

The UCLA high gain infrared free electron laser¹

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Abstract

A high gain SASE FEL amplifier designed to operate in the infrared (near 10 μm) is being commissioned in the Particle Beam Physics Laboratory at UCLA. The high brightness beam needed to drive the FEL is provided by an RF photocathode gun employing solenoidal emittance compensation. A novel linac (a Plane Wave Transformer) accelerates the beam to a final energy ≤ 15 MeV. This beam is to be sent through a 60 cm long undulator with a period of 1.5 cm and an undulator parameter $K \approx 1$. Near future experiments will focus on FEL physics relevant to proposed short wavelength devices. Investigations of start-up from noise (SASE), effects of beam parameters on gain as well as noise fluctuations are of particular interest. Here we present an overview of the hardware including relevant diagnostics, measured beam parameters, FEL simulation results and the status of proposed experiments.

1. Introduction

The UCLA Particle Beam Physics Laboratory (PBPL) was designed as a high-brightness electron beam facility for the education of students and the study of accelerator physics with an emphasis on beam-radiation and beam-plasma interactions. PBPL is in the process of commissioning a high gain Infrared Free Electron Laser Amplifier to study issues relevant to future short wavelength devices. A lack of suitable mirrors make oscillators impractical at short wavelengths necessitating a high gain system. A lack of suitable sources at short wavelengths makes operating from Self-Amplified Spontaneous Emission (SASE) a precursor to designing future short wavelength devices [1].

1.1. The beamline

The entire beamline including the gun, linac, electron beam optics, and undulator is shown in Fig. 1. The high-brightness beam needed to drive the FEL is provided by a Brookhaven National Lab (BNL) 1.5 cell photocathode RF gun [2]. The UCLA gun [3] described elsewhere was damaged, ostensibly from contamination,

resulting in low quantum efficiency and nonuniform emission. Photoelectrons are produced by a frequency quadrupled (266 nm), pulsed compressed (~ 2 ps) Nd:YAG laser. RF is provided by a SLAC XK5 Klystron. Solenoidal focussing controls the highly divergent beam and provides emittance compensation [4] into the Plane Wave Transformer (PW) Linac [5] which accelerates the beam to its final energy. The beamline has bend dipole magnets, before and after the undulator, which serve to both measure the energy and energy spread, and isolate the infrared beam for detection. Focussing quadrupole magnets provide matching into the undulator.

1.2. The undulator

The 40 period planar undulator is a modified hybrid design with an on axis peak field ~ 0.75 T, 1.5 cm period, and a fixed gap of 5 mm [6]. Prior to installation into the beamline, a Hall probe verified the peak field and a new pulsed wire system showed the field uniformity (first and second integral) was within acceptable levels for FEL operation. Predicted FEL performance is shown in Table 2, and recent FEL measurements are discussed in the next section. Measuring the sensitivity of the FEL to changes in electron beam parameters requires single shot, non-destructive diagnostics.

1.3. Electron beam

Charge measurements are made with an Integrating Current Transformer (ICT) and Faraday Cups. A slit

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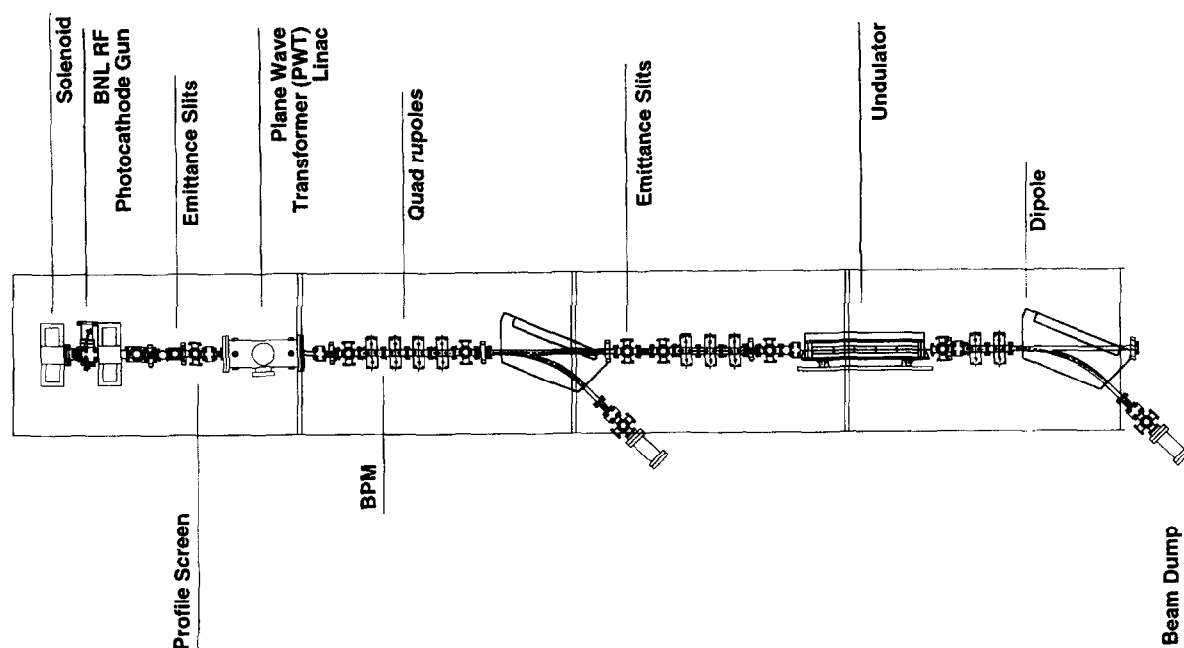


Fig. 1. The UCLA PBPL Beamline including the gun, linac, associated optics, and the undulator.

Table 1
Single shot electron beam parameters

Energy	13 MeV
Energy spread (rms)	0.2%
Peak current	200 A
Emittance (normalized rms)	< 10 mm-mrad at 1 nC

Table 2
Undulator parameters

Length	60 cm
Period	1.5 cm
Peak field	0.75 T
Fixed gap height	5 mm
Undulator parameter	1

system [7] is used to measure the emittance and phase space of the highly space-charge-dominated beam at both low energy out of the gun and again at the final energy out of the PWT. Stripline Beam Position Monitors (BPMs) provide position and charge before the undulator. A diagnostic to measure the longitudinal electron beam bunching resulting from the FEL process, using Coherent Transition Radiation (CTR), is being developed at UCLA [8].

Table 3
FEL parameters (simulation)

Nominal wavelength	~ 20 μm
Gain at 60 cm	~ 500
Peak power	1 W

1.4. Infrared radiation

The experimental setup for the initial measurements is shown in Fig. 2. A high-speed (~ 5 ns), liquid helium-cooled, copper-doped Germanium detector measures the FEL output. To reduce the path length and minimize potential complications in detecting the FEL output, a single focussing mirror ($f = 6''$) directs the infrared signal to the detector. A cooled Winston Cone (non-imaging optic) collects the infrared signal on to the 3 mm diameter detector. The detector and amplifying electronics are shielded with lead bricks.

2. Present status

The beam has recently been propagated through the undulator for the first time and undulator radiation has been observed (see Figs. 3(a) and (b)). Fig. 3(a) shows an oscilloscope trace of the undulator radiation. Fig. 3(b) shows the X-ray-induced background at the output of

IR FEL Operational Diagnostic Layout

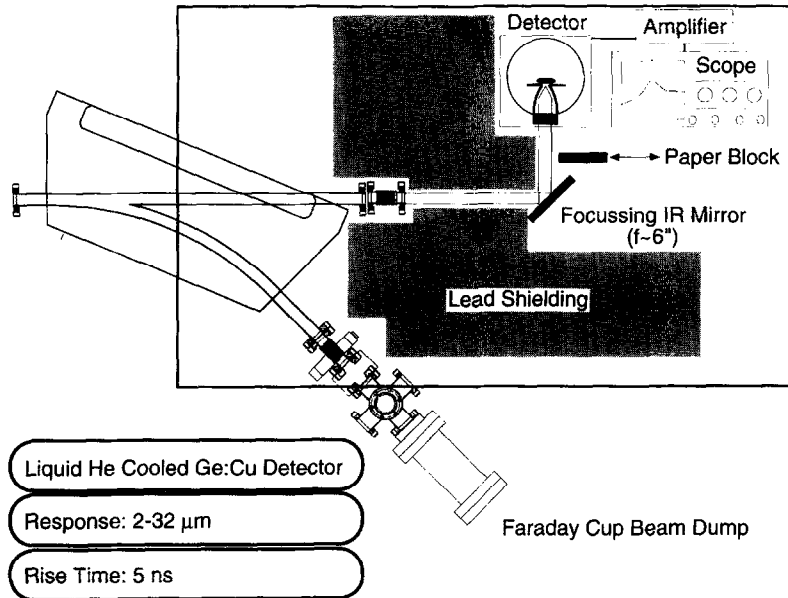


Fig. 2. IRFEL detector set-up for the initial spontaneous emission measurements.

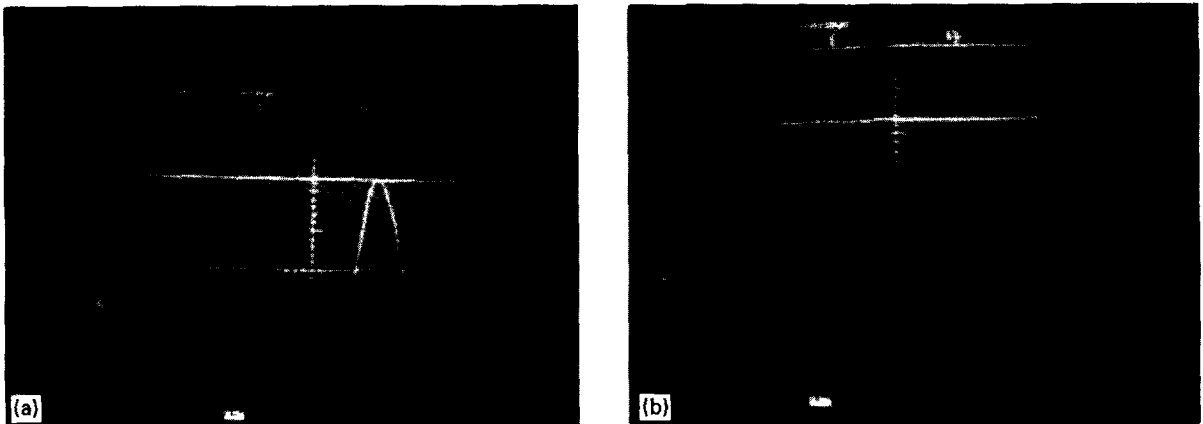


Fig. 3. Oscilloscope traces of the undulator radiation signal and the X-ray background: (a) Spontaneous emission signal; (b) X-ray background. X-ray background arrives ~ 2 ns after the Spontaneous Emission Signal. Both signals are photocurrent-dependent. Repeatable.

the detector amplifier when a paper block covers the detector window. The following checks ensured that Fig. 3(a) was in fact undulator radiation. First, the signal amplitude scaled with charge in the electron beam. Secondly, the signal was related to the photoelectron beam – shuttering the gun drive laser (no photocurrent) eliminated the signal. Finally, introduction of the paper block consistently eliminated the undulator radiation signal.

3. Future work

Although encouraging, the recent results are preliminary and the signal/noise ratio is not sufficiently large to make the required measurements. The near term focus will be on optimizing the present signal by decreasing the background and improving beam transport through the undulator. Once there is sufficient dynamic range, issues relevant to the start-up regime will be explored: signal

dependence on beam charge and a proof of principle experiment for the CTR bunching monitor. The moderate gain predicted by Tran and Wurtele's TDA3D code [9] (~ 500) of the present 60 cm undulator is insufficient to explore issues relevant to saturation.

A 2 m undulator now under construction will focus on the saturation regime. With the higher gain (predicted $\sim 10^6$) the functional dependence of the gain on various beam parameters such as current and emittance will be studied. The CTR monitor will measure the highly bunched beam.

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