THE CSU ACCELERATOR AND FEL FACILITY*

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Abstract

The Colorado State University (CSU) Accelerator Facility will include a 6-MeV L-Band electron linear accelerator (linac) with a free-electron laser (FEL) system capable of producing Terahertz (THz) radiation, a laser laboratory, a microwave test stand, and a magnetic test stand. The photocathode drive linac will be used in conjunction with a hybrid undulator capable of producing THz radiation. Details of the systems used in CSU Accelerator Facility are discussed.

FACILITY GOALS

There is an expanding demand across a wide variety of discipline in academia, laboratories, and industry for particle accelerators [1,2]. The growing demand of trained accelerator experts continues to motivate the expansion of facilities in a university setting dedicated to training engineers and physicists in accelerator technology. Part of the goal of the CSU Accelerator Facility is to provide a place where both accelerator research and training of high-school through post-doctoral students can flourish. The CSU Accelerator Facility will initially focus on generating long-wavelength free-electron lasers, electron-beam components, and peripherals for free-electron lasers and other light sources. It will also serve as a test bed for particle and laser beam research and development.

FACILITY OVERVIEW

There are four major systems to the CSU Accelerator Facility: an accelerator and FEL system, a laser laboratory, a microwave test stand, and a magnetic test stand. A diagram of the setup of the major accelerator and FEL components is shown in Figure 1. Overviews of the accelerator, undulator, the laser laboratory, the microwave test stand, and the magnetic test stand are given in the following sections.

The Accelerator

The linac to be used was constructed by the Los Alamos National Laboratory for the University of Twente. The University of Twente has generously donated the entire system for use at CSU and their team will remain in close collaboration with CSU.

The accelerator is a five and a half cell copper structure operating at an RF frequency of 1.3 GHz. The accelerator will operate at a 10-Hz repetition rate and a micropulse repetition rate of 81.25 MHz (the 16th subharmonic of 1.3 GHz). Additional specifications are given in Table 1.

Table 1: Linear Accelerator Characteristics

Energy	6 MeV
Number of Cells	5 ½
RF Frequency	1.3 GHz
Unloaded Q	18,000
Axial Electric Field	
Cell no. 1	26 MV/m
Cell No. 2	14.4 MV/m
Cell No. 3 - 6	10.6 MV/m
Peak Solenoid Field	1,200 G

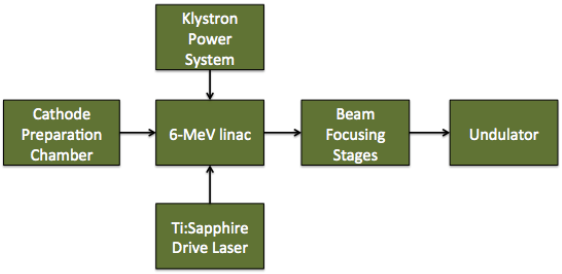

Figure 1: Schematic of the accelerator and FEL.

Initial characterization of a single linac cell was performed using SUPERFISH (Figure 2) [3]. This included an assessment of the variation in resonant frequency due to thermal expansion. Thermal expansion calculations showed a possible shift of about 200 kHz/°C that is acceptable for resonant tuning via water temperature control.

Work is currently being done to build a total cavity model combined with solenoid and beamline models to establish the initial setup requirements for operation.

The cathode preparation chamber for the accelerator can support a variety of cathode types, including those previously used: CsK_2Sb, K_3Sb, and copper. In the high vacuum of the preparation chamber (~4×10^{-10} Torr), it has been demonstrated that acceptable cathode lifetimes can be on the order of days.

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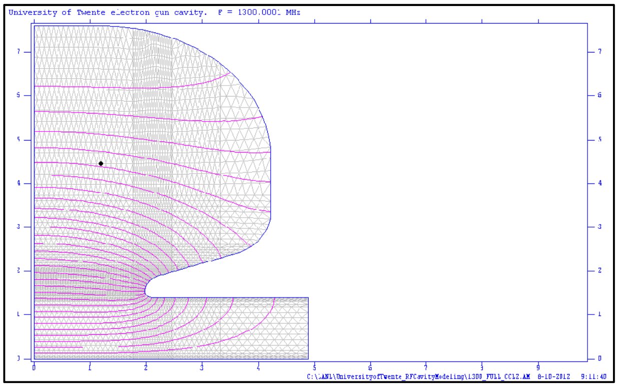

Figure 2: Single cell model of the RF cavity performed using SUPERFISH.

The Laser Laboratory

The laser laboratory will have a Coherent, Inc. mode-locked Ti:Sapphire oscillator operating at a repetition rate of 81.25 MHz coupled to a regenerative amplifier single pass amplifier combination operating at up to 1 kHz. This laser system will be used both as the drive laser for the photocathode and to perform independent experiments. The Boeing Company generously donated the laser to CSU.

Table 2: Laser System Characteristics

Micra Oscillator	
Avg. Power	>300 mW
Rep. Rate	81.25 MHz
Pulse Width	<15 fs
Legend Elite Duo Amplifier	
Avg. Power (800 nm)	>10 W @ 1kHz
Avg. Power (256 nm)	>1 W
Pulse Duration	40 fs (FWHM)

An optical transport system has been designed to achieve the desired laser pulse parameters at the cathode for the aforementioned Ti:Sapphire laser system. A schematic of the component layout on the optical table next to the photocathode rf gun is shown in Figure 3.

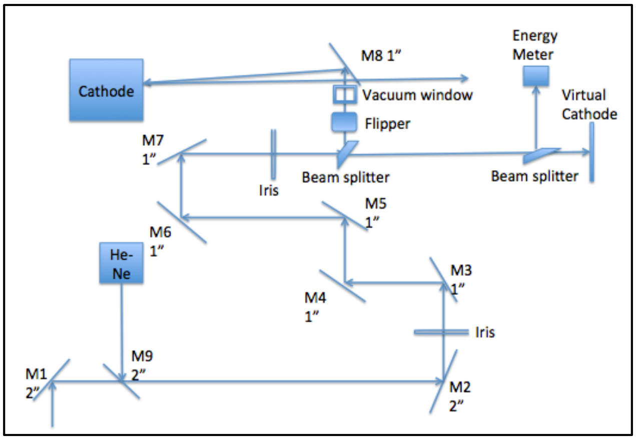

Figure 3: Layout of the optical table next to the photocathode-driven accelerator.

The Undulator

The undulator was also part of the donation from the University of Twente [4]. The hybrid undulator is powered by Sm_1Co_5 magnets and utilizes curved 2V-permendur pole tips to achieve equal focusing in both planes. It has a nominal design peak magnetic field of 0.61 T with a period of 25 mm, and yields a K-value of about 1. The undulator has 50 periods and a gap size of 8 mm. The undulator parameters are given in Table 3.

In the original setup this undulator was placed inside an optical cavity with planar mirrors at either end. The downstream planar mirror was movable over a 1-cm distance to allow for tuning of the cavity. After the undulator, there was a spectrometer to capture the energy spectrum of the electron bunch and an interferometer to examine the FEL spectrum [5] as shown in Figure 4.

CURRENT STATUS OF THE FACILITY

At present (Summer 2012), the laboratory space is being cleared prior to installation of the accelerator and undulator. The magnet measurement and microwave measurement laboratories are currently being set up in a separate dedicated lab area.

The accelerator is set to arrive at CSU in early Fall 2012. The laser system will arrive at CSU in early September. All linac and laser system components will be tested in the laser, microwave, and magnetic measurement laboratories that have been established at CSU. Peripheral system checkout and installation will occur soon thereafter.

The Magnetic Measurements Laboratory

At present, a Lake Shore Cryotronics, Inc. Gaussmeter has been set up and mounted to take magnetic field profile measurements of the accelerator components. This will serve as the test-bed for evaluating the components for the 6-MeV linac and other components developed in our group. A LabVIEW program has been developed to iterate through specified magnet current setpoints and record the current settings and magnetic field values.

The laboratory will also have the capability for undulator characterization through modification of the test stand and data acquisition software. The University of Twente undulator will be the first to be characterized in the laboratory.

Table 3: Basic Undulator Characteristics

Type	Hybrid: Sm_1Co_5
K value	1 (at 8 mm gap)
Undulator period	25 mm
Total periods	50
Half gap	4.0 mm
Overhang of magnet	6.0 mm
Half thickness of pole	2.00 mm
Half thickness of magnet	4.25 mm
Height of pole	40.0 mm
Height of magnet	45.0 mm
Half width of pole	15.0 mm
Half width of magnet	21.0 mm

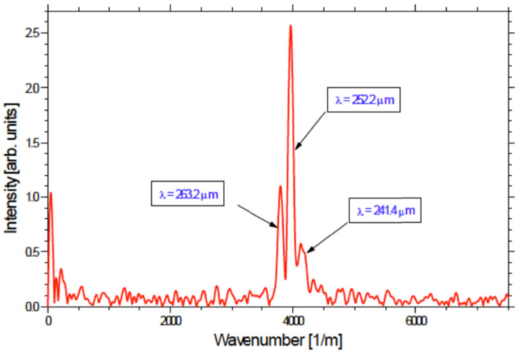

Figure 4: Wavelength spectrum of FEL radiation.

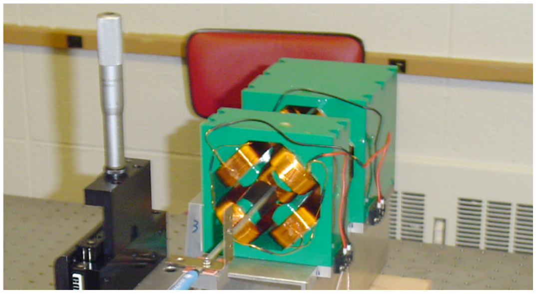

Figure 5: University of Twente quadrupole doublet undergoing initial measurements.

The Microwave Laboratory

A microwave test stand is being established for use in characterization of accelerating structures. Initially the setup will be used as a training platform for executing electric field measurements of cavity structures. The setup will measure transmission and reflection in conjunction with perturbations to map the internal cavity fields. The first test piece will be a X-band RF accelerating structure on loan from the SLAC National Laboratory.

A mount has been designed, fabricated and installed for use in holding an X-Band cavity during bead pull measurements for cavity characterization (Figure 6). The necessary electronics for these measurements have been installed and calibrated. Stepper controller and measurement system programming for the test stand is still in progress.

Other RF measurement configurations will include ballistic bunch compression and higher-order mode guns donated by Argonne National Laboratory [6]. Additional linac and other RF devices developed here at CSU will also be tested.

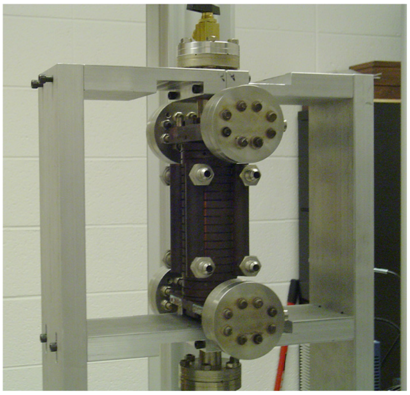

Figure 6: X-band cavity mounted in test stand for electric field characterization.

PLANNED FIRST EXPERIMENTS

Following initial commissioning of the linac/laser system, the accelerator facility will first replicate the FEL experiment originally performed at the University of Twente. This will serve as a baseline characterization of the machine and allow the CSU users to become familiar with the equipment. Following the initial FEL test the accelerator will then be used as a platform for testing newly developed technologies and for training.

In parallel to the linac/laser commissioning tests we will also be developing an electro-optical sampling (EOS) system for high-power, relatively low-energy beam applications. Initially, two methods of EOS will be tested in the lab against a balanced diode detection system. Plasma THz pulses will be generated with the amplified Ti:Sapphire laser at 800 nm. These pulses will be used to simulate the low energy electron beam bunches for each method of electro-optical sampling. One method will utilize only the Ti:Sapphire oscillator for the EOS measurement, while the other will require the amplified laser pulses. Each method uses a probe pulse through an electro optical (EO) crystal that is polarized to act as a gate; this gate will open only when the electric field from an electron bunch is present. The plasma THz pulses in the lab could in theory be used to simulate low emittance, high current bunches. Measurement of the simulated bunch profiles by the EO crystal systems will be compared against a balanced diode detection system known to be too susceptible to noise to be useful in a beam environment. [7,8]

Work will also be conducted on the testing of new materials for photocathode use. The first of these experiments will be centered on $12CaO\text{-}7Al_2O_3$ (electride), a crystalline ceramic. Electride is a promising candidate for use as a photocathode material due to its very low work function of 0.82 eV [9] and resistance to contamination. Using the laser laboratory at CSU, investigation into electride's quantum yield as a function of incident light wavelength will be performed.

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