BUNCH SHAPE MONITOR MEASUREMENTS AT THE LANSCE LINAC*

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Abstract

Two Bunch Shape Monitors (BSM) have been developed, fabricated and assembled for the first direct longitudinal beam measurements at the LANSCE linear accelerator. The BSM detectors use different radio frequencies for the deflecting field: first harmonic (201.25 MHz) and second harmonic (402.5 MHz) of the fundamental accelerator radio frequency. The first BSM (BSM 201) is designed to record the H^+ beam phase distribution after the new RFQ accelerator at the beam energy of 750 keV with a phase resolution of 1.0° and covering phase range of 180° at 201.25 MHz. The second BSM (BSM 402) is installed between DTL tanks 3 and 4 of the LANSCE linac in order to scan both H^+ and H^- beams at a beam energy of ≈73 MeV with a phase resolution of 0.5° in a phase range of 90° at 201.25 MHz. Preliminary results of bunch shape measurements of both beams for different pulse lengths and repetition rates will be presented.

INTRODUCTION

The Los Alamos Neutron Science Center (LANSCE) sustains a broad user program that includes the neutron scattering studies, radioactive isotope production, basic science research and national security programs by providing multiple accelerated beams to several different experimental areas. The LANSCE linac accelerates protons (H^+) and negative hydrogen ions (H^-) to 800 MeV simultaneously. Accelerated H^- beam is delivered at 20 Hz to the proton storage ring, delivered to a moderated neutron production target for neutron-scattering experiments at the Lujan Center, at 100 Hz to an un-moderated spallation target for weapons nuclear research programs (WNR) and commercial programs, an on-demand or low repetition rate for proton radiography experiments (pRad), and at 20 Hz for ultra-cold neutron production (UCN). At present, protons are only delivered for isotope production (IPF) at 100 MeV. The LANSCE accelerator operates at 120 Hz [1, 2]. Operational parameters are listed in Table 1. All beams are delivered to the LANSCE experimental areas on a pulse-by-pulse basis, initially accelerated in separate Cockcroft-Walton-based injectors, to energy of 750 keV, and to a final beam energy of 800 MeV by a 201.25-MHz-drift tube linac (DTL) and 805-MHz coupled cavity linac.

In order to better understand longitudinal dynamics of both beams during tuning and operations we have purchased bunch-length measurement systems from the Institute for Nuclear Research of Russian Academy of Science in Moscow in 2012. Both BSMs were delivered and assembled at LANSCE during summer 2014. Preliminary monitor commissioning, instrument calibrations, laboratory tests and tuning without beams were performed at that time. Based on a project review in 2015, the decision was made to install the first BSM 402 between DTL tanks 3 and 4 during the next extended maintenance period. The second BSM 201 installation is awaiting completion of the RFQ test stand. The BSM 402 detector was successfully mounted and aligned in the beam line in July 2016. First bunch monitor shape measurements of low current tuning H- beam (1 mA) were recorded on August 7, 2016 during start-up of the LANSCE linac. With BSM 402 located between DTL tanks 3 & 4 we are now able to measure the bunch shapes for both beam species under variable operating conditions up to a 4-Hz repetition rate (Table 1). In this paper we discuss the first direct measurements of H+ and H- bunch profiles.

Table 1: Typical 120-Hz LANSCE Beam Parameters

Area/Beam	Duty Factor	Chopping Specs
Lujan, H^-	20 Hz x 625 µs=1.25%	290 ns burst every 358 ns
WNR, H^-	100 Hz x 625 µs=6.25%	Single micropulse every 1.8 µs
pRad, H^-	1 Hz x 300 µs = 0.03%	20-30, 60 ns beam bursts, variable spacing
UCN, H^-	20 Hz x 625 µs = 1.25%	Variable
IPF, H^+	100 Hz x 625 µs=6.25%	None

BUNCH SHAPE MONITOR

The basic working concept of the bunch shape monitor is straightforward. First, the device transforms longitudinal distribution of ion beam into a spatial distribution of secondary electrons emitted from a thin wire, inserted into the beam. These electrons are then analysed using a transverse modulation from an RF deflector synchronized with the basic RF frequency of the linac, which selects a specific phase slice of the original ion beam to be sampled. The detailed description of the operation of the BSM detector is published elsewhere [3, 4]. The LANL BSMs which use two different frequencies for the RF deflecting field are shown in Fig 1. The fundamental linac frequency of 201.25 MHz is used in BSM 201 with the phase resolution of 1°. BSM 402 uses second harmonic frequency of 402.5 MHz with corresponding phase resolution of 0.5°. Both detectors have an energy-selecting bending magnet which separates low energy secondary

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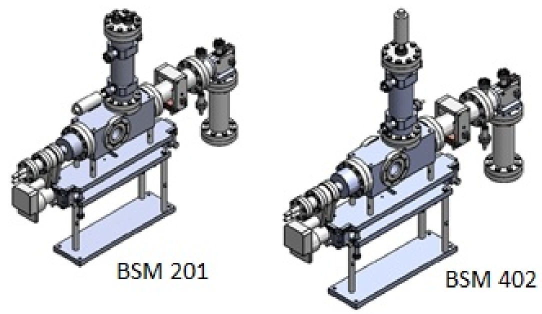

Figure 1: 3D models of BSM 201 and BSM 402.

electrons from high-energy stripped electrons and increases the dynamic range of measurements. A set of BSM working parameters obtained during laboratory tuning with thermal electrons from the heated target wire are listed in Table 2. The same set of parameters was used in the first bunch scans with BSM 402 except for the steering voltage which was found to be optimal at 226 V.

Table 2: Optimized Setting Points of LANL BSMs

Parameters	BSM-201	BSM-402
Target potential, kV	-10.0	-10.0
Focus. lens voltage, kV	-6.85	-7.05
Steering voltage, V	179	129
Steering magnet, mA	+34	0.0
Bending magnet, mA	330	350
SE multiplier tube, kV	1.0÷1.3	1.0÷1.3

EXPRIMENTAL RESULTS

At LANSCE, during accelerator start-up periods, longitudinal tune-up to set the phase and amplitudes of the bunchers and DTL tanks are performed using a phase scan procedure (PS201) at low peak beam currents of 1 mA. These interceptive phase scans provide an indirect estimate of the beam phase distribution at nominal 5° resolution. Using the new BSM 402, the beam phase can be measured now with an order of magnitude higher resolution. A new master timer gate (DIAG) was required to enable triggering of the BSM electronics. This new gate allows us an easy switch between various beams: the long bunch enabled gate (LBEG) for PSR/Lujan, the micro pulse enabled gate (MPEG) for WNR, the H+ isotope production gate (H+IPG) etc.

First Longitudinal Profiles of H^+ and H^- Beams

We have successfully recorded various bunch profiles at data sampling rates of 1 and 4 Hz. Typical pulse length for all measured beams was 150 μsec. A BSM measured was triggered about 3000 μsec before incoming beam pulse intersects with the target wire. Characteristic 3D BSM recorded bunch profiles of negative ion beam and protons are shown in Fig. 2. In Fig 3 to Fig 6 show the phase profiles (left graphs) and measured secondary electron currents emitted from target at 10 kV high potential (right graphs) for three H^- ion beams and H^+ beam. In this presentation we are using the signal intensities that are summarized over each phase step or time increment. Recorded profile data also provide a monitoring of the time evolution of bunch shapes along the beam macro pulse. The H^- beams have different profiles from H^+ beam. The low current H^- beam has a main peak at the

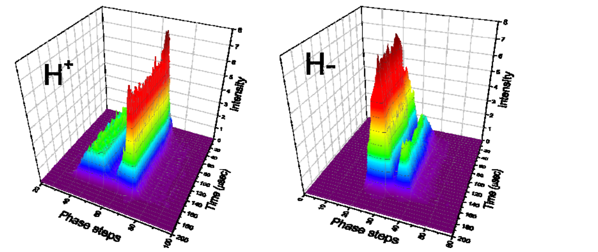

Figure 2: Typical BSM data of H^+ and H^- ion beams.

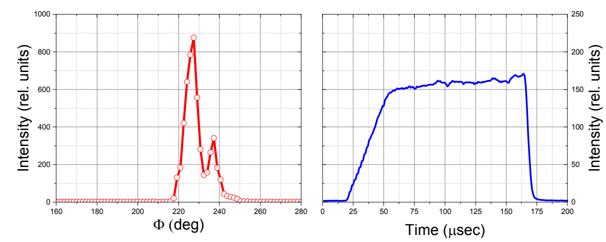

Figure 3: Bunch shape profile of 1 mA peak H^- beam and secondary electron current along the macro-pulse.

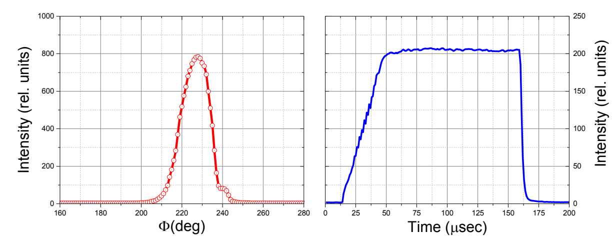

Figure 4: Bunch shape profile of 10 mA peak H^- beam (LBEG) and secondary electron signal along macro-pulse.

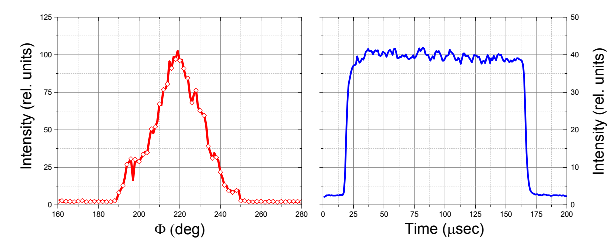

Figure 5: Bunch shape scan of 17 mA peak micro-pulse H^- beam (MPEG) and macro-pulse current signal.

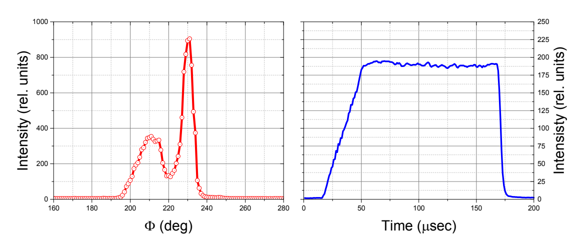

Figure 6: Bunch shape scan of 4 mA peak H^+ beam (H+IPG) and macro-pulse current signal.

phase Φ=226.3±0.5° with the FMHW=7.3±0.5° and it has a tail with an additional peak on the high phase side. The H^+ ion beam has a reversed shape and the main peak has the phase centered on Φ=230.1±0.5° and the width of 6.4°. The H^+ beam has also very strong tail on the low phase beam side (see Fig. 3 and Fig. 6). The high current H^- beam has more symmetric profile without strong tails (Fig. 4). This LBEG beam is twice as wide (FWHM= 13.4±0.5°) and the centroid of H^- beam peak did not move (Φ=226.8±0.5°, Fig. 4). The micro pulse beam for WNR target has 10x smaller signal intensity due to the time structure of beam (see Table 1). For the beam setting with a count-down (CD) of 1, 150 µsec length, 4Hz repetition rate, the observed bunch has width of 28.4 ±0.5° and its position is measured on phase of Φ=219.2 ±0.5° (Fig. 5). The error bar of 0.5° is determined mainly with the instrument resolution. Additionally, the phase calibration of the BSM was verified using an external phase shifter inserted between the BSM electronic control unit and the 402.5 MHz references signal.

Sensitivity of Longitudinal Phase Measurements

The BSM detectors have been used for linac tuning and troubleshooting at several accelerators for many years [5, 6]. To understand the sensitivity of our bunch shape measurements and their value as a tool for tuning and troubleshooting the LANSCE accelerator, the phase and amplitude set points of the pre-bunchers and main buncher in the low-energy beam transport section of the accelerator were varied and the sensitivity of the measured bunch shapes to these operational parameter changes were studied. Figure 7 shows the results of varying the H^+ prebuncher set points from the nominal phase and amplitude of 103° and 30%, respectively, to new set points: Φ_{pb}=130° and A_{pb}=45% and then returned back (set point changes made in A->B->C->D->A order).

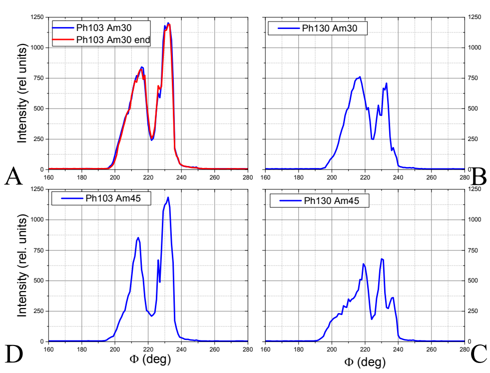

Figure 7: H+ ion bunch shape sensitivity on variations of prebuncher phase and amplitude.

The H^+ bunch shapes showed strong changes in form and signal intensity. The plot 7a shows the reproducibility of the bunch profiles recorded at the beginning and end of set point variations In Fig. 8 are shown results when H^- prebuncher set points were changed for ΔΦ=35° and ΔA_{pb}=10%. The variation of prebuncher amplitude didn't affect the BSM scan, but the change of prebuncher phase shifted the bunch peak for ΔΦ=-3.6° and made the bunch width broader for 4.3° (width increase from 15.7° to 20.0°). In third set we have made changes of main buncher set points higher for 10° and 10%. The phase scans and noise level are presented in linear and logarithmic scale in Fig. 9. The applied changes of the main buncher set points did not modify the phase distribution of H^+ beam.

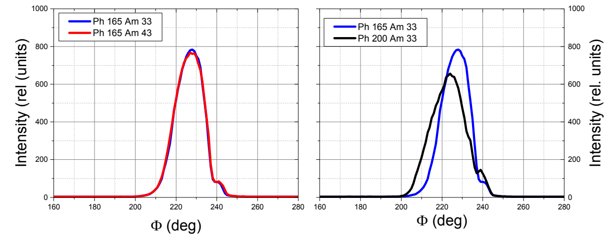

Figure 8: H^- ion bunch shape sensitivity on variations of prebuncher phase and amplitude.

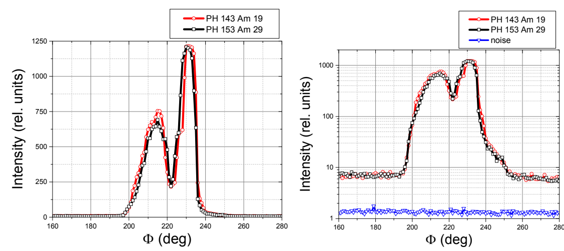

Figure 9: H^+ ion bunch shape sensitivity on variations of main buncher phase and amplitude.

CONCLUSION

We have presented the results of the first longitudinal beam profiles of H^+ and H^- ion beams with high phase resolution (0.5°) using the newly-installed bunch shape monitor at the LANSCE linac. This new capability will provide valuable information about linac set points during beam tuning including aiding in improving beam losses, help with troubleshooting linac performances, and to benchmark beam simulation models. Future application of the newly-installed BSM will be to study longitudinal halo effect or to estimate the longitudinal beam emittances.

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