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INITIAL LASER ACCELERATION EXPERIMENTS OF THE E163 PROGRAM AT SLAC*

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Abstract

This paper presents the initial results in laser electron acceleration from the newly commissioned E163 program at SLAC and an outline of the initial wave of experiments. These results include an inverse free electron laser (IFEL) interaction with 800nm light from a Ti:sapphire laser which will be used along with a chicane to produce optically spaced electron microbunches. The microbunching is independently diagnosed via coherent optical transition radiation (COTR) at the second harmonic (400nm) in order to avoid large background at the fundamental due to the laser. We will also discuss experiments that take the microbunch train formed by the IFEL/chicane and perform net acceleration using a second stage: an inverse transition radiation accelerator (ITR). This discussion includes the experiment layout and hardware as well as simulation of expected results.

THE E163 FACILITY

The E163 program is hosted by the NLCTA facility at SLAC. An S-band photoinjector was installed to produce sub-picosecond, 50 pC electron bunches that are accelerated to 60 MeV with <0.1% energy spread. An additional beamline was added to bring the beam into an adjoining experimental hall [1]. The laser room housing the drive laser for the photoinjector also houses a second laser for laser-electron experiments. Both lasers are driven off of a common oscillator providing excellent timing stability [2]. The experimental hall houses a large 2'x3' vacuum box for experiments. This is followed by an electron spectrometer providing 2 keV energy resolution. A streak camera and Cherenkov radiator are used to time the laser and electron beams prior to the experiment. Figure 1 shows the layout of the full net acceleration experiment.

Commissioning [3] of the newly completed beamline began in March of this year and to a certain degree remains on-going. The initial month long commissioning did not include any experimental hardware in the vacuum chamber. The hardware was installed during the month of April and the experiment started up again in May. Initial results for an IFEL interaction were obtained and are presented in this proceedings along with simulations of the expected COTR soon to be measured and the full net acceleration experiment.

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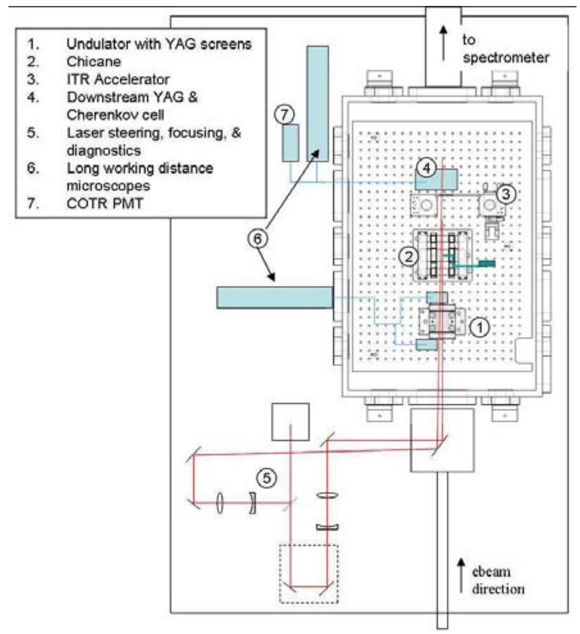

Figure 1: Layout of the hardware inside the experimental chamber. Optics adjacent to the chamber focus and steer the laser through the undulator. Long working distance microscopes image screens both fore and aft of the undulator as well as after the tape for the ITR experiment.

MICROBUNCHING HARDWARE

The microbunching hardware consists of a 3-period undulator and a hybrid coil-permanent magnet chicane. Key dimensions are given in table 1. The hardware is designed to sit entirely within vacuum. Attached to the undulator are YAG screens for aligning the electron and laser beams. The coils on the chicane allow for 15% variation in the field strength. Since the chicane sits in vacuum, heat dissipation becomes an important issue. The chicane is therefore supported by a copper frame with water cooling coils attached to the base.

The two pieces of hardware sit 5 cm apart in vacuum. Initially the laser was introduced 30cm upstream of the undulator via a dielectric coated pellicle mirror. This mirror was found to cause significant beam degradation. Numerical estimates using [4] indicate an emittance growth by at least an order of magnitude. As a result beam spot sizes in the chamber were larger than expected. The pellicle was latter removed and the laser introduced further upstream at a window at the dogleg bend where the electron beam is

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Undulator	
Period	1.8 cm
Number of Periods	3
K_w	0.70
Pole Material	Vanadium permendur
Magnet Material	NdFeB B_r=1.25 T
Pole/Magnet Thickness	4/5 mm
Chicane	
Field strength	0.25 - 0.41 T
Gap	7mm
Pole Thickness	19.5/38mm
Pole Spacing	5 cm center-to-center

Table 1: Microbunching hardware key properties.

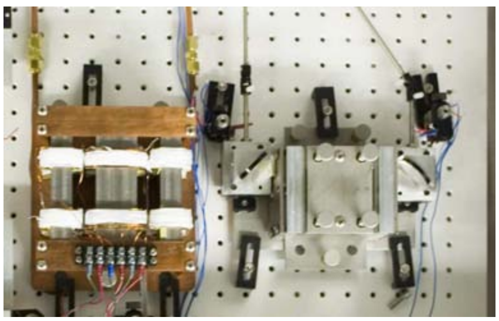

Figure 2: The undulator and chicane installed inside the vacuum chamber. Two screens fore and aft of the undulator allow alignment of the laser to the electron beam.

brought in from the adjacent NLCTA beamline. Table 2 gives a list of current measured experimental parameters.

Parameter	Value
E-beam energy	60 MeV
E-beam initial energy spread (rms)	40 keV
E-beam charge	50 pC
E-beam pulselength (rms)	0.5 ps
E-beam normalized emittance	unkown
E-beam focused vertical width (FWHM)	100 μm
E-beam focused horizontal width (FWHM)	100 μm
Laser pulselength (FWHM)	0.4 ps
Laser wavelength	800 nm
Laser energy	0.4 mJ
Laser focused spotsize (FWHM)	99 μm

Table 2: Experimental parameters. The electron beam pulse length and transverse size were measured using the IFEL data.

INITIAL MEASUREMENTS

Despite the larger than expected spot sizes at the interaction point due to the pellicle, IFEL interactions were initially observed on the scale of 20-35 keV energy modulation. Putting the measured beam parameters including the larger spot sizes into a particle tracking simulation verify that the expected modulation is around 35 keV. After removing the pellicle considerable improvement was seen in both the beam profiles as well as the energy spread at the spectrometer. Subsequent IFEL interactions then reached closer to the 100 keV RMS modulation expected from design simulations.

The data is gathered at 10 Hz and takes the form of cross-correlation plots of electron beam energy width versus laser delay. The laser is randomly turned on and off to help distinguish the interaction peak and to provide a non-interacted data set for other diagnostic analysis. Because of low energy tails seen in most runs, analysis is done using the half width of the high energy side of the distribution. Figure 3 shows a typical data run scatter plot with a fit to the laser on data. We subtract in quadrature the fit baseline from the amplitude to calculate the induced spread due to IFEL alone. In this particular run from the fit parameters we get an RMS modulation of 54 keV. Note that the fit is pulled down by large jitter at the interaction peak. The strongest interactions in the run reach greater than 55 keV half-width, half-maximum, corresponding to an RMS modulation of 93 keV. From the IFEL interaction combined with prior knowledge of the laser pulse length from autocorrelation[5] we are able to infer an upper limit for the electron pulse length of 0.5 ps. We can also note from the fact that the data under the peak of the interaction is lifted away from the baseline that the temporal jitter is quite small. Longer data runs with a fixed laser delay showed a continued interaction over 5 minutes, the length of the run.

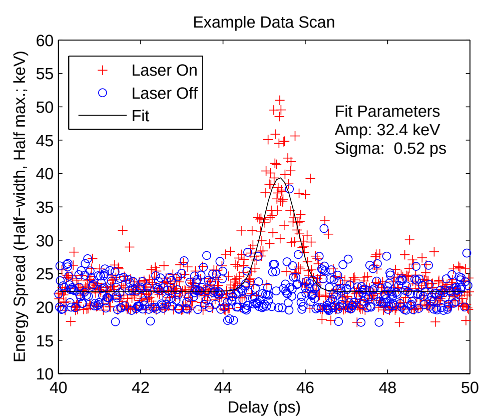

Figure 3: Example IFEL interaction. Run consists of 1020 events. A cross-correlation signal is clear. From the fit we infer an interaction of 64 keV FWHM. We also obtain from the correlation width an electron pulse width of around 0.5 ps.

THE COHERENT OPTICAL TRANSITION RADIATION (COTR) EXPERIMENT

The first goal after establishing an IFEL interaction is to observe the COTR radiation. The energy modulation resulting from the laser-electron interaction in the IFEL is converted to a density modulation in the chicane. Equation 1 gives an expression for the resulting longitudinal charge density modulation. Here η is the strength of the IFEL modulation and β is a dimensionless parameter describing the strength of the chicane such that $\beta = k_l \eta R_{56}$; R_{56} is the dispersion of the chicane. ρ_0 is the initial charge density, σ_γ the initial energy spread, and k_l the wavenumber of the laser. Figure 4 shows the resulting COTR output at various harmonics as a function of the chicane strength. Notice that each of the harmonics are maximized at different values of the chicane.

$$\rho(z) = \rho_0 \left[1 + 2 \sum_{n=1}^{\infty} J_n(n\beta) \exp\left[-\left(\frac{n\sigma_\gamma}{2\eta} \right)^2 \right] \cos(nk_l z) \right] \tag{1}$$

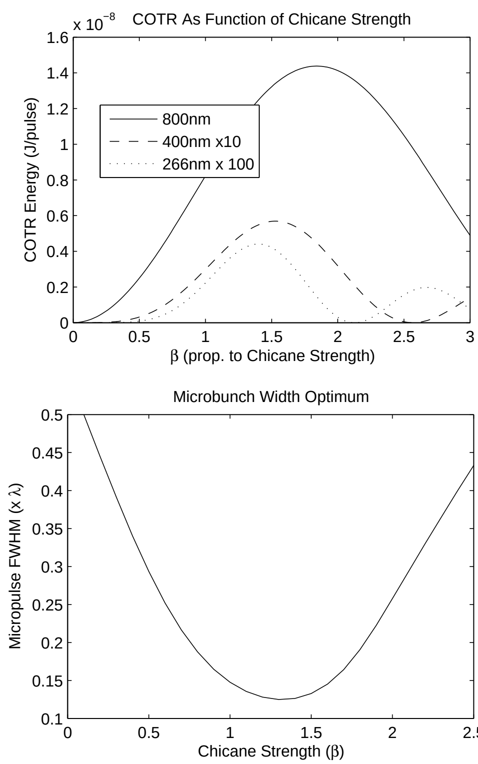

Figure 4: Above: Expected COTR output at various harmonics for 50pC bunch with a 30 μm spot size as a function of the chicane strength and $\eta/\sigma_\gamma = 2.5$. The actual COTR is much less due to the larger spot size. Below: Optimization of microbunch FWHM for the same parameters. Notice the tightest bunching occurs for a different chicane strength than the greatest COTR output.

A screen downstream of the chicane is used as the radiator with a flip mirror to intercept light going to the camera and divert it to a photomultiplier tube. To avoid the large background at 800nm, COTR is observed at the second harmonic using a PMT with two 400 nm bandpass filters. The PMT is also shielded from x-ray background. Data is again taken as a cross-correlation experiment with the PMT output being used as the signal.

Although efforts were made in this initial run to observe COTR, no signal was found. This is likely due to the transverse spot size still being too large. Figure 4 assumes a spot size of 30 μm, for a spot of 100 μm the coherent output is down almost a factor of 100. Later efforts will employ a pinhole collimator and a dedicated foil for transition radiation in order to observe the microbunching.

THE NET ACCELERATION EXPERIMENT

The net acceleration experiment will combine the microbunching hardware with an inverse transition radiation accelerator structure[6]. The ITR accelerator provides a modest energy modulation of 70 keV, but has the benefit of relatively large acceptance compared to other optical accelerator structures. The ITR setup has also already been exercised in prior experiments and is known to work. When combined with the microbunching hardware, simulation indicates a net acceleration of 25 keV can be achieved. Figure 1 shows the layout of the net microbunching experiment. Both the IFEL and the ITR are driven from a common laser split on an optical table adjacent to the experiment chamber. Separate steerers and optics allow independent alignment and a delay stage allows scanning the ITR past the IFEL in time, both on a coarse level as well within a single optical cycle. Just after the ITR tape a tungsten collimator limits the ebeam horizontally. Because the ITR requires the laser at an angle of $1/\gamma$, electrons at the same time but with different horizontal positions see different optical phases of the laser. In order to observe net acceleration we therefore have to limit the beam to 50 microns in the horizontal direction. While in theory the final focusing triplet should be able to achieve this, it will likely help to have the additional slit collimator.

For an accelerated beam to be useful it will need to have a relatively small energy spread and thus a narrow pulse length relative to the acceleration wavelength. This would tend towards setting the chicane strength to increase the higher harmonic content of the COTR. However, to get the most net acceleration over the entire bunch, the only term that matters in equation 1 is the first harmonic, thus $\beta = 1.84$. The next quantity to optimize is the distribution of laser power between the IFEL and ITR. Figure 5 shows an optimization of of laser power to the experiment for 1 mJ/pulse availabe power. Little acceleration is seen until the IFEL modulation starts to exceed the initial energy spread. Too much power to the IFEL and there is not enough power left over to accelerate. The optimum varies for the amount of power available but generally stays around 1/3 of the power going to the IFEL.

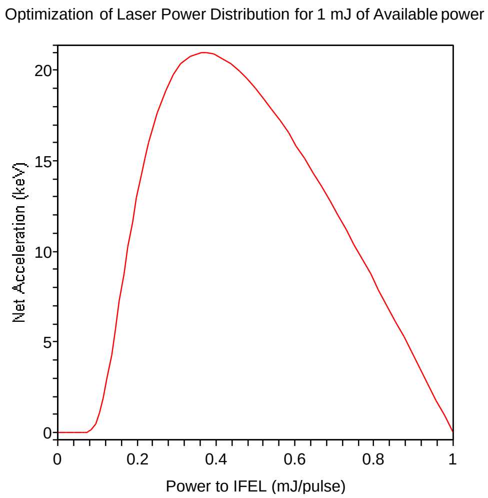

Figure 5: Optimization of laser power distribution for the net acceleration experiment. Plot assumes an initial energy spread of 40 keV, an IFEL modulation strength of 100 keV for 1 mJ/pulse laser energy, and an ITR modulation strength of 70 keV for 1 mJ/pulse available.

Simulations of the net acceleration experiment were performed using a simple particle tracking code and magnetic fields for the microbunching hardware output from Radia[7], a boundary element method magnetostatic field solver used in the original design of the hardware. The laser is described by the analytic paraxial wave approximation for a TEM_{00} mode[1]. Figure 6 shows a simulation of the net acceleration experiment. The simulated parameters are the same as table 2 with the addition of a second laser beam driving the ITR stage with 0.6 $mJ/pulse$ and a 50 μm waist.

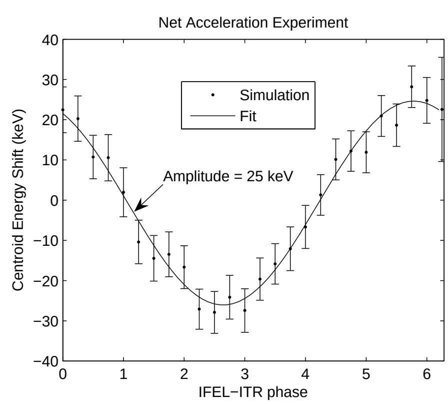

Figure 6: Expected results for the net acceleration experiment. The plot shows the shift in the beam energy as a function of the IFEL laser versus ITR laser relative phase. A fit to the data gives an expected amplitude of 30 keV shift.

The total energy spread after the IFEL and ITR interactions is expected to be 150 keV. The centroid jitter has been measured to be similar, though avenues for reducing this jitter have been identified and will be pursued. Nevertheless, with sufficient statistics it should be possible to observe the centroid shift with optical phase delay between the IFEL and ITR.

[1]The actual laser has an M^2 of 1.5.

THE NEAR FUTURE OF E163

It is expected that the experiments described here will be executed within a few months. It is likely a few iterations on the net acceleration experiment will be necessary to address possible optical phase jitter due to vibrations or improved ebeam focusing and collimation if necessary. Also planned are a series of experiments studying ITR at varying tape surfaces[8] including varying the tape angle, surface type (metallic, flat dielectric, rough surface) and also a clear tape that should allow acceleration at both the upstream and downstream interfaces.

The experiments will then change direction to begin studying optical scale structures. This will start with the testing of a permanent magnet triplet[9] to obtain the tight focusing necessary to couple the electrons through the small structures. We look to observe Cherenkov induced wake in a photonic bandgap structure[10] and pending successful observation of the wake accelerate electrons by coupling in laser light from an optical parametric amplifer at the same wavelength as the wake. Another structure we plan to test is formed by two gratings close together excited by a laser pulse traveling transverely through the structure[11].

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