EFFECTS OF LOW FREQUENCY BUNCHER (LFB) FIELD VARIATION ON AN H^- BEAM PHASE-ENERGY*

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Abstract

We examined the correlation between phase-space distribution of a 750 keV H^- beam and amplitude set-point of a low frequency (16.77 MHz) buncher (LFB) cavity. The beam current, x–y dimension, and Courant–Snyder twiss parameters are reported for variation of LFB amplitude set-point. Measured data indicated that a tuned peak voltage of LFB is essential to optimize the beam bunch and current.

INTRODUCTION

With RF linacs, phase-energy bunching of the beam is necessary to accumulate particles inside the separatrix [1]. This bunching is different than temporal compression [2] (used to obtain higher compression ratio). The phase-energy bunch must be optimum before injection into RF Drift Tube Linac (DTL) to ensure: (1) the beam capture rate, (2) reduced beam loss, (3) improved final beam quality, and (4) reduced radiation spill.

The Los Alamos Neutron Science Center (LANSCE) accelerator simultaneously utilizes H^+ and H^- beams to support multiple user sites [3,4], such as the isotope production (IPF), Weapon Neutron Research (WNR), and Proton radiation (PRad). Cockroft-Walton based injectors are used to accelerate H^- and H^+ beams up to 750 keV. The long pulsed beams are then converted into bunches and passed onto the Drift Tube Linac (DTL) cavities. After traversing all four DTL tanks, the bunch energy is increased to 100 MeV. The H^+ species are deflected into the IPF line, while the H^- continue on to the Couple Cavity Linac (CCL). The 44 modules of the CCL are used to increase beam energy to 800 MeV. The final beam is then delivered to Lujan, WNR and PRad facilities.

For the WNR facility, linac micropulses are initially formed in the low energy transport section. A part of this section is shown schematically in Fig. 1. The segment, consists of a signal pattern generator chopper (not shown); a 16.77 MHz Low Frequency Buncher (LFB) and the 201 MHz Main Buncher (MB). The chopper cuts the initial 625 µs beam into 347 mini pulses. Each of these chopped 20 nsec pulses are space by 1780 nsec. The beam energy is sinusoidally modulated by the buncher gap voltage. Once the beam crosses this bunching occurs at a distance as beam drifts downstream. The regular spacing between linac microbunches is 1.8 µs. Therefore, these micropulses predominantly depend upon the 16.77 MHz low frequency buncher field.

The drift distance at which a maximum bunch change is expected, changes, if the LFB RF voltage set-point is not optimized. Additional tuning is required to compensate for variations. The beam tuning is optimized, based on hardware and software utilization properly. The LANL developed TRACE model [5] was used to calculate the required strength of focusing magnets at the low energy (750 keV) transport to DTL sections. Experimental measurement of Twiss parameters α, beta (β); and emittance (ε) are utilized to run the code [5]. Therefore, it is of considerable interest to verify the Twiss parameters stability with minor or major change of LFB amplitude set-point.

In this proceeding, modulation of a cavity peak voltage, and change of drift length for a given peak voltage are addressed. The low frequency buncher instrument set-point calibration is presented. The beam emittance, current, and profile are reported. Finally, the beam phase-energy variation with variation of cavity peak voltage is analyzed using a computational code PARMILA [6].

MODULATION OF RF PEAK VOLTAGE AND BUNCH LENGTH

The phase-energy bunch is defined by the field of RF. The cavity field applies a kick to the energy of the pulse. As a result, the phase projection of the phase-energy coordinates is affected, and a narrower bunch is shaped at some drift distance; based on correlation of time and off-momentum particles coordinates [7]. A modulated voltage (V) of cavity is written as,

$$V = V_0 \sin(\omega t), \tag{1}$$

where, V_0 is the peak voltage; $\omega = 2\pi f$, is angular frequency of the cavity field for RF frequency (f); and t is the time. The RF phase (ϕ) is ignored in above equation as a net gain of energy not expected. Figure 2 shows modulated voltage ramps with time for variation of peak voltages. A phase-energy bunching distance, L, from a cavity, is written by [1],

$$L = \frac{\lambda}{2\pi}\frac{mc^2\beta^3\gamma^3}{qV_0}, \tag{2}$$

where, λ is the RF wave-length (a ratio of light velocity to RF frequency); m, c, q have its usual meaning of mass, velocity of light, and charge of a particle; γ is the Lorentz factor, and β is the relativistic velocity factor; V_0 is the peak voltage of cavity (a product of peak RF field (E) and length of cavity). Figure 3 shows phase-energy bunching distance vs peak voltage, calculated using the Equation (2). As seen in the graph, distance of a phase-energy bunching is perturbed once the cavity's field is altered. That means, a bunch can

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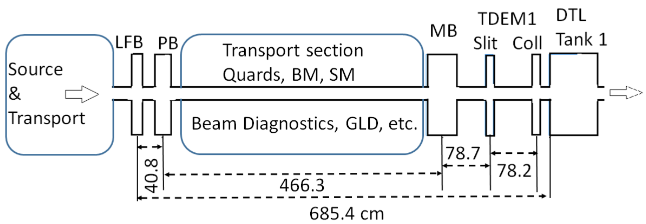

Figure 1: A sketch represents major components of 750 keV beamline, consists of 16.77 MHz Low Frequency Buncher (LFB); emittance scanner (TDEM1 slit and Coll); Main buncher (MB). Other components, such as, Quads, Bending Magnet (BM), Steering Magnet (SM), diagnostics, Ground Level Deflector (GLD) etc. are also equipped in the transport section. A current monitor (TDCM1) is located at between TDEM1 slit and collector.

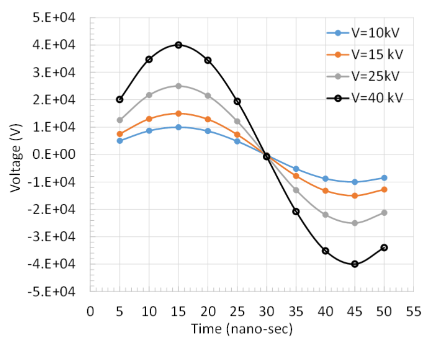

Figure 2: Modulated voltage ramps with time for voltages of 10 kV, 15 kV, 25 kV, and 40 kV, calculated, using the Equation (1) for RF frequency of 16.77 MHz.

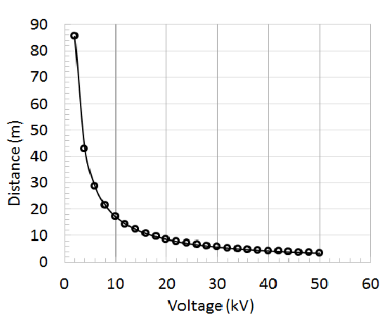

Figure 3: A calculated result of bunching distance (L) vs cavity peak voltage (V). The Lorentz factor (γ=1+beam energy/proton rest energy), and relativistic velocity factor (β) are of 1, and 0.04, respectively, for a H^- beam of energy 750 keV.

occur at near and far distances to the cavity dependent on the magnitude of cavity peak voltage. The bunch time length and momentum spread are manipulated by cavity field and beam velocity.

LANSCE LOW FREQUENCY BUNCHER

Figure 4 shows a sketch of two gap cavity low frequency buncher [8]. A distance between the gap cavity is ≃ 35.71 cm, known as cavity length. An acceleration gap length is of 0.953 cm. The velocity of 750 keV low energy beam is of 1.19x10^7 m/s; flight time through an acceleration gap is of ≤ 0.80 nsec. An operating frequency of buncher is of 16.77 MHz (60 nsec period), as mentioned earlier. This frequency is 12 times smaller than the LANSCE DTL operating frequency. A main buncher (MB) of frequency 201.25 MHz modulates beam with DTL 201.25 MHz frequency. Figure 5 shows typical operational waveforms of the LFB RF signal; reflected power signal, and cavity amplitude.

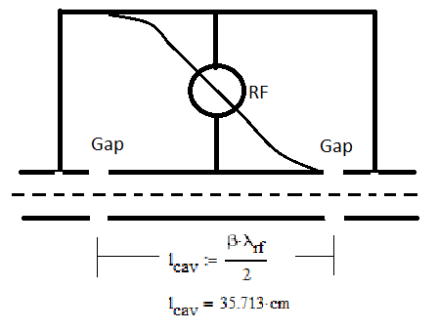

Figure 4: The buncher consists of two gaps, each of 0.953 cm, separated by a distance of 35.7 cm. This distance is traveled by synchronous particles during 180° of RF rotation.

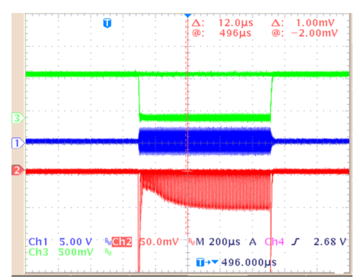

Figure 5: Typical operational waveforms of the LFB RF signal (line in blue, channel 1). The reflected power signal (line in red, channel 2) amplitude is lower compared to RF signal (line in blue) represents good standing of RF system. The line in green (channel 3) represents amplitude of cavity. Note: scale for blue=5V, red=50 mV.

LFB Set-point Calibration

Figure 6 shows measured peak voltages corresponding to the cavity amplitude set-points. The cavity set-point was calibrated [9] using a standard method [10, 11], which uses a direct measurement of RF voltage between two spheres – before a flash-over. It was observed that the voltage breakdown threshold is lower than the DC for several MHz RF signal. As an example, a 15 kV DC gap would breakdown at ≃ 13 kV RF; and a 7 kV DC gap would break down at 6 kV. An RF breakdown is ≃ 85 % of the DC value [9]. Measured voltage was an output of a resonant circuit; and the net buncher peak voltage is of twice [12] for two-gap cavity.

Table 1: Measured Twiss parameters, Emittance (E) with variation of the LFB voltage. The beam current was measured at upstream of first tank of DTL (TDCM1, energy 750 keV) and downstream of tank 2 of DTL (02CM1I3, energy 40 MeV).

LFB	Profile (cm),16%-84%		α		β		4*E(rms) (πmm-mrad)		Peak current (μA)	
(%)	Hori. (x)	Ver. (y)	Hori.	Ver.	Hori.	Ver.	Hori.	Ver.	750 keV	40 MeV
55.6	0.56	0.84	−0.172	−0.593	0.139	0.194	2.02	2.67	-442	-247
57.6	0.59	0.85	−0.196	−0.642	0.141	0.199	2.05	2.66	-449	-241
59.6	0.61	0.86	−0.228	−0.690	0.150	0.200	2.03	2.76	-447	-227
61.6	0.62	0.87	−0.262	−0.786	0.153	0.213	2.02	2.75	-444	-215
63.6	0.64	0.88	−0.310	−0.861	0.162	0.221	2.07	2.70	449	-202
65.6	0.65	0.90	−0.352	−0.934	0.169	0.231	2.08	2.72	-441	-183
67.6	0.67	0.91	−0.414	−1.021	0.180	0.243	2.09	2.68	-441	-162

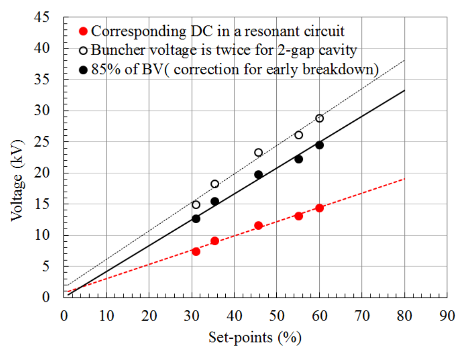

Figure 6: The buncher peak voltage corresponds to an amplitude set-point (ASP). ASP can be varied between of 0 and 999, corresponding to the operator's knob range is of 0 to 100 %. The data in line with red dots represent peak voltage for a gap. The voltage that was measured an output of a resonant circuit. An actual reading is twice for the 2-gaps as shown in line with hollow circles. The data in line with black dots represent buncher peak voltage with correction for early breakdown at a temperature of 72.8° F.

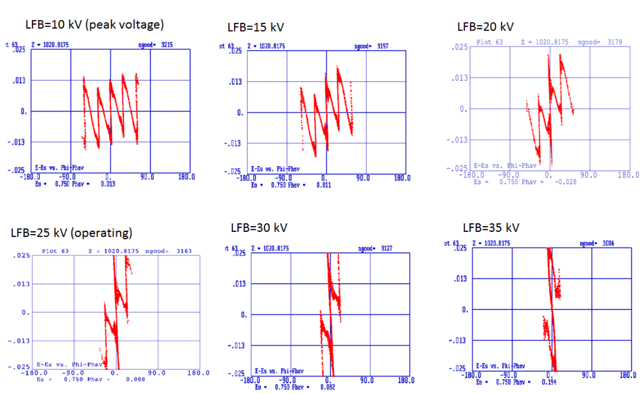

Figure 7: The beam phase-energy spectrum at upstream of DTL, with variation of LFB peak voltage; calculated using PARMILA. A well bunched phase-energy spectrum is observed with peak voltage of 25 kV to 30 kV.

BEAM MEASUREMENT AND RESULTS

The beam emittance was measured downstream of the bunchers (TDEM1, see Fig. 1). This position is roughly a meter upstream to first DTL tank. A slit and 70 wire collector module were used to measure emittance of 750 keV beam. Emittance code developed at LANL was used to calculate α, β and 4 rms emittance using experimental data. The beam profile was measured using a harp type assembly (local name TDHP01, not shown in Fig. 1), located upstream of emittance device (TDEM1 slit). The beam current was measured between slit and collector of the emittance station (TDEM1), and at downstream end of tank 2 & 3 of DTL. Table 1 shows the results of the measurement. Measured Twiss parameter α and β represent that divergence and the transverse size of the beam increased with increasing LFB amplitude. An increase of horizontal and vertical profile (16% and 7.7%, respectively for increment of LFB amplitude) support the measured results of α and β. An increase of 4*emittance (rms) of 3.4% was observed for an increase of LFB amplitude from 55.6% to 67.6%. Though a significant change of beam current was not observed at upstream of first DTL tank, it was changed at the downstream end of DTL tank2 with increase of LFB amplitude, and thus the capture was changed from 55% to 37% (for 55.6% to 67.6% change of the LFB amplitude). But the model, shown in Fig. 7, using PARMILA shows that a better bunch was observed at a cavity peak voltage of 25 to 30 kV. Further analysis of data and co-relation to the model will be investigated in the future.

CONCLUSION

The 750 keV beam profile and phase-space distribution were measured as the LFB peak amplitude set-point was varied. The Twiss parameters and captured beam size increased when peak voltage set-point was increased. This observation also reflected a variation in the phase-energy distribution when cavity peak voltage is varied.

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