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FACET FIRST BEAM COMMISSIONING*

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Abstract

The FACET (Facility for Advanced aCcelerator Experimental Tests) facility at SLAC has been under Construction since summer 2010. Its goal is to produce ultrashort and transversely small bunches of very high intensity (20kA peak current) to facilitate advanced acceleration experiments like PWFA and DLA. In June of 2011 the first electron beam was brought into the newly constructed bunch-compression chicane. Commissioning work included restarting the linac and damping ring, verifying hardware, establishing a good beam trajectory, verifying the optics of the chicane, commissioning diagnostic devices for transverse and longitudinal bunch size, and tuning up the beam size and bunch compression. Running a high-intensity beam through the linac without BNS damping and with large energy spread is a significant challenge. Optical aberrations as well as wakefields conspire to increase beam emittance and the bunch compression is quite sensitive to details of the beam energy and orbit, not unlike what will be encountered in a linear-collider final-focusing system. In this paper we outline the steps we took while commissioning as well as the challenges encountered and how they were overcome.

THE FACET COMPLEX

The FACET chicane and final-focus are built at the 2/3 point in the SLAC linac, just before the LCLS. It utilizes the first 20 sectors of the SLC accelerator, including the North Damping Ring (NDR) and the CID thermionic gun. Beam is extracted from the NDR with a bunch length of approximately 6mm σ_z and goes through the first stage of compression in the North Ring To Linac (NRTL) transport line. At the end of the NRTL, the beam is over compressed, with a bunch length of about 1.2mm. After applying an energy correlation on the beam with nine 100m-linac sectors of RF, the beam goes through a second stage of compression—the LBCC, or Linac Bunch Compression Chicane, where it's further compressed to about 50μm. After another 10 sectors of acceleration, the beam enters the FACET chicane proper and goes through its final stage of compression to less than 20μm [1].

INITIAL COMMISSIONING

In April of 2008, the first 2/3 of the SLAC accelerator complex was turned off after the final PEP-II run. In anticipation of FACET running in 2010, a hot-check run was performed in November of 2009 to ring out any major outstanding issues from the accelerator laying fallow for a year and a half.

Construction of the new FACET chicane and Final Focus was complete in June 2011. The first beam down through the beam-line and on to the new dump was on 23-June-2011.

Commissioning began with low charge, low energy spread, long bunches (turning off the second stage of compression in the LBCC and putting the beam on-crest in the RF), so-called "pencil beam", to perform first-order optics verification, beam-based alignment (BBA), and aperture scans.

The aperture scans and BBA revealed several vacuum chamber misalignments that both clipped the beam and required strong orbit deviations from nominal. After locating the misalignments and correcting them, beam-loss was much reduced.

Following the pencil-beam studies, charge was increased to nominal and the second stage of compression in the LBCC was dialed in. Linac emittances are difficult to maintain through the first half of the linac in this state given the high charge (3.2nC), long bunch (1.2mm), and very strong early lattice (>110deg/cell) running without BNS damping [2]. Very small orbit changes in the early linac cause highly variable tails at the end of the linac (see Figure 1).

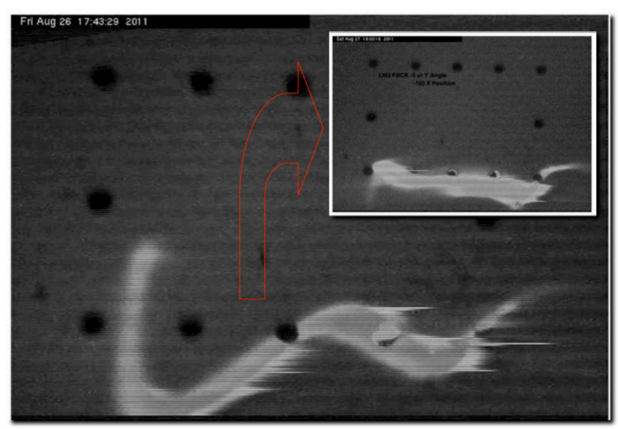

Figure 1: Beam distribution on profile monitor in dispersive region after first bend in chicane. High energy is to the left. Inset image is beam distribution after linac tuning bumps in early part of accelerator.

Setting up the longitudinal beam profile was initially performed using one device at the end of the FACET chicane—an OTR that couples out THz radiation into a pyro-electric device. This, however, only shows the final

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sum of all compression stages, not if each stage is set up optimally.

These first few observations in the initial beam-on run in 2011 led to several additions in hardware during the downtime between the 2011 and 2012 run.

NEW HARDWARE

Several upgrades and additions to the accelerator facility were added during the downtime between the 2011 first beam and 2012 commissioning run. Several of the additions were a direct response to the lessons learned in the first beam-commissioning run of 2011.

Sector 10 Chicane

An upgrade to the sector 10 linac bunch compression chicane was installed in winter 2012 that will allow the concurrent operation of electrons and positrons in the main linac. Positrons are scheduled to be commissioned during the 2013 run with availability to users by 2014.

LI02 Bunch Length Monitor

In order to maintain the optimal compression from the NRTL into the SLAC main linac, a ceramic gap bunch-length monitor was installed just before the first accelerating structure in sector 2. An off the shelf ceramic HV stand-off was inserted in the beamline replacing a drift tube and mated to a network of waveguide and high-frequency diodes. The signal is sent to a gated ADC (GADC) in the legacy SLC control program (SCP) and read out on a pulse-by-pulse basis.

LI18 Bunch Length Monitor

Since it's not always desirable to send the beam through the FACET chicane during initial tune-up, a 1mm thin retractable titanium foil was installed at the instrumentation section at 18-9. Transition radiation from the foil is directed into a pyro-electric detector and then routed into the SCP via a GADC.

LI18 Wire Scanner

A new wire scanner was installed in the same instrumentation section as the LI18 bunch length monitor. The closest upstream beam emittance measurement device is in sector 11, close to a kilometer away. In addition to the new wire, four quads were split out from their bulk power supply and given individual control. This allows for both quad scans on the wire, as well as adding additional matching from the SLAC main linac into the FACET chicane and experimental area.

SD2 Sextupole Movers

The FACET lattice has quite strong chromatic correction [3] and is sensitive to orbit deviations of less than 50μm. The two strongest sextupoles in the chicane, SD2E-L and SD2E-R, were put on stages that offer three degrees of adjustment—x, y, and roll. These movers were key to achieving the small spots in the IP since the FACET lattice offers very little in the way of orbit correction dipoles due it's aggressive betatron phase-advance. Additionally, BPMs were added into the newly redesigned vacuum chambers.

The sextupole movers have proved very successful in correcting the dispersion in the FACET chicane (Figure 2). The residual vertical eta is much reduced and we're able to force the zero crossing to be at the interaction point for the various experiments.

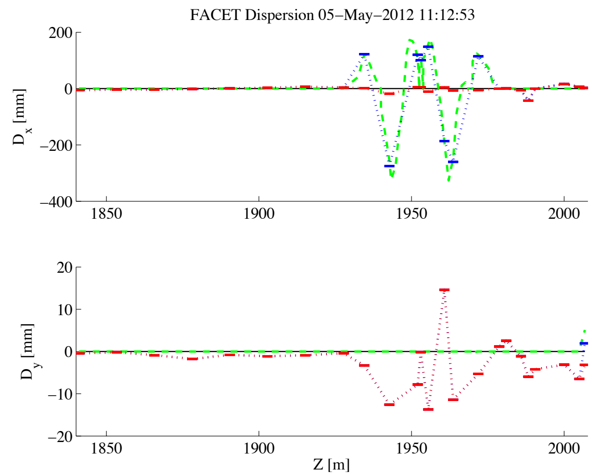

Figure 2: FACET dispersion after correction with sextupole movers.

LONGITUDINAL

Making very high peak current, FACET beam requires an energy-time correlation ("chirp") along the linac so it can be compressed longitudinally in two chicanes. The LBCC chicane has an R56 of -38mm and the FACET W-chicane has a nominal R56 of 4mm.

The nominal chirp is set up such that it is "staggered" in the first 10 sectors of the linac. That is, the number of degrees off-crest on the RF is minimized in the first sectors of the linac where the lattice is strong and grows semi-linearly until just before the LBCC chicane. The "equivalent" chirp ends up being around -20deg for sectors 2-10.

With the new devices in LI02 and LI18 to measure and possibly feedback on the bunch length came new setup and simulation [4].

Extensive studies in LiTrack and Elegant were performed to understand how the setup of each stage of machine compression would look on the BLMs. Further studies with beam were performed to calibrate these devices.

One of the sanity checks in determining the bunch-length in the linac is through wake-loss scans [5]. With a wakeloss of about 125MeV (Figure 3), we seem consistent with a 50μm bunch length given that FACET has half the accelerating structures after the LBCC than SPPS had with 250MeV loss.

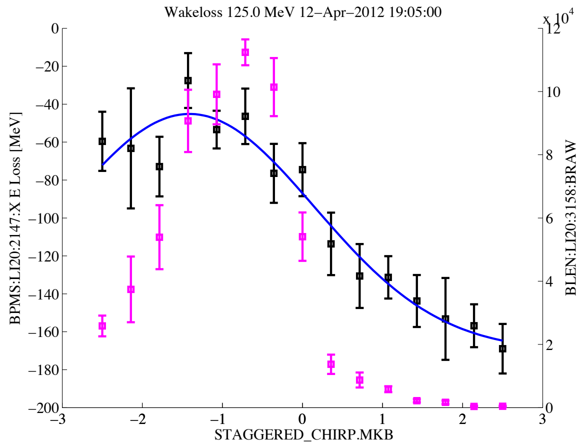

Figure 3: Measuring the energy loss in the linac due to wakefields and comparing to the peak pyrometer signal at the FACET IP.

TRANSVERSE SETUP

After several years of not using the first two-thirds of the SLAC two-mile linac, it was re-commissioned for use in FACET operations.

The induced energy-time correlation setup described above has the opposite sign to the typical used for BNS damping and therefore any orbit deviation from on-axis kick the tail of the beam more than the head causing emittance growth [6].

Any dispersion created along the linac can create similar emittance growth effects due to the very large energy spread required for compressing the bunches longitudinally.

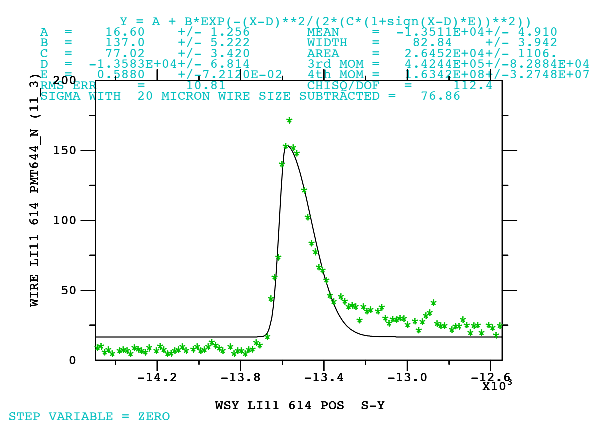

Figure 4: Linac vertical wire beam-projection in Sector 11 shows long tail.

Any seed of asymmetry early on in the linac can filament out and become long tails (Figure 4) which spoil the emittance, cause backgrounds, and are ultimately of little use to the experimenters as that charge is wasted and not added into the peak current.

Ultimately, we've not been able to bring the linac emittances to their design parameters of 50μmR x 5μmR in sector 18. The best achieved has been closer to 150μmR x 50μmR, yet transporting these less than optimal beams through the IP has still yielded IP wire sizes very close to desired parameters (Figure 5).

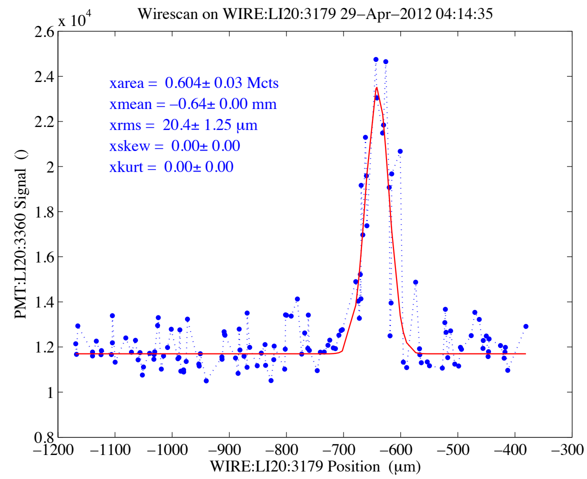

Figure 5: FACET IP Horizontal wire size 20μm.

ACHIEVED PARAMETERS

The key to optimizing the IP spot sizes really rests on following a procedure of establishing the optimized on-axis orbit through the FACET chicane, correcting any energy deviations, and putting the strong sextupoles to the center of the beam to correct for dispersive aberrations and coupling errors. By bringing the linac emittances down closer to design, we should be able to bring these IP wire sizes down even further.

ACKNOWLEDGMENT

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