STATUS OF THE NPS FREE-ELECTRON LASER*

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Abstract

The Naval Postgraduate School (NPS) is in the process of designing and constructing a free-electron laser (FEL) laboratory to pursue FEL-related research and introduce students to modern accelerator and FEL technology. The laboratory will pursue research on high-brightness injectors, fundamental and applied beam dynamics, energy recovery linear accelerators, as well as FEL experiments.

The accelerator will be based around two, Stanford-Rossendorf type cryomodules, each of which houses two, 9-cell TESLA-type cavities. RF power will be provided by four, 10-kW CW L-band klystrons. With a nominal beam current of 1 mA, this provides an energy gain of 10 MV per structure. Intended operating modes include single-pass, energy recovery linac, and 2-pass microtron.

This paper provides an introduction to the NPS-FEL program goals, site and vault layout, and preliminary experimental plan.

PROGRAM GOALS

The Naval Postgraduate School has committed to the construction and operation of a free-electron laser and accelerator physics laboratory, NPS-FEL.

One of the primary missions of the NPS-FEL will be student education. NPS grants Master's and Ph.D. degrees in a variety of disciplines, including physics, mechanical and electrical engineering. Accelerators by their nature require multidisciplinary efforts to construct, operate and characterize; thus, the NPS-FEL represents an opportunity for cross-disciplinary study and research.

The NPS-FEL experimental program is intended to address technical challenges relevant to next-generation accelerator, light source and FEL design, and study topics of fundamental interest in accelerator physics. There is, naturally, substantial overlap, such as beam merger design, coherent synchrotron radiation effects, beam halo formation, etc.

FACILITY

Location

The NPS-FEL laboratory will be located at an existing building at the Monterey Pines golf course, a Navy-owned facility adjacent to the NPS main campus (see Figure 1). The NPS-FEL laboratory building is one of several research buildings at Monterey Pines, including a jet-engine test laboratory, several wind tunnels, oceanographic laboratories, machine shops, and a flash X-ray facility.

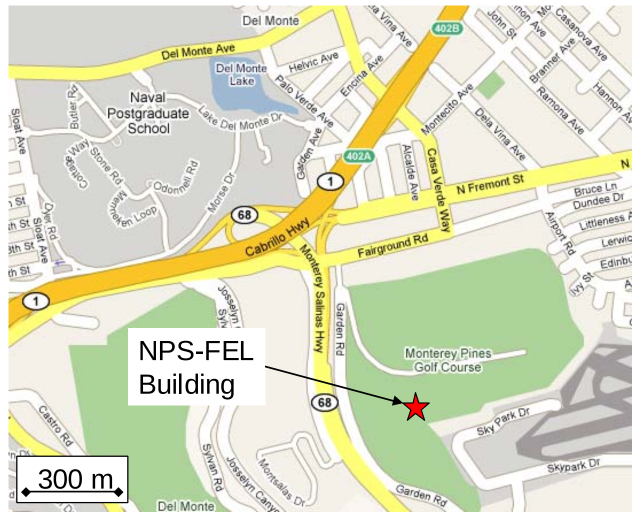

Figure 1: NPS-FEL facility location relative to the Naval Postgraduate School campus.

Site Preparation

The laboratory building is a metal-frame structure with steel side-panel walls and a concrete slab foundation, which until recently served as a laboratory and repair bay for an autonomous underwater vehicle (AUV) research program. The AUV laboratory move was completed in June 2008.

Site preparation began in early 2008 with the installation of a new electrical substation near the building, capable of supplying an additional MW for power supplies, cryogenic systems, and RF power sources.

Renovation for the NPS-FEL will include addition of an on-grade radiation shield vault, replacement and insulation of the building skin, and reconstruction of the interior laboratory and office space.

Interior Layout

The building is a rectangle approximately 40' (12.2 m) wide by 162' (49.4 m) long. There is a secondary pad to one side of the main foundation, approximately 22' (6.7 m) square, that will serve as a base for the eventual cryogenics plant.

The shield vault will take approximately half of the building, with the remaining half being dedicated to laboratory and office space. Figure 2 shows a conceptual sketch of the building layout; the vault design and interior space allocation have not been finalized as of this writing, however.

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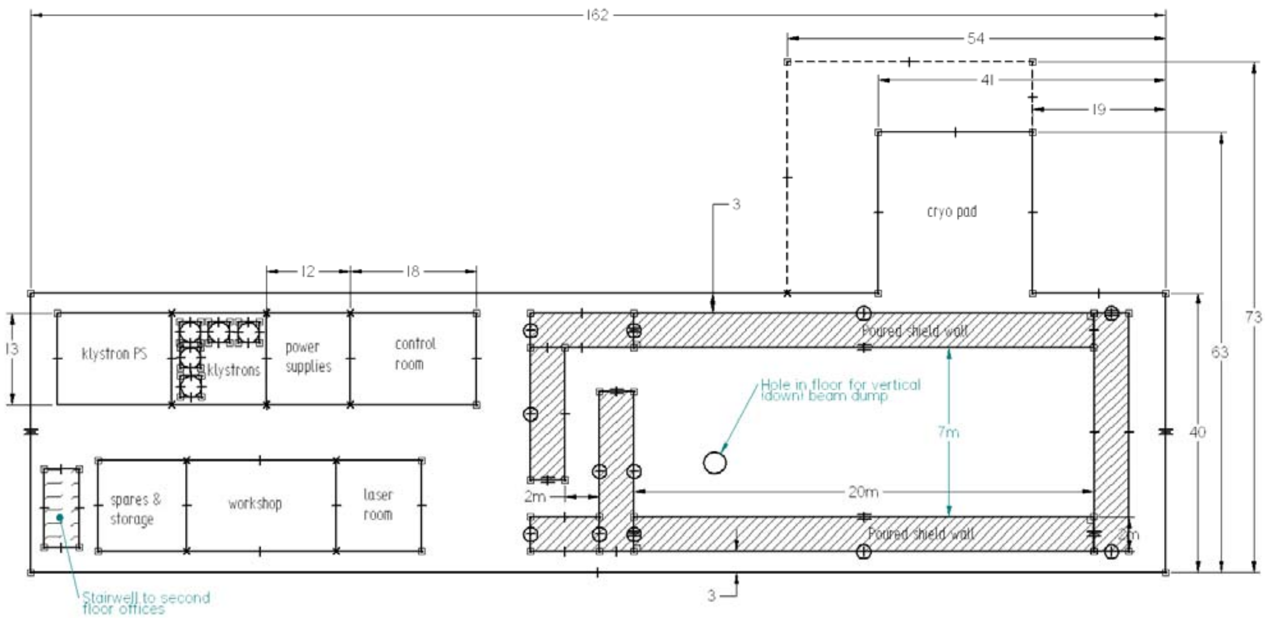

Figure 2: Preliminary layout of the NPS-FEL laboratory building. All dimensions without units are in feet.

Shield Design

Based on the nominal RF power to be installed, and the capability of the structures to run CW, the maximum electron beam power will be 40 kW. The shield has been designed based on the assumption that, when operating at full beam power, transport losses are minimal and the beam is directed into a well-shielded beam dump. The design targets are for a maximum radiation level of less than 2 mRem / hour and less than 500 mRem / year [1] at the exterior of the shield vault at ground level.

Four beam loss scenarios were considered: a major beam excursion and total loss at maximum beam energy; halo effects during injector testing at low voltage; halo effects at full beam energy; and beam misalignment at full energy. The first scenario assumes the beam will be shut down within 200 µs of the excursion; the others assume CW operation. Beam loss monitors and radiation monitors will be included into the safety interlock system to force a shutdown should average current losses exceed acceptable limits, or external dose rates exceed the thresholds listed above.

The baseline shield design is for 3’ (0.9 m) thick walls, and a 2’ (0.61 m) thick ceiling, of normal-density concrete (approximately 2400 kg/m^3). The thinner ceiling shield allows equipment placement above the vault, but will not be occupied when the FEL is in operation.

The mass of the shield will require modifications to the building foundation. We are considering making the foundation capable of supporting 4’ (1.2 m) thick walls, but initially installing the planned 3’ thick walls. This will allow us to easily add supplemental shielding in the event beam losses are larger than anticipated, or to more readily accommodate a higher-average power machine in the future, should there be interest in doing so.

The interior vault dimensions are intended to accommodate several potential machine configurations. There is also the possibility of pursuing independent operation of two separate accelerator lines, or a dedicated injector test area.

ACCELERATOR

The initial configuration for the NPS-FEL will be a traditional in-line arrangement, without energy recovery. This will allow commissioning of most major subsystems with minimal ambiguity and startup difficulties. It is also probably the most straightforward configuration to use when performing high-brightness injector testing.

Folded ERL

The conceptual folded ERL arrangement is shown in Figure 3. The intent of the design is to minimize the length of the ERL, at the expense of the width. For wavelengths in the 1 – 10 µm range, this is a potential option for a more compact arrangement compared to more traditional designs.

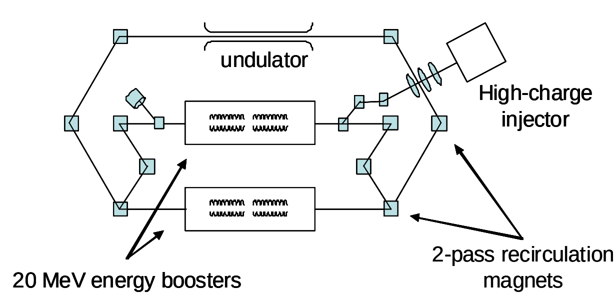

Figure 3: Conceptual layout of folded ERL.

The folded ERL configuration also presents many opportunities for studying effects such as coherent synchrotron radiation, beam merge, and optimal bunch compression methodology in compact FELs.

Injector System

The initial injector for the NPS-FEL will be the 230-kV ($\beta \sim 0.75$) DC gun and subharmonic buncher, previously installed at the Superconducting Accelerator (SCA) at Stanford University [2].

As installed at Stanford, the SCA injector used a gridded thermionic cathode, and injected beam directly into one of the speed-of-light, 9-cell TESLA-type structures. Phase slip was significant and limited voltage gain through the first cavity.

The DC gun is presently being retrofitted to operate with a photothermal cathode [3] and will serve as a platform for initial experiments in a temporary facility until the NPS-FEL vault is completed.

Design has also begun on a 2-MV energy booster cavity. This will effectively eliminate the phase slippage, and will deliver a reasonable beam energy for ERL merger testing. A conceptual sketch of the injector layout is shown in Figure 4.

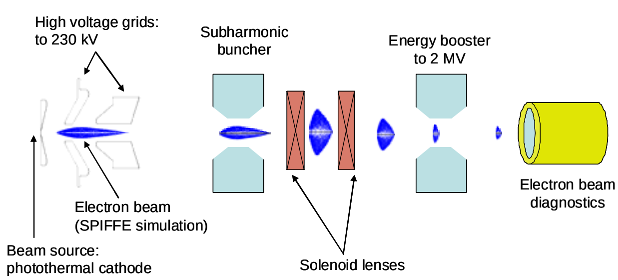

Figure 4: Conceptual layout of modified DC injector for the NPS-FEL.

Injector studies are expected to commence by the third quarter of 2008, focusing mainly on photothermal cathode performance and other cathodes of interest. The 2-MeV energy booster is expected to start testing in mid-2009.

FREE-ELECTRON LASER

In both the in-line and folded-ERL configurations, the NPS accelerator will be used to drive a free-electron laser. In both cases the maximum beam energy will be approximately 40 MeV, with the initial FEL configuration as an oscillator.

The existing FIREFLY electromagnetic undulator has 25 periods, with a K-value of 1 and a 6-cm period [4]. The resulting optical radiation will be 9.5 μm, given a 40-MeV electron beam energy.

We would like to extend the FEL operation to shorter wavelengths, via the use of a shorter-period undulator. Also, exploration of novel undulator technology, such as solenoid-derived, variable-period undulators, is of interest [5]. Given an undulator period of 1 cm, and K-parameter of 0.7, wavelengths down to approximately 1 μm may be achievable. A fixed-period solenoid-derived unduator with these parameters [6] has already been used in a far-infrared FEL.

CONCLUSIONS

Construction has started on the Naval Postgraduate School free-electron laser laboratory, NPS-FEL. The laboratory will be capable of hosting a 40-MeV, 40-kW electron accelerator in any of several configurations.

The initial injector for the NPS-FEL, a 230-kV DC gun, is being retrofitted to support photocathode operation. A 2-MeV energy booster is being designed and is expected to begin commissioning in mid-2009.

Lattice design for the NPS-FEL ERL configuration has begun, and will emphasize support for experiments on electron beam merger techniques, coherent synchrotron radiation, and other topics relevant to compact, high-power ERL design.

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