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The Source Development Lab Linac At BNL

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Abstract

A 210 MeV SLAC-type electron linac is currently under construction at BNL as part of the Source Development Laboratory. A 1.6 cell RF photoinjector is employed as the high brightness electron source which is excited by a frequency tripled Titanium:Sapphire laser. This linac will be used for several source development projects including a short bunch storage ring, and a series of FEL experiments based on the 10 m long NISUS undulator. The FEL will be operated as either a SASE or seeded beam device using the Ti:Sapp laser. For the seeded beam experiments; direct amplification, harmonic generation, and chirped pulse amplification modes will be studied, spanning an output wavelength range from 900 nm down to 100 nm. This paper presents the project's design parameters and results of recent modeling using the PARMELA and MAD simulation codes.

Introduction

The National Synchrotron Light Source has been engaged in the development of an FEL facility operating in the ultra-violet for more than five years. The Source Development Lab (SDL) has been established to pursue critical experiments on the path to short wavelength FELs, including development of high brightness beams, bunch compression and transport to high energy, and a broad range of SASE and seeded single pass FEL experiments. These FEL experiments will include study of startup, optical guiding, saturation, linewidth and fluctuations. The SDL is comprised of three major programs:

- Electron beam development and experiments.
- Coherent synchrotron radiation experiment.
- UV project FEL.

The electron beam development will be devoted to producing high brightness beams with peak current of 1 kA, normalized RMS emittance of 1π mm-mrad, and subpicosecond bunch lengths. The effects of coherent synchrotron radiation[1] and space charge forces[2] are expected to be significant with these parameters. Beam experiments will be devoted to studying their effect on emittance.

Our FEL program starts with SASE operation of the FEL at 900 nm. Harmonic generation[3] and chirped pulse amplification[4] experiments will follow with the addition of an energy modulation wiggler and dispersive section.

Laser Driven RF Photocathode

The electron source[5] is a radio-frequency photocathode developed by a collaboration from BNL, SLAC, and UCLA. It consists of a 1.6 cell RF structure driven at 2856 MHz. The maximum gradient has been measured at 140 MV/m, yielding an exit energy of approximately 8 MeV. Improvements over the original BNL design[6] include elimination of the side coupling into the half-cell to reduce emittance growth due to the TM_{110} mode, installation of a removable cathode allowing different cathode materials (e.g. magnesium) to be used, and increasing the half-cell length to increase RF focusing and decrease the peak field on the cell-to-cell iris. The emittance correction solenoid has also been improved with the addition of a re-entrant iron flux return to produce a more uniform magnetic field with little fringing. PARMELA runs[5,7] indicate that this RF gun is capable of producing electron bunches with 7 ps flat top, 1 nC charge, and normalized RMS emittance of 1.3π mm-mrad. The laser system used to excite the RF photocathode is based on a wide-band Ti:Sapp oscillator[8] mode-locked to the 35th subharmonic of the RF frequency. Phase jitter is less than 1 ps. The light output from the oscillator enters a multipass amplifier that stretches the pulse, amplifies it, and recompresses to produce 10 mJ in a final pulse length of 150 fs. Up to 0.4 mJ of the 266 nm third harmonic of the amplified pulse is then stretched to a final pulse length adjustable from 300 fs to 20 ps. An aberrated telescope is used to produce an elliptical beam for a square transverse intensity profile and 65 degree wavefront tilt to match the incidence angle on the RF photocathode. The square intensity profile is optimal for emittance correction. The wide bandwidth of the Ti:Sapp laser allows for longitudinal pulse shaping so that nonlinear emittance correction may be investigated.

Linac and Magnetic Bunch Compressor

The linac (Figure 1) currently consists of four SLAC-type constant-gradient linac tanks operating at 2856 MHz, with provision for installation of a fifth section.

The first two linac tanks are used to accelerate the beam to approximately 84 MeV. They also produce an energy chirp on the electron beam in preparation for bunch compression in a magnetic chicane. The compressor may be operated at any value from zero field to full strength. A phosphor flag and collimator are installed at the point of maximum dispersion for use as energy-spread diagnostics, and for slice emittance[9] studies. Tracking studies with MAD indicate the bunch should compress by a factor of 12, from an RMS length of 600 μm to 50 μm. For 1 nC of charge, this will increase the peak current to 2 kA. Following the chicane the beam is accelerated through two more linac tanks to a maximum energy of 230 MeV.

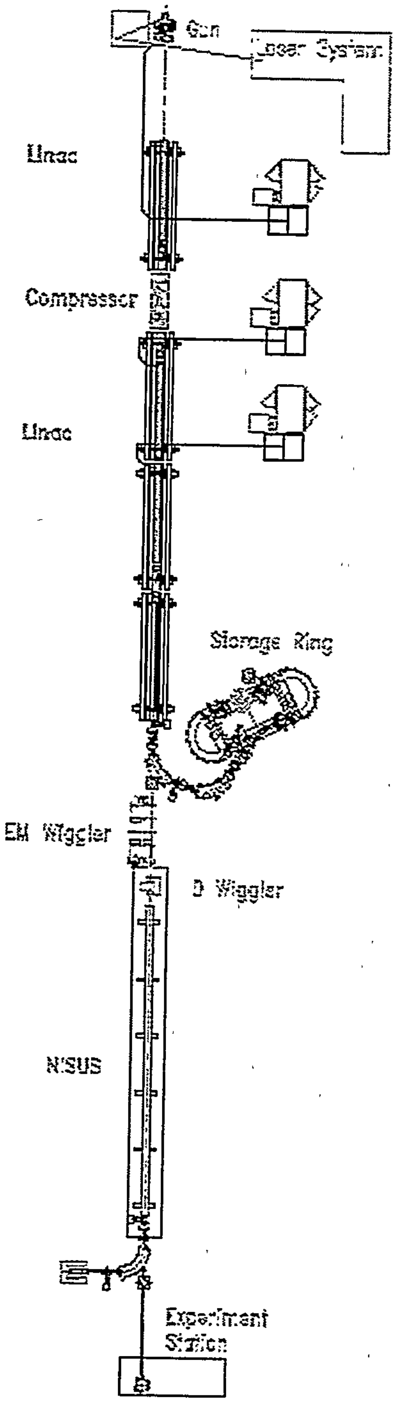

Fig. 1. Layout of SDL linac and experiments.

Wiggler

Following the linac is the 10 m long NISUS wiggler[10] originally built by STI, Inc. for Boeing Aerospace (see Table 1). This wiggler is constructed of vanadium-permendur poles and samarium-cobalt magnets, with iron shims added for error reduction. The gap is remotely adjustable, has a maximum field strength of 0.56 T, and can produce a compound taper to improve efficiency for high gain FELs. There are 256 periods, each of length 3.89 cm.

Table 1

<u>Electron Beam</u>	
Max. Energy	230 MeV
Peak Current	2 kA
Bunch Length	200 fs < σ_z < 20 ps
RMS Emittance	< 2 π mm-mrad
ΔE/E	0.5%
<u>Wiggler</u>	
Length	10 m
Period	3.89 cm
Peak Field	5.6 kG
Num. Poles	256
aw	1.44 max
Min. Gap	1.44 cm
Energy Taper	< 20%
<u>FEL</u>	
Wavelength	80 nm < λ < 1000 nm
Peak Power	70 MW
Gain Length	xx cm at 900 nm

The vacuum pipe through the wiggler is constructed of 8 independents sections. Each section has two ports for pop-in phosphor screens, two ports for pick-up electrodes, and two sets of steer/focus wires that can produce external dipole and quadrupole fields. The wiggler poles are canted to produce focusing in both planes.

Electron Beam Experiments

Several of the important beam parameters for the FEL experiments have an unusually large range of adjustment. The pulse length and energy spread can be varied and optimized with both the drive laser and the magnetic chicane. The initial pulse length may be varied by nearly two orders of magnitude via the Ti:Sapp laser alone. Recent magnetic compression studies[11] have shown that shorter electron pulses may ultimately be created by compressing a relatively long pulse. This is because the more intense wakefields and higher space charge of an initially short bunch increase the nonlinear distortion in the energy-phase correlation used for compression[12]. Finally, one can optimize the bend angle in the compressor so that the nonlinear effects of the longitudinal wakefield and RF are partially canceled by the effect of the nonlinear dependence of path length on the energy deviation.

Longer initial pulses will also reduce emittance growth due to transverse wakefields.

Very short, high current bunches propagating through bends can experience significant transverse emittance growth through two distinct effects, the longitudinal coherent space charge force (CSCF), and coherent synchrotron radiation (CSR). Emittance growth due to CSCF scales as $Q\,(a/\delta)^2$ where Q is the bunch charge, a is the bunch radius, and δ is the bunch length. Similarly, CSR scales as $Qa/\delta^{4/3}$. Simulations with a version of MAD modified by one of us (TR) to include CSR indicate that the emittance grows from 1.2π mm-mrad to 2.0π mm-mrad in the final bend of the compressor when compressed to a final bunch length of 0.6 ps. Greater compression is possible, but results in larger emittance. The bunch length, transverse size, and charge will all be varied in order to study the magnitude and scaling of these effects. The compressor vacuum pipe has a radiation port to capture synchrotron radiation which will be used as a diagnostic for bunch length and beam size. The emittance may be measured immediately before and after the compressor to isolate the effects of CSR and CSCF.

At high energy, the bunch length will be verified through two methods. By passing the beam through a foil, coherent optical transition radiation (OTR) will be generated at wavelengths comparable to the bunch length. An experiment is planned following the linac which measures the coherent OTR spectrum. Additionally, the final linac section and bend may be used to produce an energy chirp which can then be "streak" a phosphor screen to measure bunch length. profile measurement combined with charge measurements in the Faraday cup or BPMs will give the bunch charge profile. The drive laser pulse is approximately 1mm long by 1mm in radius. The very short longitudinal profile significantly affects the minimum emittance achievable via solenoidal emittance correction[13]. By varying this profile, we will study the relative strength of the nonlinear terms in the emittance correction. Measurements of the slice emittance as developed at BNL's Accelerator Test Facility will be used in these studies.

FEL Experiments

The FEL development program for the SDL can be broken into stages based on machine requirements and modifications. In the first stage, a normalized emittance of 6.5π mm-mrad at a beam energy of 130 MeV is required. SASE experiments will be conducted at roughly 1μm wavelength with an anticipated peak power of 70 MW. Tapering and harmonic content will be investigated. The first seeded beam operation will be at the Ti:Sapp fundamental (900 nm). Chirped pulse amplification experiments at this wavelength will yield photon pulses as short as 10 fs. After adding an energy modulation wiggler and dispersive section at a later date, the FEL output wavelength will be pushed to 200 nm using harmonic generation. A 400 kW beam from the Ti:Sapp at 400 nm will bunch the electron beam, which will then lase on the 2nd harmonic, producing 70 MW at 200 nm. With the addition of a 5th linac section increasing the beam energy to 310 MeV, and emittance of 1π mm-mrad, FEL operation below 100 nm should be possible, including the demonstration of CPA at 80 nm with a 5 fs pulse duration.

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