OPTIMIZATION OF THE BUNCH COMPRESSOR AT BNL NSLS SOURCE DEVELOPMENT LABORATORY*

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Abstract

At BNL NSLS Source Development Laboratory (SDL) 70MeV electron bunches are compressed by the bunch compressor (BC) consisting of a linac section followed by a 4-magnet chicane. The achievable beam compression is limited by nonlinear beam dynamics in the BC and by coherent synchrotron radiation (CSR) effect. In this report we present a novel beam-based technique of chicane calibration, describe the measurements of CSR effect on the beam in the chicane, and discuss the possible scenarios of the BC optimization.

INTRODUCTION

The R&D program at SDL [1] is aimed at achieving high-brightness electron beam with a charge of 1nC and a bunchlength of 0.5ps (FWHM). The beam is generated in a photocathode RF gun, accelerated to 70MeV, and compressed in the bunch compressor (BC) consisting of the linac section, which introduces correlated energy spread, and the four-bend chicane which produces relevant momentum compaction. The BC is followed by three linac sections, which are capable of accelerating beam up to 300MeV. Fully accelerated beam is fed to the 10m long undulator to produce coherent radiation from IR to XUV. The SDL beamline is equipped with a spectrometer magnet located downstream of the BC. The SDL layout is schematically shown in Figure1.

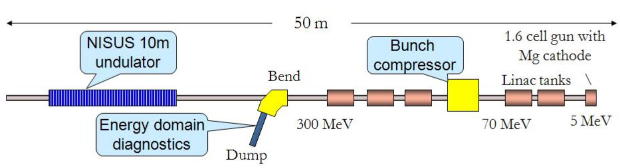

Figure 1: The SDL layout. The gun and first two linac tanks are fed by a single klystron.

CALIBRATION OF SDL BUNCH COMPRESSOR

The SDL BC was designed to compress 5ps (FWHM) beam to 0.5ps. As will be shown below, at nominal BC settings the chicane R_{56} is 4.3cm. Therefore, the maximum compression should be achieved when the 36MeV beam with uncorrelated relative energy spread of σ_E=0.1% is accelerated in second linac section (Linac2) at -36 degrees off-crest. In practice though it was found beneficial to operate Linac2 at smaller energy chirp of -20 to -28 degrees off-crest producing an undercompressed beam. We suggest that such a difference in calculated and experimental optimal settings of the BC parameters points to the presence of strong CSR.

As a first step towards detailed understanding of the SDL BC we performed a beam-based calibration of the chicane R_{56}.

The beam-based calibration of the chicane R_{56} is realized by measuring the change in the zero phase of the third linac section (Linac3) caused by turning the chicane on and off. The zero phase of the Linac3 can be found by measuring beam energy with the spectrometer as the phase of Linac3 is varied; the last two linac sections must be turned off and Linac2 phase is suggested to be on-crest to simplify the measurement. Linac3 zero phase depends on whether the chicane is switched off or on, since the increased path length of the chicaned beam changes the relative phase of beam's arrival to Linac3.

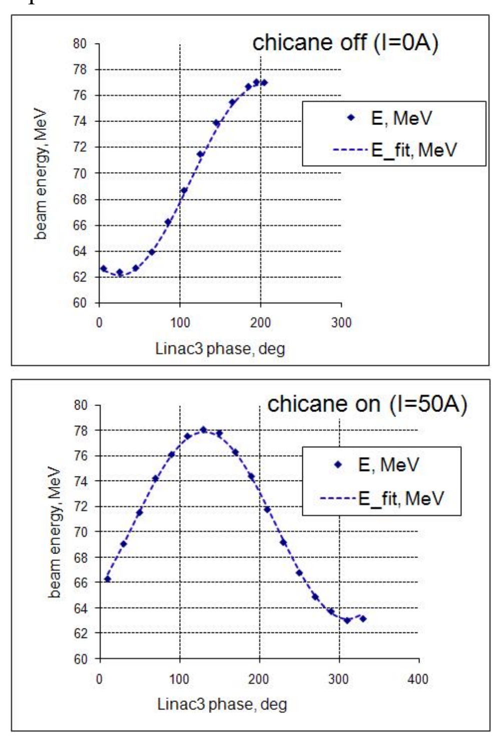

Figure 2: Beam-based measurement of chicane R_{56}. Beam energy is measured by spectrometer as the Linac3 phase is changed. The upper plot provides Linac3 zero phase for the chicane turned off. The lower plot shows the measurements for powered chicane. Dashed line is the fit of the measurements (dots) with sinusoidal function.

Figure 2 shows that turning chicane on at the nominal current of 50A shifts Linac3 zero phase by 73 degrees. The measurement presented in Fig.2 was done for 70MeV beam; measurements performed at different beam

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energies give consistent results. The path length difference between chicaned and straight ahead beams is given by:

$$\Delta S = \beta c \cdot \Delta\varphi / (2\pi f_{RF}) \quad (1)$$

Here c is the speed of light, β is relativistic factor, $\Delta\varphi$ is 0 phase shift in radians, and f_{RF}=2.856GHz is RF frequency. On the other hand, it is easy to show that for the chicane consisting of four rectangular bends of equal bending angles the path length difference is given by:

$$\Delta S = 2\left[\frac{2L_B\theta}{\sin(\theta)} + \frac{L_D}{\cos(\theta)} - 2L_B - L_D\right] \quad (2)$$

where L_B is bend's length, θ is bending angle, and L_D is a bend-to-bend drift. Obtaining θ from Eq.1 and 2 we find R_{56} (given by Eq.3) to be equal 4.3cm.

$$R_{56} = \frac{4L_B(\theta - \tan(\theta))}{\sin(\theta)} - \frac{2L_D \cdot \tan^2(\theta)}{\cos(\theta)} \quad (3)$$

Finally, the beam compression rate was directly measured for fixed Linac2 phase of -20 degrees and for varying chicane current. Figure 3 compares results of this measurement with theoretical predictions for the bunch compression rate, in which we assumed that at 50A chicane current R_{56}=4.3cm. The bunch length was measured with zero-phasing technique [2]. Measurements were done at 50pC beam charge.

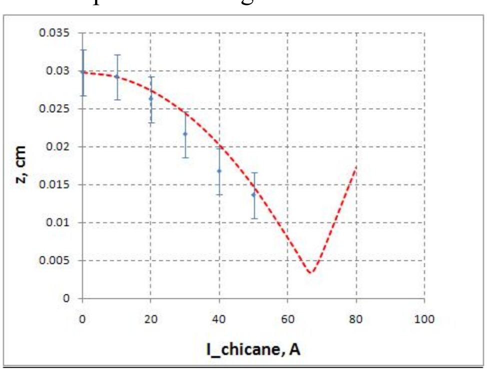

Figure 3: Comparison of measured bunch length with theoretical predictions for compression rate at different chicane currents (I=50A corresponds to R_{56}=4.3cm).

CHARACTERISATION OF CSR EFFECT IN SDL BUNCH COMPRESSOR

To characterize CSR effect on the compressed beam and to benchmark longitudinal beam dynamics simulations, which are performed with ELEGANT [3], we adopt an approach similar to the one outlined in [4].

The beam affected by CSR loses its energy as it is travelling through the chicane and is getting compressed. In a dipole magnet CSR causes an average energy loss per electron per unit length of

$$\frac{dE}{ds} = \frac{1.8Ne^2}{\rho^{2/3}\sigma_z^{4/3}} \quad (3)$$

where N is total number of electrons, ρ is dipole bending radius, σ_z and is bunch length. The beam gets kicked horizontally at the exit of the chicane due to the loss in energy. Consequently, the compressed beam's trajectory downstream of the chicane is changed from the uncompressed one.

To perform CSR effect measurements we gradually change beam compression by changing the phase of Linac2 at fixed chicane current. The beam horizontal position is observed on the beam profile monitor (BPM) located 4m downstream of the chicane. Linac3 as well as all the focusing and steering magnets in between the chicane and the BPM are switched off. The beam energy is changed both due to CSR related energy loss and the reduced acceleration in Linac2. The current SDL setup (the gun and first two linac sections are powered by a single klystron) makes compensating the reduced acceleration impractical. Because of that, we take BPM readings for both positive and negative chirp of Linac2, which produces stretched and compressed beams of the same energy. Difference between two data sets gives CSR related motion of the beam centroid.

Figure 4 shows CSR related change in beam centroid position for varied Linac2 phase. Data were taken at chicane current of 60A to reduce correlated energy spread (and potential beam losses) at the phase of maximum compression. The maximum compression at 60A chicane current corresponds to Linac2 phase of -27 degrees off-crest. Data were taken at 0.7nC and 0.9nC beam charges.

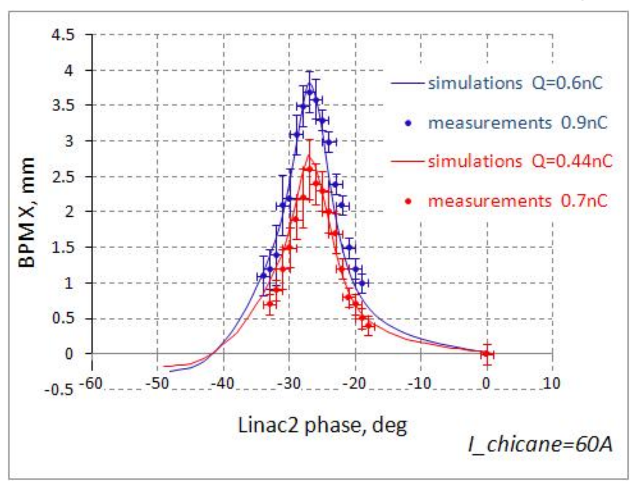

Figure 4: CSR related change in beam centroid position measured by BPM located downstream of the chicane for varied Linac2 phase. Data were taken at 0.7nC (red) and 0.9nC (blue) beam charges. Dots represent measured data; solid lines stand for ELEGANT simulations. The beam charge had to be reduced in simulations to fit measured data. Data were taken at chicane current of 60A, the maximum compression at this current corresponds to Linac2 phase of -27 degrees.

The measured data were compared to simulations performed in ELEGANT. To fit the measurements we had to reduce the beam charge in simulations by about 0.3nC in both cases. At the present time we measure beam charge in the gun only. We speculate that the beam is partially lost in the beamline, mostly in the chicane due to the high energy spread induced by Linac2. There is also an uncertainty in the initial bunchlength, which can explain the discrepancy in the amplitude of the peaks of the measured and simulated beam trajectories.

We performed described measurements for 0.7nC beam at four different chicane currents (50A, 55A, 60A and 65A). Figure 5 demonstrates that at each current the peak of the trend coincides with the predicted phase of maximum compression within 1 degree accuracy.

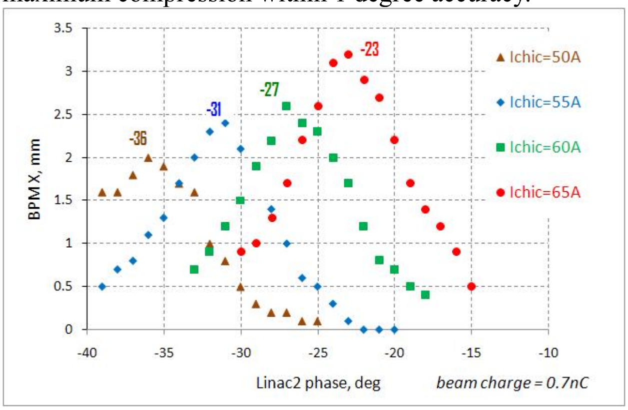

Figure 5: CSR related change in beam centroid position measured by BPM located downstream of the chicane for varied Linac2 phase. Data were taken for 0.7nC beam at four fixed chicane currents.

SDL BUNCH COMPRESSOR OPTIMIZATION

At the present time the SDL accelerator is routinely operated at relatively low beam charge of 300pC, and the nominal chicane current of 50A.The above considerations suggest that switching to higher charges might require moving the BC to an operation point with higher chicane current and lower off-crest phase of Linac2. Simulations presented in Figure 6 show that changing chicane current from 50A to 65A still produces a short enough bunches.

We plan to upgrade SDL accelerator with a beam charge measurement system downstream of the chicane, which will remove the ambiguity in CSR effect measurements.

In case farther studies prove that detrimental CSR effect prevents us from getting 0.5ps FWHM beam of 1nC charge, one can consider rearranging compression in two stages. The first stage, either conventional magnetic or ballistic compression [5], can be performed right after the gun. The compression ratio of the first stage must be kept small to limit detrimental longitudinal space charge effects. The second stage will require lower compression ratio with respect to current BC setup, therefore lowering CSR related degradation of longitudinal beam properties.

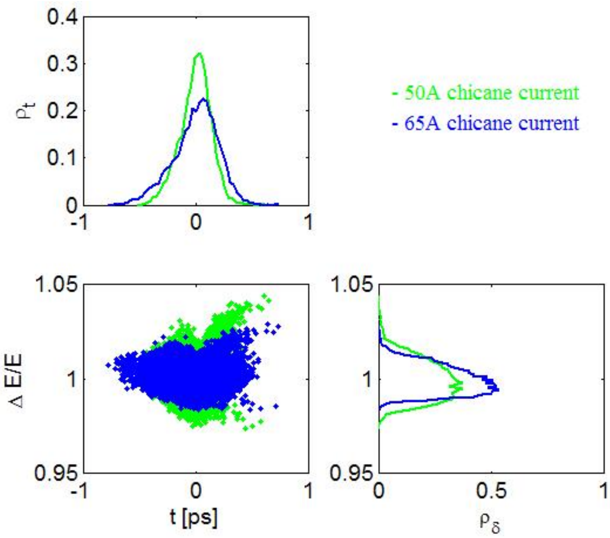

Figure 6: Compressed beam at 50A (green) and 65A (blue) chicane currents.

CONCLUSION

In the course of studies of the SDL bunch compressor aimed at achieving 0.5ps FWHM 1nC beam we performed the beam-based calibration of chicane momentum compaction. We characterized CSR effect on the compressed beam and benchmarked ELEGANT simulations of the longitudinal beam dynamics in the BC. Improvements of the SDL beam diagnostics and more advanced measurements are in progress.

ACKNOWLEDGEMENTS

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REFERENCES

[1] J.B. Murphy and X.J. Wang, “Laser-Seeded Free-Electron Lasers at the NSLS”, Synchrotron Radiation News, Vol. 21, No. 1, 41, 2008.

[2] W.S. Graves et al, “Ultrashort Electron Bunch Length Measurements at DUVFEL” Proceedings PAC-01, 2001.

[3] M. Borland, “User's Manual for ELEGANT”, http://www.aps.anl.gov/Accelerator_Systems_Division/Operations_Analysis/manuals/elegant_latest/elegant.html.

[4] Z. Huang et al, “Measurements and modeling of coherent synchrotron radiation and its impact on the Linac Coherent Light Source electron beam”, PRST-AB, 12, 2009

[5] X. J. Wang, et al., Phys. Rev. E 54, R3121 (1996).