.299	0.22	0.12
H V	Off	On	1.039 1.167	0.29	0.19
H V	Off	Off	1.039 1.042	0.41	0.15

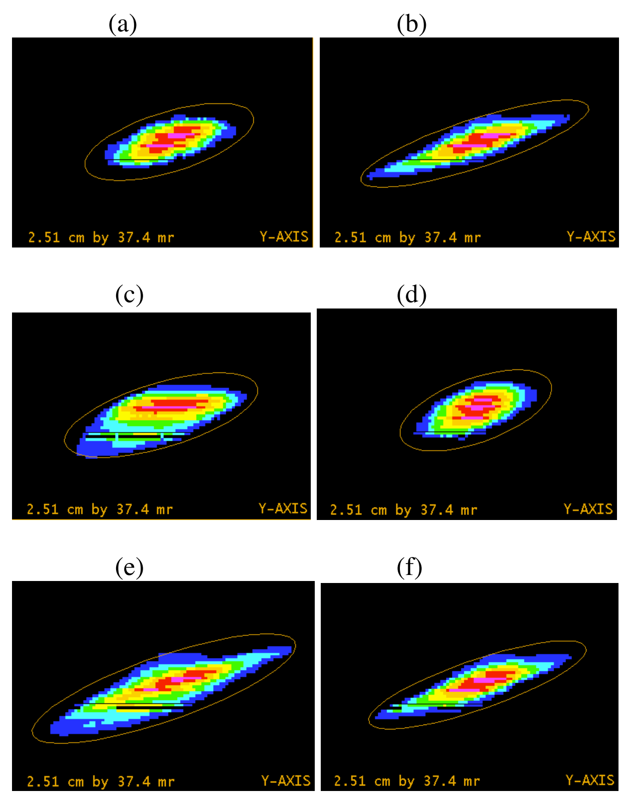


Figure 6. Effect of chopping and bunching on vertical emittance at TDEM1: (a) Chopper Off, Bunchers Off, (b) Chopper Off, Bunchers On, (c) Chopper 36 ns, Bunchers Off, (d) Chopper 290 ns, Bunchers Off, (e) Chopper 36 ns, Bunchers On, (f) Chopper 290 ns, Bunchers On.