Multibunch Beam Physics at FACET

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(Dated: November 16, 2012)

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.

INTORDUCTION

Plasma wakefield studies are normally run 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 will be possible to perform non-equilibrium plasma wakefield acceleration (PWFA) at FACET by configuring the linac for multibunch operation. We discuss the changes in machine operation and the associated challenges here.

INJECTOR

The electron source is a thermionic cathode driven by a multi-channel pulser. The pulser is composed of two planar triode amplifiers that couple into a common amplifier that drives the cathode. The two triodes can be fired independently to produce electron pulses from the cathode with arbitrary separation. The maximum charge per pulse is roughly 27 nC, which is almost an order of magnitude greater than the 3.2 nC used for PWFA [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 good charge capture is 5.6 ns, or 16 S-band buckets. The subharmonic buncher is followed by a 10 cm S-band buncher in Sector 0 and on-crest acceleration in Sector 1, reaching 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. It is unnecessary to calculate the effect of these actions on the electron bunch if it is possible to get full charge capture in the ring. The bunch phase space at the exit of the ring reflects the equilibrium emittance of the damping ring rather than the phase space of the bunch upon entering the ring. We will assume that it is possible to get full charge capture for two 3.2 nC bunches in the ring until proven otherwise.

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 is a pulsed magnet with a pulse length less than 60 ns that provides a 7 mead kick to the beam [2]. The kicker is controlled by a thyratron that produces a 40 kV pulse with an extremely fast rise and fall time. This magnet represents the first potential constraint on bunch spacing in the FACET linac. If the two electron bunches are significantly close to each other (less than 16.8 ns apart) they should both receive a strong enough kick to be captured in the ring. It does not matter if the two bunches see a different field in the magnet, so long as they see a strong enough deflection to be captured in the ring. Any orbital errors will be damped. For longer separations (say 33.6 ns), the two bunches will see roughly half of the peak field in the injector and will not be captured in the ring. For the longest separation (61.6 ns), it is possible to inject the beams on separate pulses. However, we will not satisfy the tolerance on the extraction kicker field at this longest bunch separation given the current hardware configuration.

Single Bunch Instability

The single bunch instability in the NDR is a microwave instability driven by inductive impedances in the NDR vacuum chamber. Since 1994, the threshold for the instability has been roughly 1.5×10^{10} electrons per bunch [4]. 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.

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 A π-mode instability arrises when the two bunches

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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