MODULATION OF LOW ENERGY BEAM TO GENERATE PREDEFINED BUNCH TRAINS FOR THE NSLS-II TOP-OFF INJECTION*

G.M. Wang#, W.X. Cheng, T. Shaftan, R. Fliller, R. Heese, J. Rose, Photon Sciences, BNL, Upton, NY, 11973, U.S.A

Abstract

The NSLS II linac will produce a bunch train, 80-150 bunches long with 2 ns bunch spacing. Having the ability to tailor the bunch train can lead to the smaller bunch to bunch charge variation in the storage ring. A stripline is planned to integrate into the linac baseline to achieve this tailoring. The stripline must have a fast field rise and fall time to tailor each bunch. The beam dynamics is minimally affected by including the extra space for the stripline. This paper discusses the linac beam dynamics with stripline, and the optimal design of the stripline.

INTRODUCTION

The NSLS-II linac is a turn-key project produced by Research Instruments Gmbh. The linac beam parameters are listed in Table 1 In the baseline [1] design,. It operates in two modes. The first mode is long pulse mode where the linac will produce 15 nC in 80-150 bunches separated by 2ns. In the second mode the linac will produce a small number of bunches each with 0.5nC. The geometric emittance of the beam is specified to be $4\sigma_x\sigma_{x'}$=150 nm, with 0.5% energy spread.

Table 1: Beam Parameters from the Linac

Energy	200 MeV
Relativecharge difference between bunches in the pulse	≤ 10%
Relative energy spread	≤ 0.5% (rms)
Geometric emittance (4σxσx') at 200 MeV	≤ 150 nm.rad in x&y plane
Bunch train charge in the long pulse mode	≥ 15 nC (80-150 bunches)
A single bunch charge in the short pulse mode	≥ 0.5 nC

Specifications for the storage ring bunch pattern given by the NSLS-II users requires sharp edges of the circulating bunch trains and uniform distribution of charge per bunch. This translates into challenging requirements on the gun pulser since its electronics defines quality of generated macropulse.

In order to mitigate such risk we propose to include a short kicker at low beam energy, just downstream of the 90-keV gun. This kicker will permit passing only beam inside the desired macropulse, deflecting bunches before and after it to the wall. The gun pulser electronics is therefore greatly simplified and the gun will emits long bunch trains with loose requirements on the edges. The kicker will select the most uniform part of the bunch train and cleanly chop the edges.

The other advantage of this compact device is minimizing the useless and harmful charge outside of the bunch train from being accelerated and preventing production of beam losses at high energy. Thus the radiation background in the whole injector will be reduced.

The linac vendor has already included extra space for the kicker and for a variable size limiting aperture as shown in Figure 1.

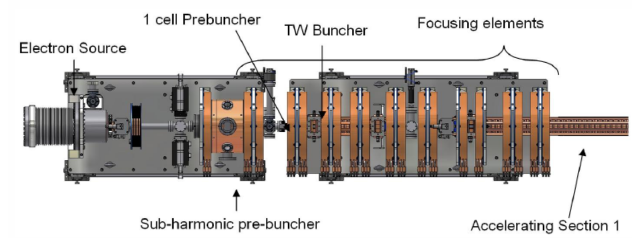

Figure1: Linac layout with chopper and adjustable aperture.

The stirpline is located at low energy, so its effect on the beam dynamics should be considered. In this paper, we will discuss the effect of the stripline on the beam dynamics and the stripline preliminary design.

BEAM DYNAMICS

The principle of the stripline is to give the beam a transverse 'kick'. If the stripline kicker angle is a few times larger than the beam divergence, the head and tail of the beam can be separated from the core beam. Meanwhile, a collimator with adjustable aperture is used downstream of the stripline to help cutting unwanted beam by creating a smaller kick force.

With a simple DC model, ±voltage V on the opposite electrode, the beam gets a transverse momentum

$$\Delta p_t = F\Delta t = e(2V/d)(L/v_z) \quad (1)$$

where d is the electrode distance, L is the electrode length, and v_z is the beam velocity. After the SL, beam changes the direction of motion by an angle

$$\theta = \Delta p_t/p_z = (2VL/d)(e/\beta^2 E_{tot}) \quad (2)$$

where $\beta = v/c$ and E_{tot} is the beam energy.

The needed electrode voltage is proportional to the beam energy. The lower the beam energy, the less voltage it needs. The lower beam energy, the shorter electrode

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#gwang@bnl.gov

length. In the linac, to minimize the SL cost, the optimal beam energy is at 90 keV.

At 90 keV, the linac elements are designed as compact as possible to minimize the beam emittance to be blowout from the space charge effect. A 20 cm additional space is designed to accommodate this stripline.

There are two 90 keV possible locations for the SL: 1) between the gun and the sub-harmonic pre-buncher (SPB), and 2) between the SPB and 1 cell pre-buncher (PBU). Studies show that extending the space by more than 10 cm after the SPB has a large effect on the beam longitudinal dynamics (i.e., the bunch length and energy spread).This is because the drift space between SPB and PBU is used for bunch length compression. And if the SL is put after SPB, the optimal beam energy and position correlation from SPB must change, compared with the baseline working point. That results in the compressed bunch length being longer and the final energy spreader larger, which is not good. However, extending the space between the gun and SPB has little effect on beam longitudinal dynamics, as the beam from gun does not have energy-position correlation. Figure 2 shows the bunch length and energy spread spectrum when the space is extended up to 20 cm. It shows that comparing with the baseline, the extra space effect on longitudinal dynamics is tiny. For the transverse plane, beam emittance is also very close to the baseline design.

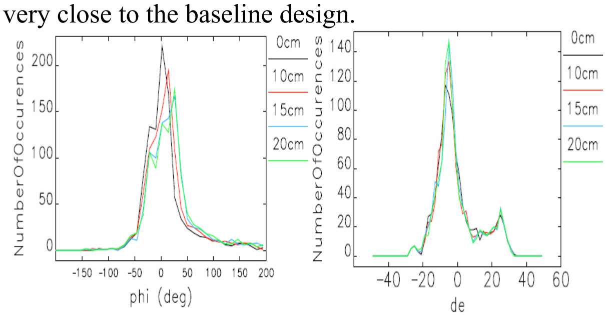

Figure 2: Bunch length and energy spread spectrum at FBU when the space between the gun and SPB is extended by up to 20 cm.

With the stripline before the SPB, all the RF cavity phases relative to each other are the same as the baseline, as the distance between them does not change. The simulation code is PARMELA [2]. All the solenoids' strengths are re-optimized. The goal is to optimize the beam size at the collimator and the beam emittance at the end of linac. The transverse beam size at collimator relative to the transverse displacement is small so that the core beam is not affected by the collimator.

After optimization, the beam transverse phase space before collimator is shown in figure 3. The stripline kick angle is 100 mrad, which is ~3 times bigger than the beam divergence. The kicker is implemented with 20*5 mrad kickers every 0.5 cm drift space. With a 0.6 cm aperture collimator, no beam can pass through.

The core beam property at the exit of the linac is shown in figure 4 with the stripline turned off. The beam parameters are after a ±4 MeV energy cut and the main bucket limit. The particles within these limits are useful. The results are shown in table 2.

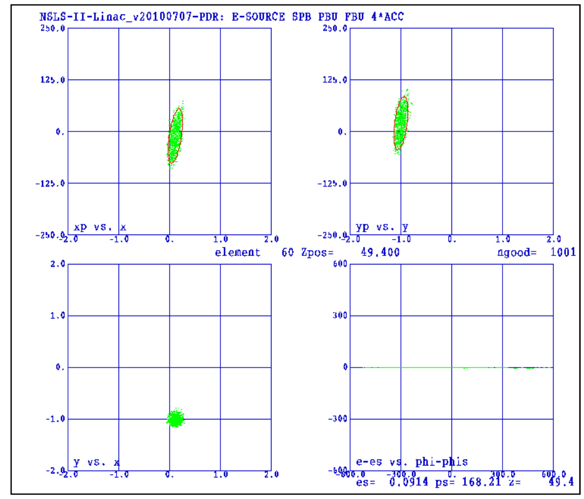

Figure 3: Beam phase space before collimator with 0.1 rad from stripline kick.

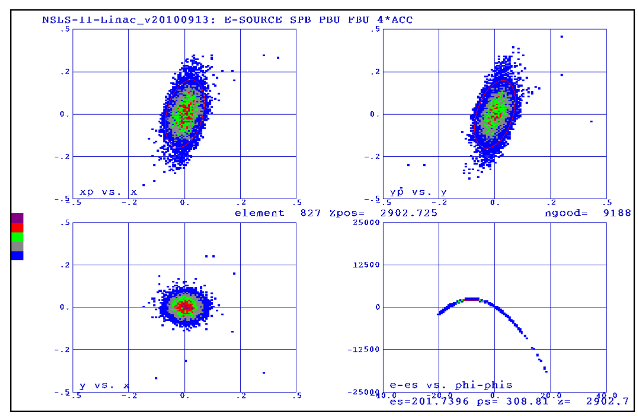

Figure 4: Beam phase space at the exit of the linac.

The overall transmission is 91.1% with stripline. The final beam energy is 203 MeV, the energy spread is 0.47%, the bunch length is 4 ps, and the RMS normalized emittance is 15.7 mm-mrad, which is slightly larger than the RI result, but is still within the acceptance.

Table 2:. Beam Parameters at the End of the Linac with and without Stripline

Beam parameters	With stripline	Baseline
Energy (MeV)	203	203
Geometric emittance (4σxσx')(nm-rad)	158/156	151/151
Energy spread (%)	0.47	0.48
Phi (degree)	4.3	4.6
Transmission ratio	91.13%	88.09%

STRIPLINE DESIGN

With the 20cm space available for the stripline, we designed a stripline deflector with 10cm electrode length to leave room for flanges.. From Eq (1), 1.8kV is required on the electrode to have 100mrad deflecting angle of the 90 keV beam. 5kV pulse voltage should be sufficient for the application, including the electrode geometrical factor effect and the over head. The pulse shape, as shown in figure 5, is a double flat waveform with sharp rise and drop edge to trim the head and tail of bunch train. Only the head and tail of the bunch train get a semi-DC electric kick.

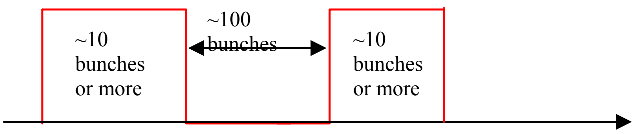

Figure 5: Stripline pulse shape

A two plate stripline was designed using high frequency structure simulation code HFSS [3]. We use the nominal vacuum pipe with radius of 17 mm. The electrode is planar shape, with 10mm plate height and 5.7mm plate width to match 50 Ω impedance. The electrode has round tips to get a better field uniformity and minimize discharge issue. The cross-section of stripline is shown in Figure 6.

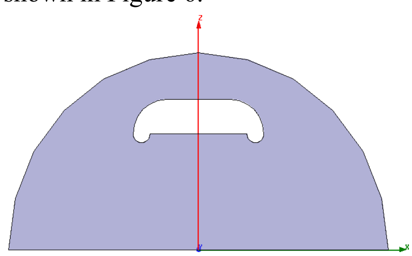

Figure 6: Stripline cross-section (electrode height:10mm, pipe radius: 17mm, plate thickness: 3mm, round tips radius: 0.75mm).

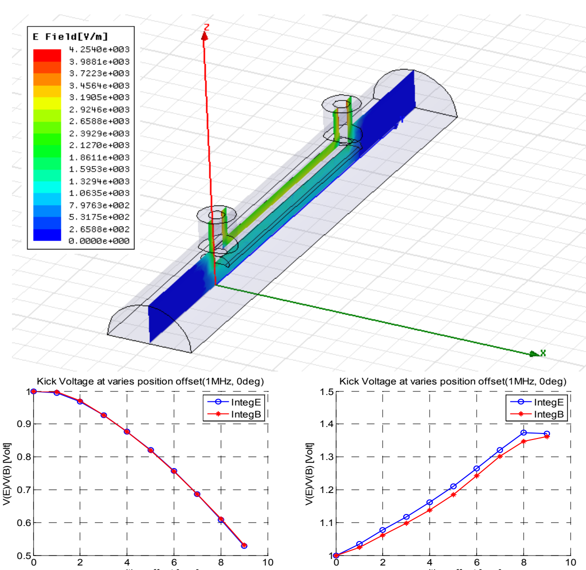

Figure 7: Electric field distribution with 1W power feed into the stripline (upper) and the normalized field uniformity with offset beam position (bottom).

A commercial high-voltage N-type feedthrough will be used to drive the stripline. Figure 7 shows the electric field distribution with 1W power added on the input port (1MHz, 0-deg). Integration along the beam trajectory gives the total transverse deflecting voltage. The field uniformity verse position curve is plotted by offset the electron beam path. This can be improved by increasing the electrode width and height.

SUMMARY AND OUTLOOK

A stripline is to be integrated in the linac to match the storage ring uniform bunch charge requirement, which simplifies the gun pulser electronics and looses the edge uniform requirement. It is located at low energy to lower the stripline power supply requirement and limit the dumped electron radiation. By turning off the stripline, the beam dynamics through linac is comparable with the baseline design.

More advanced ideas can be explored. If a DC corrector along with the stripline is used, the core bunch trains gets kick from the stripline while the head and the tail of bunch train just gets a DC kick. The stripline power supply waveform is a single flat top waveform with fast rise and drop and the pulse length is ~200 ns long or 100 bunches, which may be easier from the power supply view point. We are also considering the bunch by bunch charge manipulation to match the storage ring uniform bunch charge distribution requirement. By modulating the flat top waveform at 250 MHz with adjustable amplitude, each the bunch center is either at 45 degree or 135 degree. Only the head or tail of the bunch is trimmed out. Although each bunch center deviation from idea center is very different at low energy, it is gradually minimized with beam energy increase.

REFERENCES

[1] K. Dunkel. “3200 BNL 200 MeV Linac”. Resesrach Instruments Gmbh. Document Number 3200-BP-8530-B.
[2] L. Young, PARMELA, Copyright 1985-2005.
[3] http://www.ansoft.com/products/hf/hfss/