Multibunch Beam Physics at FACET

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Abstract

We propose to operate the FACET linac with multiple electron bunches per RF pulse. We will produce two electron bunches at the thermionic cathode, separated by integer multiples of 5.6 ns, the period of the subharmonic buncher. Several accelerator subsystems will be significantly affected by the transition from one to two electron bunches per RF pulse. These include the injector, North Damping Ring (NDR), North Ring to Linac (NRTL), and the main linac. In addition, the primary beam diagnostics, including BPMs, will not be able to resolve the individual bunches at their closest separations. We discuss methods to extract information from the diagnostics in this case as well as the use of Lucretia for multibunch beamline simulations.

INTRODUCTION

Plasma wakefield studies are normally conducted as single-shot experiments. Here, a single-shot means that the plasma returns to its original state before the subsequent bunch passes through the plasma. The time scale for the plasma to return to equilibrium is 10-100 ns, which is comparable to the bunch separation in proposed linear colliders. It is possible to perform non-equilibrium plasma wakefield acceleration (PWFA) at FACET by configuring the linac for multibunch operation. In this paper, we discuss changes in machine operation for multibunch studies and the relevant accelerator physics.

INJECTOR

The electron source is a thermionic cathode driven by a multi-channel pulser. The pulser is a circuit with two planar triode amplifiers that couple into a common amplifier driving the cathode. The two triodes can be fired independently to produce electron pulses from the cathode with arbitrary separation in time. The maximum charge per pulse is roughly 27 nC, which is almost an order of magnitude greater than the 3.2 nC per pulse used in PWFA studies at FACET [1].

Charge from the gun is captured by the subharmonic buncher in buckets separated by integer multiples of 5.6 ns. The subharmonic buncher runs at 178.5 MHz, or 1/16 the S-band frequency. Therefore, the smallest feasible bunch separation with decent charge capture is 5.6 ns, or 16 S-band buckets. After the subharmonic buncher, the beam is accelerated to an energy of 1.19 GeV before being diverted to the North Damping Ring.

In Sectors 0 and 1, the beam energy is low and the bunch is strongly affected by space charge forces and wakefields. In addition, there will be beam loading in the buncher cavities resulting in a phase shift for the trailing bunch, and beam loading in the accelerating cavities that reduces the energy gain of the trailing bunch. We do not model multibunch effects in the injector because we assume that the bunching and acceleration processes work sufficiently well for the full bunch charge to be captured in the ring. Once the bunches are captured in the ring, the bunches' phase space coming out of the ring is determined solely by the properties of the ring.

NORTH DAMPING RING

The North Damping Ring (NDR) reduces the beam emittance ϵ through the synchrotron radiation damping mechanism. Low emittance beams are needed for PWFA experiments because the final spot size is proportional to $\epsilon^{1/2}$. The electron bunches are diverted from the linac to the NDR by a dipole magnet at the Damping Ring Interaction Point (DRIP). The bunches traverse the North Ring to Linac (NRTL) arc and enters the NDR via the injection septum magnet and injection kicker.

Injection Kicker

The injection kicker has a pulse length of approximately 60 ns [2]. The magnet provides a 7 mrad kick to the beam after it enters the NDR via the injection septum magnet. The kicker is controlled by a thyratron that produces a 40 kV pulse with an extremely fast rise and fall time. Ideally, the pulse has a long flat top so that each bunch sees the same field as it passes through the aperture in the magnet. In reality, the pulse for the injection kicker is not particularly flat. Fortunately, the bunches can tolerate small mis-kicks upon injection because orbital errors are damped by synchrotron radiation. The injection kicker imposes the constraint that the two bunches be separated by less than roughly 60 ns in order to see a strong enough kick to be captured in the ring. As we will see, the extraction kicker imposes much stricter constraints on the bunch separation.

π-Mode Instability

The π-mode instability is a coupling that can occur between the two electron bunches in the ring. A single bunch executes a synchrotron oscillation with respect to the fundamental frequency of the RF cavities as it circles the ring. A second bunch in the ring will also execute a synchrotron oscillation in the RF cavities. Now we consider the problem of coupled oscillators. The two bunches will oscillate with respect to one another and the fundamental RF frequency. The coupled motion is a superposition of two normal mode oscillations. The 0-mode is a net oscillation of the two bunches with respect to the synchrotron frequency. This oscillation equivalent to a single bunch synchrotron oscillation and it is damped in the same way that single bunch would be damped (Robinson damping). The second normal mode is an oscillation of the bunches that is 180^o out of phase with each other called the π-mode. A π-mode instability can occur if the frequency of the oscillation matches a high order odd harmonic of the RF cavity [4].

To counteract this instability, a passive cavity was added to the ring in 1992 [5]. At the time, the cavity was tuned to 1062.4 MHz, just below the 125^{th} revolution harmonic to accommodate two bunches with a bunch separation $t_i = 61.6$ ns. This was the nominal bunch separation during SLC operation. The chosen frequency corresponds to a minimum in the odd harmonic spectrum and a maximum in the synchrotron sideband driven by the π-mode oscillation.

We do not expect the optimal cavity frequency to remain the same as we change the bunch separation. Fortunately, the cavity is equipped with a plunger that can be controlled remotely to adjust the cavity frequency. The tuning range should be sufficient to accommodate the new bunch configuration.

Sawtooth Instability

The sawtooth effect is a single bunch instability in the NDR, discussed here for completeness. It is a microwave instability driven by inductive impedances in the ring vacuum chamber. When the beam enters the ring it is relatively long, but synchrotron radiation damping cause the beam to shrink down to a minimum bunch length determined by the shape of the RF potential in the ring. If there were no ring instabilities, a 3.2 nC bunch would damp to an equilibrium bunch length of roughly 6 mm. However, as the beam reduces in size the peak beam current increases, and large peak currents can strongly drive high frequency impedances. Eventually the bunch becomes short enough to excite a very high frequency resonance. The high frequency resonance corresponds to a short wavelength wakefield in the time domain that acts back on the bunch to modulate its energy spectrum on length scales shorter than the bunch length. The bunch rapidly lengthens as particles with different energies follow different paths around the ring. The timescale for the

Since 1994, the threshold for the instability has been roughly 1.5×10^{10} electrons per bunch [6]. At 2×10^{10} electrons per bunch, we will exceed the threshold. However, the effect of the instability is small at this bunch charge and the machine is usually run in this mode. Using two electron bunches in the ring instead of one should have no impact on the strength of the instability or the threshold, because the instability is a single bunch, short wavelength effect. Nevertheless, this effect is worth studying. We will use the existing synchrotron light optical system to measure the bunch profile using a streak camera.

Extraction Kicker

Discuss limits on extraction pulse/

NORTH RING TO LINAC

Discuss beam loading induced phase shift and jitter.

LINAC

Discuss general linac orbit considerations and diagnostics limitations.

Beam Loading

Describe energy spread compensation with SLED timing. Phase shift in Sectors 2-10.

Transverse Wakefields

Discuss dipole modes and flat top approximation.

INTERACTION POINT

Discuss effect of energy spread at final focus. Use of ICCD for beam diagnostics.

LUCRETIA

Do Lucretia sims.

CONCLUSION

Finito.

Thanks everybody.

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