ANOMALOUSLY LONG BUNCHES FROM THE SLAC NORTH DAMPING RING*

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Abstract

During the FACET run of 2012, several days were dedicated at the end of the run to high-charge running in the damping ring and first two sectors of the linac. A study of the bunch length in the North Damping Ring (NDR) was undertaken to characterize the longitudinal behavior of the beam at various charges and accelerating voltages. It was found that the bunch length deviated from the canonical measurements made in 1996[1] that informed the design of FACET by a significant amount. Studies performed in LiTrack were undertaken to understand how the bunch lengthening would affect the performance of the FACET accelerator program.

FACET DESIGN

The FACET design was predicated on a 6mm bunch length exiting the NDR to achieve the proper longitudinal profile in the experimental area. The three stage compression scheme relies on the large R56 of the North Ring To Linac (NRTL) transport line to compress the bunch from 6mm to about 1.1mm before going through the other stages of compression.

STREAK CAMERA MEASUREMENTS

A Hamamatsu C5680 streak camera with syncroscan tuned to 476MHz (the NDR RF frequency) was utilized to measure the turn-by-turn bunch length in the NDR.

Camera Initialization

The streak camera was set up in the NDR kicker-support building, directly above the ring vault, in a temperature-controlled area.

Data Acquisition

The gap voltage was varied from 200kV up the maximum available from the NDR klystron of about 750kV. At each step of gap voltage, the electron intensity in the ring was increased from 1e10 electrons to 4e10 electrons.

The final 12 turns of the NDR storage cycle were sampled by the streak camera (see Fig. 1) in order to get statistics about the beam right before extraction, and thus the best representation of the bunch length as seen by the NRTL compression scheme.

Data Analysis

The streak camera creates large, uncompressed TIFF files and Matlab was used for the image processing, background subtraction, and the fitting routines.

Automation routines were developed to sort through the hundreds of images and do peak detection in order to bin the data in a reasonable amount of time.

After finding the central distribution of each of the 12 peaks on the streak camera image, an asymmetric Gaussian is fitted to each profile. These 12 Gaussians are averaged then to give the longitudinal bunch length and asymmetry resulting from resistive-wall effects (See Fig. 2).

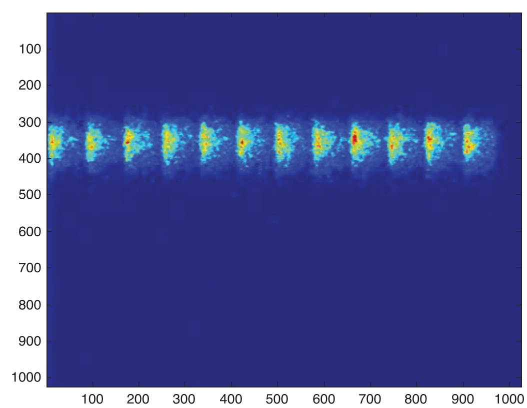

Figure 1: The last 12 turns of the NDR store before extraction.

The turn-to-turn phase stability for the final cycles before extraction was less than 1ps, and thus no instability was thought to be interfering with the data acquisition.

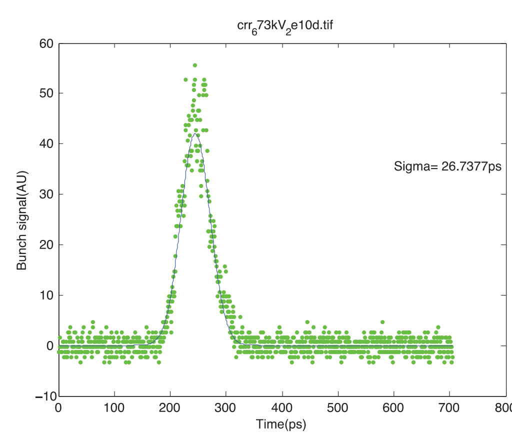

Figure 2: An example fitted profile after MATLAB data analysis.

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RESULTS FROM STUDY

Nine settings of the input current were scanned at six different gap voltages.

At the FACET-nominal 2e10 electrons/bunch current, the bunch length was measured to be close to 8mm. This is in strong disagreement with the measurements made in 1996[1] that the FACET user facility is predicated upon.

As seen in Fig. 4, the bunch length at 725kV gap voltage starts at about 7.5mm for 1.5e10 electrons and lengthens to over 9mm for 3.5e10.

At the canonical 2e10 electrons/bunch setting, the NDR gap voltage was ranged from its lower stability limit of about 350kV up to its klystron-limited peak gap voltage of about 750kV. The bunch length starts at a staggering 10.25mm at 350kV and only shortens to 8mm at close to 750kV (Fig. 3).

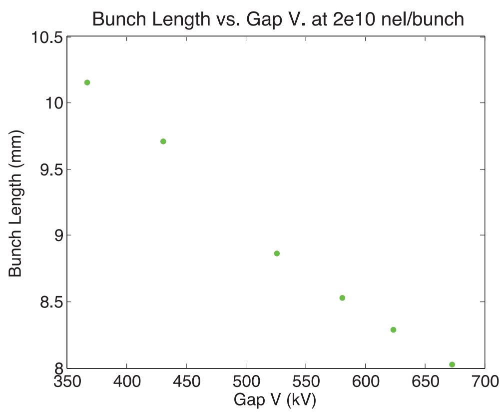

Figure 3: Bunch length in mm vs. NDR gap voltage in kV.

The slope of bunch-length vs. charge at various gap voltage settings was made and as seen in Fig. 5, a bunch lengthening vs. charge relation can be made with respect to the gap voltage. For example, at 2e10 electrons/bunch, the bunch-length grows at a rate of about 420μm/100kV gap voltage and at 3e10 electrons/bunch the growth rate is closer to 600μm per 100kV of gap voltage.

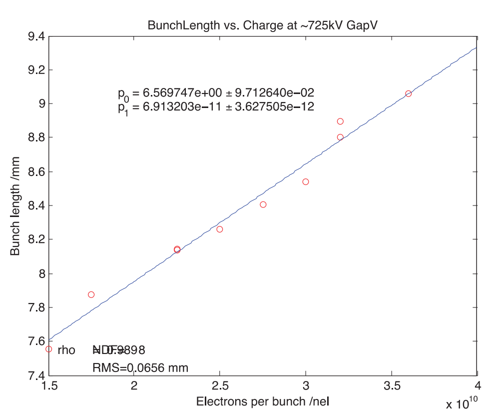

Figure 4: Bunch length in mm vs. ring current as measured in the NRTL in e- per bunch.

Measurement Q&A

After the discovery of these anomalously long bunch lengths, much discussion and follow up of the measurement was made with local experts. As of this writing, no error was found in the measurement

SETUPLITRACK SIMULATION

An end-to-end LiTrack [2] simulation was undertaken to understand the impact that 25% longer initial longitudinal bunches would have.

LiTrack Setup

A more advanced LiTrack deck was developed that included the so-called "Staggered Chirp" of the SLAC main linac [3] and wake-effects taken into account for each RF accelerating structure rather than treating the entire linac as a monolithic hole.

Additionally, code was developed to perform N-dimensional scans of parameters in LiTrack for optimizing bunch profiles at arbitrary locations in the accelerator.

LiTrack Simulation Time

These n-dimensional scans are very processor intensive, and on the author's computer took approximately 1-day per optimization setting to perform.

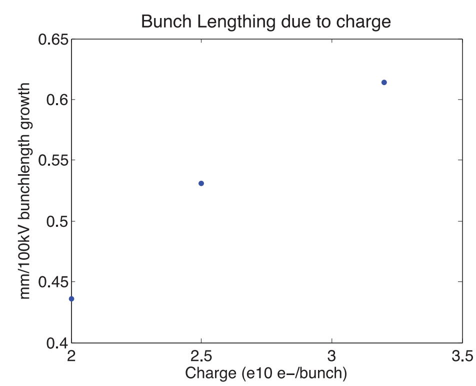

Figure 5: Bunch lengthening due to charge.

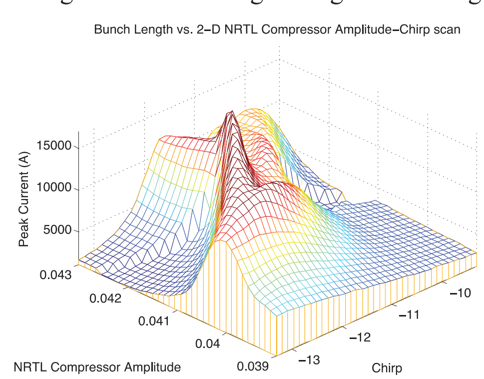

Figure 6: Simulated peak current from LiTrack in the FACET experimental area for 6mm long NDR bunches as a function of NRTL compressor amplitude and "staggered_chirp" setting.

At the now-nominal initial bunch length of 8mm as an input to the first stage of compression, the peak current achieved in the FACET experimental area is of concern.

Figure 6 shows a 2-D scan of peak-current as monitored at the end of the FACET chicane as a function of optimizing the first stage of compression with the NRTL compressor amplitude and the effective chirp in the first half of the FACET accelerator with the nominal 6mm long initial NDR bunches.

Figure 7 is a similar scan with an initial bunch length from the NDR of 8mm. As is evident from the plots, the peak-current achieved at the end of the accelerator can be compensated for with the longer bunches to be similar magnitude of 17kA.

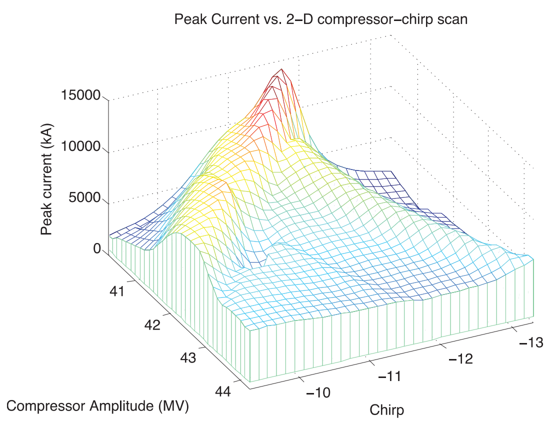

Figure 7: Simulated peak current from LiTrack in the FACET experimental area for 8mm long NDR bunches as a function of NRTL compressor amplitude and “staggered_chirp” setting.

Figures 8 and 9 show the longitudinal beam profile at the end of the FACET chicane after optimizing for bunch length, rather than peak current. Both bunch-lengths can be seen to be around 20 micron and the distributions both nicely Gaussian.

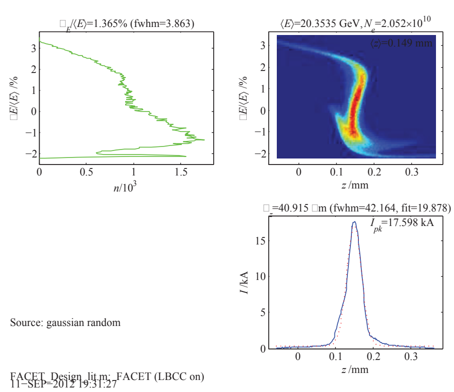

Figure 8: Simulated bunch profile from LiTrack in the FACET experimental area for 6mm long NDR bunches.

MITIGATION

In the downtime between the previous FACET run and this year, tuning work was performed on the NDR klystron to increase its output power commensurate with achieving 1MV gap voltage in the NDR. Extrapolating from measurements done last year, this should correspond with an initial bunch length of close to 6mm coming from the NDR into the NRTL.

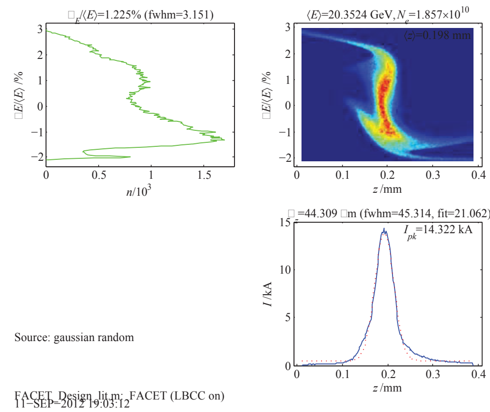

Figure 9: Simulated bunch profile from LiTrack in the FACET experimental area for 8mm long NDR bunches.

CONCLUSIONS

The LiTrack simulations shown above indicate that similar peak-currents and bunch-lengths are achievable simply by re-optimization of the longitudinal setup in the linac.

Further, the increased performance from the NDR klystron to achieve 1MV gap voltage cavities mitigates these concerns.

FUTURE STUDIES

As of this writing, follow-up studies have not yet been scheduled for the 2013 FACET run to re-measure the bunch length at this higher gap voltage setting.

ACKNOWLEDGMENT

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REFERENCES

[1] R. Holtzapple, Ph.D. Thesis, SLAC-487, 1996.
[2] K. Bane, LiTrack: A Fast Longitudinal Phase Space Tracking Code with Graphical User Interface, SLAC-PUB-11035,
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