

# DIAGNOSTIC AND NUMERICAL STUDIES OF THE IPNS LINAC WITH A RECENTLY INSTALLED BUNCHER AMPLIFIER\*

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## Abstract

The Intense Pulse Neutron Source (IPNS) 50-MeV Drift-Tube Linac uses a single-gap, single-harmonic buncher cavity to increase transmission efficiency. However, it is also the case that the linac output beam longitudinal and transverse emittance is dependent on buncher amplitude and phase as well as with the input beam energy and emittance. The linac is the injector for a Rapid Cycling Synchrotron (RCS) that increases the beam energy to 450 MeV and shortens the pulse to the 100 ns region. The RCS is operated loss-limited, and its operating current is strongly dependent on the properties (emittance, and its variation during the pulse) of the beam from the linac. A new amplifier has been installed allowing for better amplitude and phase control of buncher rf. This new amplifier gives independent control of amplitude and phase, permitting more systematic studies of the relation between linac and RCS performance. This paper presents the results of recent studies where we characterize beam properties that lead to high efficiency operation in both linac and RCS, and compare them with simulation calculations.

with and without the buncher was measured, then the indicated voltage was adjusted to give the match to PARMILA predictions shown in Figure 1. These measurements indicate that our normal operating condition is with an input beam energy of 20 to 30 keV below the 750 keV design for the linac. The data also serves to give a measure of our normal buncher voltage, approximately 11 kV. Sparking limits the DC voltage, and with the existing pulsed buncher, for reliable operation we are limited to about 730 keV input beam energy. This has important implications for the medium energy beam transport (MEBT) system and the RCS, as will be described later in this paper.

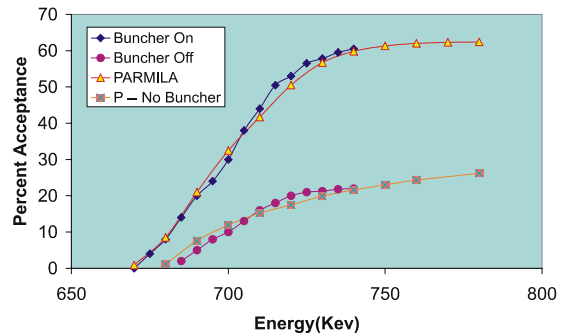


Figure 1: Linac Transmission versus input energy.

## 1 INTRODUCTION

It is known that a shift in energy spread of the linac output during the macro-pulse adversely affects the performance of the Rapid Cycling Synchrotron (RCS)[1]. Investigation into the nature of the energy spread fluctuations continues. A new buncher amplifier has been in operation since February allowing for independent control of buncher amplitude and phase. In addition to this new hardware, the Energy Spread and Energy Monitor (ESEM) provides on-line, real-time linac output data[2]. Output energy and energy spread data as well as transmission efficiency measurements are compared with an updated PARMILA model of the IPNS Linac.

## 2 PRE-ACCELERATOR BEAM

The linac is injected with H<sup>-</sup> ions extracted from an ion source located in the terminal connected to a 750 kV Cockcroft-Walton power supply. The voltage seen by the beam is the sum of the terminal voltage (DC voltage plus the contribution of the pulsed buncher) and the extractor voltage (typically 20 kV). Because we lack a precision 750 kV resistor divider and the pulsed buncher capacitively couples so that its full voltage does not appear at the terminal, we must “calibrate” the terminal potential measurement with the beam. Linac transmission

## 3 BUNCHER AMPLIFIER AND BUNCHER

The buncher amplifier is constructed using a 350-W solid-state class AB VHF driver followed by a Burle 7651 pulsed-power tetrode housed within a coaxial, resonant cavity. The amplifier underwent initial machine testing at the end of 2001, and was permanently installed and ready for our first run this year in February. The amplifier replaces a direct-coupled system where a loop was placed in the DTL tank. Phase control was accomplished using a “trombone” in the co-axial line between the pick-up loop and the buncher cavity. Though this approach worked, it was difficult to independently control the amplitude. Adjusting buncher cavity field and phase to optimize linac performance is now much easier with the new amplifier. The buncher cavity is a capacitively-loaded, ¼-wave resonator. A SUPERFISH model of the cavity is presented in Fig. 2

## 4 LINAC DIAGNOSTIC STUDIES

### 4.1 Energy Spread and Energy Monitor (ESEM)

Results of an initial study with the new buncher amplifier and its rf amplitude on linac output energy and

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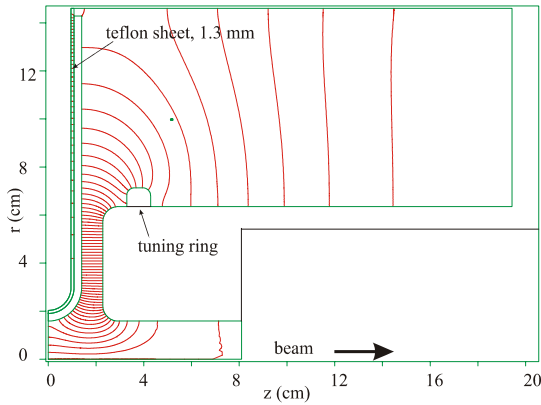


Figure 2: Quarter-wave, capacitor-loaded buncher cavity.

energy-spread are shown in Figure 3. The data was collected in December 2001 with the ESEM diagnostic, modified slightly from its earlier description[2]. The four strip-line data channels are now recorded on a Tektronix TDS7254 oscilloscope at 5 GS/s; in addition, four rf pick-up signals, 1 from the buncher and 3 from the DTL, are acquired for the same pulse using a TDS694c at 1.25 GS/s or 2.5 GS/s. The deep memory of these oscilloscopes allow the entire macro-pulse to be digitized.

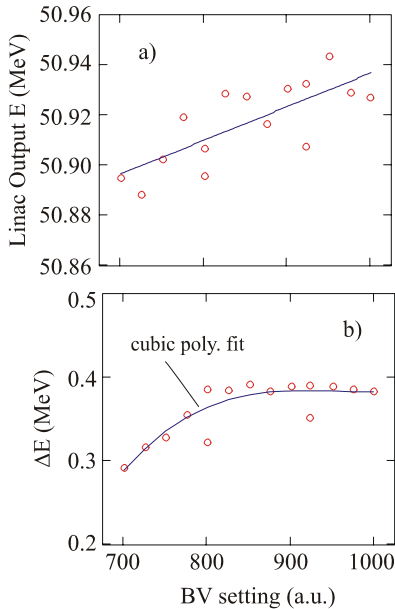


Figure 3: Linac a) output energy and b) energy spread.

#### 4.2 Wire Scanners and Fixed Wire

A persistent feature in the 50 MeV transport line is the appearance of double-peaked horizontal profiles observed on some of the wire scanners (WS). An example of a double-profile is given in Figure 4. Typically, a WS profile is built up by stepping a pair of wires through the beam while running at a low repetition rate, usually 5 Hz. The wires will step in 10 mil increments (0.25 mm) over a total distance of 3.2 in. (81.28 mm). One wire is oriented in a vertical direction to record the horizontal profile and the other wire is positioned along the horizontal axis to

sample the vertical profile. Both wires move in a plane perpendicular to the beam. The wire signals are then

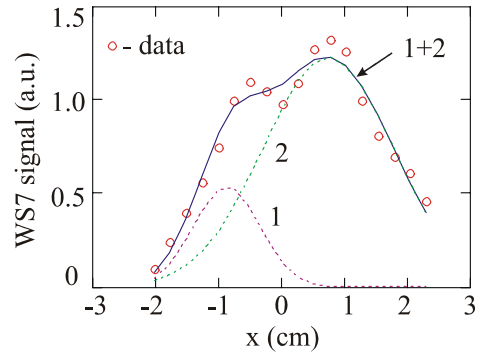


Figure 4: Horizontal wire scanner data from WS7, best fit with two Gaussian profiles.

sampled at a given time in the linac macro-pulse. In the fixed wire mode, the wires remain stationary at a specific location and the temporal signals are recorded for the full duration of the macro-pulse. The dispersion function in the transport line reaches a maximum near the location of wire scanner 7 (WS7), approximately 17.3 meters from the linac exit aperture. The dispersion coefficient at WS7,  $D=6.3$  m, can be used to estimate the energy difference between the two distributions as follows,

$$x_D = D \frac{\Delta p}{p} \quad (1)$$

The data in Fig. 4 is best fit with a double Gaussian profile having a spatial separation of 1.6 cm between the peaks. From Eq. 1, the energy separation is expressed as,

$$\Delta E = \frac{\Delta x_D}{D} \beta^2 E \quad (2)$$

or 0.25 MeV. The data presented in Fig. 4 was obtained in April 1998. Fixed wire data collected in April 2002 again shows a spatial separation of 1.6 cm between two peaks; however, the fraction of beam in each profile has changed. Table 1 summarizes best fit parameters for the data from 1998 and 2002. The bi-Gaussian results in Table 1 are not unique, other solutions are possible; however, those presented have the smallest rms errors.

Table 1: WS7 double-peak profile comparison

Date	Prof	A (a.u.)	xo(mm)	xe(mm)	err,rms
1998	1	0.544	-8.771	7.352	0.067
0421	2	1.226	7.317	14.66	
2002	1	1.552	-4.639	14.92	0.042
0430	2	0.551	11.63	19.77	

## 5 PARMILA MODELING

SUPERFISH (SF) was used to model the cells and obtain the necessary transit time factors for PARMILA. The present model takes into account transit time transitions where aperture changes occur. SF results are in excellent agreement with transit time measurements performed by D. E. Young and C.W. Owens[3,4].

PARMILA simulations suggested that several observable effects will result from variations in buncher amplitude and phase. For example, over-focusing longitudinally (buncher voltage too high) leads to a bifurcation in the linac input distribution in both space and energy. Depending on input phase, the bifurcation in the injected pulse can be amplified through the linac so that bunches of two distinct energies emerge. The effective output energy spread is significantly increased when bifurcation is fully developed. On the other hand, if buncher voltage is low, the beam exits the linac with an energy spread too narrow for stable acceleration in the RCS. Regarding input phase, offsets on the order of  $\pm 20^\circ$  lead to substantial dipole oscillations in bunch energy. The average energy of the bunch can rotate around the synchronous value with amplitudes as high as 0.25 MeV.

The mismatch between the actual and design input energy introduces a dipole oscillation in much the same way as a phase mismatch. A PARMILA plot of the micro-bunch energy distribution with respect to the synchronous energy as a function of cell number is presented in Fig. 5. In Fig. 5a) PARMILA is given the nominal design input energy of 750 keV; whereas in Fig. 5b), an input energy of 720 keV is specified. The latter value is close to the actual injected energy. A longitudinal dipole oscillation is predicted by PARMILA for the low input energy case. Phase-space plots of the output beam for the two input energy cases are given in Fig. 6. Although the mean-energy fluctuation is relatively large, the energy spread of the output beam does not change appreciably. A comparison of output energy spread predicted by PARMILA and measured by the ESEM is presented in Figure 7. Each ESEM datum is measured between 50 and 60  $\mu$ s into the macro-pulse.

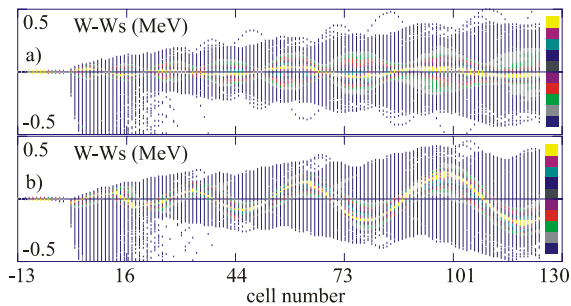


Figure 5: W-Ws a) 750 keV and b) 720 keV injected.

## 6 DISCUSSION

Varying buncher voltage and phase do lead to changes in linac output energy and energy spread (ES), in general agreement with earlier PARMILA studies[1]; however, because of the input energy offset, not modeled in the earlier work, it is difficult to draw direct comparisons. ESEM ES data presently show substantial scatter over what has been seen during the diagnostic's first full year of operation in 2001. It is not clear if this is because of some change in the linac or a problem in the data acquisition system. The ESEM ES algorithm is presently having difficulty with the temporal microbunch

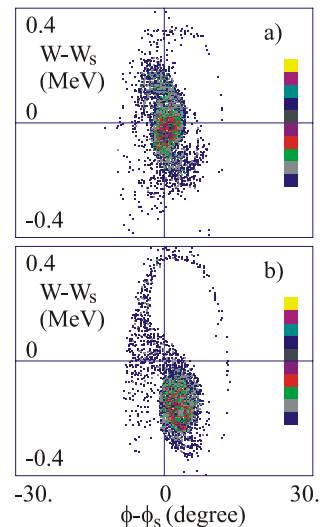


Figure 6: Longitudinal phase-space of the linac output for a) 750 keV and b) 720 keV injected energy.

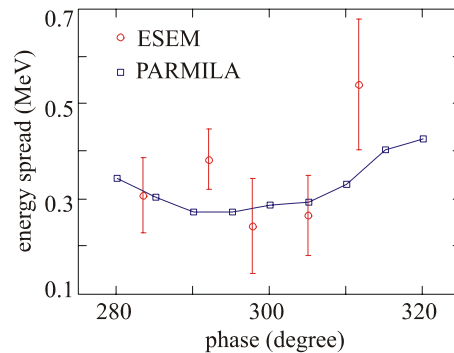


Figure 7: Linac output energy spread with buncher phase.

pulsewidth being too short at the first stripline ( $< 0.5$  ns), relative to values obtained at the other three locations.

Raising the pre-accelerator voltage improves transmission efficiency. In addition, ESEM data show a flattening in the output energy during the macro-pulse with higher input energy. Fluctuations in other parameters such as linac gradient which affect longitudinal focusing have less of an effect when the input beam is centered on the synchronous energy. We hope in the future to raise the pre-accelerator voltage to reduce the dipole effect. Because column sparking is a steep function of the DC voltage, we will do this by increasing the output of the pulsed buncher.

## 7 REFERENCES

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