RESULTS OF NSLS-II LINAC COMMISSIONING*

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Abstract

The NSLS-II linac is a 200 MeV normal conducting linac procured as a turnkey system from RI Research Instruments, GmbH. The linac and associated transport lines were installed at BNL in the winter of 2012. Commissioning activities started March 26, 2012 and lasted for 2.5 months. In this report we discuss the commissioning results of the linac and issues encountered.

INTRODUCTION

The NSLS-II linac was commissioned in the spring of 2012. After an initial period of integrated testing and RF conditioning, commissioning started on March 26, 2012. Commissioning proceeded in stages, starting with low energy, low charge for initial setup of the linac and the diagnostics system. After increasing the energy, single bunch mode was commissioned. Multibunch mode was commissioned last. During multibunch mode commissioning, a problem with the supplemental shielding was encountered which required an end to commissioning. In this report, we discuss the results of linac commissioning.

LINAC DESIGN

Figure 1 shows a drawing of the linac vault with the installed components. The NSLS-II linac consists of a DC electron gun with an EIMAC YU171 cathode. The gun can operate in two modes. The first is Single Bunch Mode where one 0.5 nC bunch per linac pulse is produced. The second is MultiBunch Mode where a bunch train with a total charge of 15 nC consisting of 80-150 bunches separated by 2 ns for a total train length of 160-300 ns is made. The bunching section consists of a 500 MHz subharmonic prebuncher, 3 GHz prebuncher, and 3 GHz traveling wave buncher. Four 3 GHz traveling wave structures accelerate the beam to 200 MeV. Three klystrons labelled M1 through M3 in Figure 1 are available to supply the RF power to the linac structures, two are in use and the third is a hot spare in case of a klystron failure. Solenoids provide focusing below 10 MeV and above 10 MeV quadrupoles triplets were used between the accelerating sections. Linac diagnostics consist of flags, wall current monitors, beam position monitors, and a faraday cup.

The linac to booster transfer line provides two beam dumps for linac commissioning and tuning. The first beam dump, LB-DU1, is in line with the linac for initial tuning and emittance measurements. The first dipole is labelled LB-B1. The second beam dump, LB-DU2, is after the first dipole for energy and energy spread measurements. A third branch delivers beam to the booster and was not used during linac commissioning. Diagnostics include an integrating current transformer LB-IT1, fast current transformer, beam position monitors, flags, and faraday cups in each of the beam dumps. There is an energy slit, LB-SL1, between the dipole and the second beam dump for energy filtering.

COMMISSIONING

Commissioning consisted of two 8 hour shifts per day, with personnel from RI and BNL staffing the shifts. Initial commissioning was done with a single low charge bunch at 50 MeV by powering only the traveling wave buncher and the first accelerating cavity. The goal was to generate the beam and transport it to both beam dumps to make initial adjustments to the diagnostics. During this phase, the RF system was conditioned without beam to improve the performance of the system. The klystrons were each able to exceed the specification of 42 MW.

The following week, the effort moved to increase the beam energy to 200 MeV. During this stage, the prebunchers were used with beam for the first time. Beam was accelerated to 200 MeV and 0.5 nC in a single bunch with nearly 100% transmission to the beam dumps. Radiological surveys showed no increase in background radiation. After two and a half weeks in this stage, we moved to commission multibunch mode in the linac.

Multibunch mode achieved 11 nC in a 300 ns pulse train. Additional shielding was placed downstream of the flag LB-VF2 where the energy spread measurements are performed, in response to radiological surveys. Commissioning then turned to demonstrating the linac performance specifications.

Charge measurements were performed with an Integrating Current Transformer (ICT) at the end of the linac. The beam dumps also function as Faraday Cups to measure the transport efficiency of the beam. Agreement between the cups and the ICT was typically within 15%.

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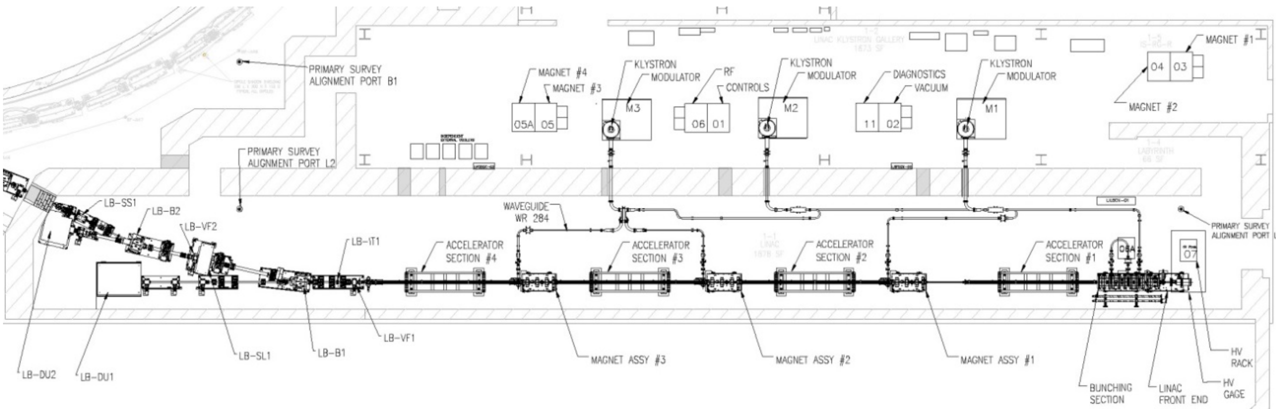

Figure 1: Drawing of the NSLS-II Linac and transport line.

For all charge measurements, the ICT current is the one reported.

Energy measurements were performed by centering the beam in the dispersive beamline using the calibrated dipole LB-B1 and reading the beam position on the downstream flag. Energy spread measurements were performed by focusing the beam on the same flag using the triplet upstream of the dipole. The dispersion at the flag is 864 mm, so 1 mm of horizontal beam size corresponds to 0.11% momentum spread.

Beam loading compensation was performed by increasing the RF power delivered to the cavity as opposed to injecting the beam during the cavity fill time [1]. Initial work on generating the RF ramp and measuring any beam energy or energy spread changes were performed.

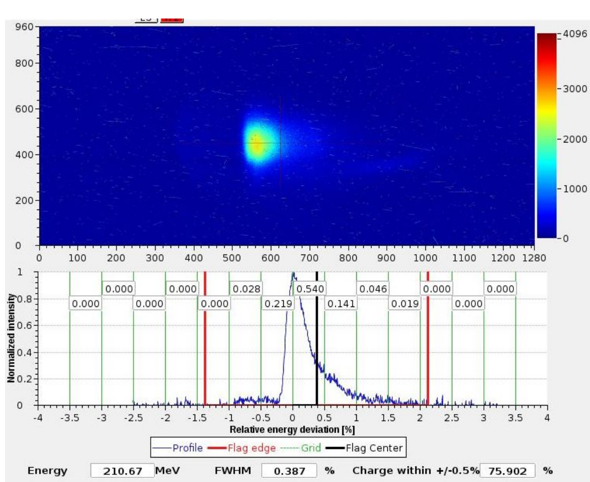

Figure 2: The energy spread measurement at flag LB-VF2 in Multibunch Mode. This is a beam image of a 11nC bunch train. The horizontal beam size is 3.5mm FWHM, corresponding to a 0.41% FWHM energy spread.

Emittance measurements were performed using a quadrupole scan. The flag is an OTR screen located 6.5m downstream of the quadrupoles used in the scan. Once the energy and energy spread were optimized, the beam was steered into the straight section and the scan initiated via an automated script. The beam would be scanned through its focus and the emittance determined via a fit.

Figure 2 shows the energy spread measurement in MultiBunch Mode [2]. In this figure, the beam energy is 211 MeV with a total charge of 11nC. The beam spot was 3.5 mm Full Width Half Maximum (FWHM). Therefore the energy spread is .41% FWHM, and 72% of the charge was within 0.5%. The beam geometric rms emittances in multibunch mode were 56 nm horizontal and 47 nm vertical.

The specification of 15 nC train charge was achieved, as shown in Figure 3, but the full set of beam parameters for the 15 nC beam was not measured.

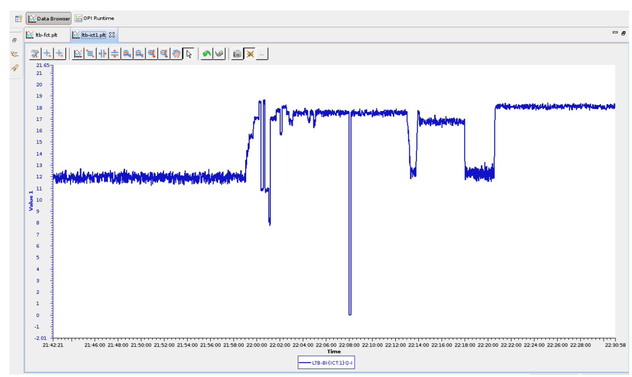

Figure 3: Multibunch Mode charge measured on ICT, LB-IT1. The horizontal axis spans 45 minutes. The vertical scale is train charge. After an initial level of 12 nC, the linac is tuned so 18nC exits the linac.

Figure 4 shows a vertical emittance measurement of a single 0.5 nC bunch at 200 MeV and is taken from the linac acceptance test report [2]. The geometric rms vertical emittance is 63 nm. The horizontal emittance is 58 nm, and the energy spread is 0.5% (FWHM) in single bunch mode.

Table 1 shows the results of beam commissioning in both modes and compares them with the linac specifications [3]. In most cases the measurements of the beam parameters meet the acceptance criteria. A full suite of beam measurements with 15 nC and beam loding compensation fully optimized remains to be completed.

Table 1: Comparison of Linac Specifications and Measurements

Parameter	Specification	Single Bunch Mode	Multi Bunch Mode
Energy	200 MeV	201 MeV	210 MeV
Charge	>0.5 nC Single Bunch Mode; >15 nC per train Multi Bunch Mode	0.5 nC	11 nC
Bunch Train Length	160 – 300 ns MultiBunch Mode	N/A	160-300 ns demonstrated
Bunch Train Uniformity	<10% MultiBunch Mode	N/A	25%
Energy Spread	<0.5% rms	0.14% FWHM, with 80% of charge within 0.5%	0.41% FWHM, with 72% of charge within 0.5%
Emittance	<38 nm rms - design <70 nm rms - acceptance	X: 58 nm, Y: 63 nm	X: 56 nm, Y: 47 nm

In all modes of operation, the transverse emittance was larger than the design emittance by a factor of 1.5 to 2. Surveys of the linac show that the gun has a vertical offset of 1 mm and an upward tilt of 5 mrad relative to the linac centerline. The first solenoid, which has a different construction than the other solenoids, has a vertical offset of 0.9 mm and a horizontal offset of 0.7 mm. All other solenoids are within 140 µm of the beam centerline. It is suspected that the gun and first solenoid misalignments are the cause of the emittance growth. This is supported by the observation that the transverse emittance is increased when the beam does not pass through the center of the subharmonic prebuncher and the S1 solenoid was found to be steering the beam out of this position. The first solenoid was manually realigned to its present position after this was found. All measurements in this paper are taken after this adjustment.

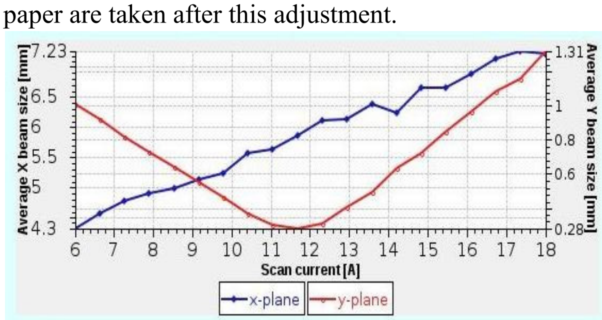

Figure 4: Vertical Emittance measurement in single bunch mode. The plot is rms beam size in the flag immediately upstream of the first dump vs. the LB-Q1 quadrupole current.

At the same time, a significant x-y coupling was observed. When the beam was imaged before any quadrupoles, it appeared symmetric in x and y. However, once it passed through any quadrupole in the linac or transport line, the coupling appeared. Initial thoughts were that this coupling it was due to a magnetized beam [4]. If this was the case, the coupled beam should rotate about the longitudinal axis and the coupling angle should change as it passes through a drift. This has not been observed. The cause of this coupling is being investigated.

Commissioning ended June 18, 2012 when it was determined that the supplemental shielding needed improvements in select locations. In particular, it was found that the LB-B1 dipole shield was not large enough to intercept all of the beam losses possible that this dipole. Extensive work has been done since then to improve the linac supplemental shielding [5].

CONCLUSION

The NSLS-II linac was successfully commissioned in 12 weeks during the spring of 2012. The linac performed up to specification in single bunch mode. Multibunch mode was commissioned to the extent of 11 nC per bunch train, which is close to our specification.

When the linac restarts, the first priorities will be to re-establish operational beam parameters and perform fault studies for the linac prior to proceeding with booster commissioning.

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