

DEVELOPMENT OF THE LINAC EXTENSION AREA 450-MeV ELECTRON TEST BEAM LINE AT THE ADVANCED PHOTON SOURCE*

W. J. Berg †, J. C. Dooling, S. H. Lee, Y. Sun, A. Zholents,
Argonne National Laboratory, Lemont, IL 60439, USA

Abstract

A high brightness low-emittance electron beam line for accelerator-based R&D hardware experimentation and study of novel accelerator techniques is under development at the injection linac of the Advanced Photon Source (APS). The Linac Extension Area (LEA) beam line will operate up to the 450 MeV energy of the APS linac. The electron beam is generated from a photo-cathode (PC) RF gun delivering 300 pC of charge with a 3 ps rms bunch length and normalized slice beam emittance of $\sim 1 \mu\text{m}$. The bunch length can be compressed to 150 fs in a flexible chicane at a beam energy of 150 MeV. The APS linac contains an extensive set of conventional and advanced beam diagnostics including a recently commissioned s-band transverse deflecting cavity. The low-emittance electron beam is transported to an independent experimental tunnel enclosure that contains the LEA beam line. Implementing the LEA beam line separate from the APS injector complex allows for on-demand access to the area to perform work without interrupting beam operations of the APS. We discuss the overall scheme of the existing linac beam delivery and diagnostic systems, and report the design of the LEA beam line and initial planned experiments.

INTRODUCTION

The APS is preparing a Linac Extension Area (LEA) beam line to provide an experimental platform for hardware installations supporting the study of future concepts and novel accelerator techniques. The linac produces up to 450 MeV electrons from a high brightness low emittance PC RF gun (see Table 1). The electron beam is compressed by a flexible chicane positioned at the 150 MeV point and transported 90 m downstream to the LEA beamline [1]. The beam line extension area is located downstream of the APS injection linac in an independent building complex. This allows access to the beam line without impacting APS user operation runs. The LEA beamline is configured with a symmetrical beam lattice and diagnostics centered about the beam interaction region where an experimental vacuum chamber is installed to enhance ease of beam perturbation studies. The beam terminates into an energy spectrometer and beam dump. Downstream tunnel space capacity has been allocated after the beam dump to allow for the addition of future hardware installation opportunities and utilizing the electron beam. The first such plan is for incorporation of the Tapering Enhanced Stimulated Superradiant Amplification (TESSA) tapered undulator system, a collaboration between APS, UCLA, and RadiaBeam [2, 3].

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† berg@anl.gov

Table 1: Linac Electron Beam Parameters

Parameter	Value	Note
Beam Energy	$\leq 450 \text{ MeV}$	Nominal
Bunch Charge	300 pC	Nominal
Bunch Length	3 ps rms	PC gun
Beam Emittance	$1 \mu\text{m}$	PC gun
Energy Spread	250 – 500 keV	Range

INJECTOR CONFIGURATION

Beam Generation

The electron beam is produced from a photo-cathode RF gun that was fabricated and installed into the linac in 2014, see Fig. 1 [4, 5]. A ND:Glass drive laser with a wavelength of 1066 nm, produces a 25 uJ/pulse in the ultra-violet (UV) at 266 nm to the copper cathode at a variable repetition rate. The PC gun generates an electron beam pulse of 300pC charge and bunch length of 3ps with an rms emittance of $1 \mu\text{m}$. The beam is accelerated by the first sectors of the s-band linac to the 150 MeV point and compressed to a bunch length of 150 fs in the flexible chicane. The beam can then be further accelerated by the next two linac sectors up to the nominal maximum linac energy of 450 MeV.

Beam Characterization and Transport

Multiple diagnostic systems have been developed to provide beam characterization including a coherent transition radiation (CTR) bunch length monitors located both before and after the chicane section, three screen emittance measurement station and s-band transverse deflection cavity (TCAV) as depicted in Fig. 2 [6, 7, 8]. The electron beam is matched for transport using the three screen in the accumulator ring bypass transport line and transported through the booster bypass transport to the LEA beam line tunnel.

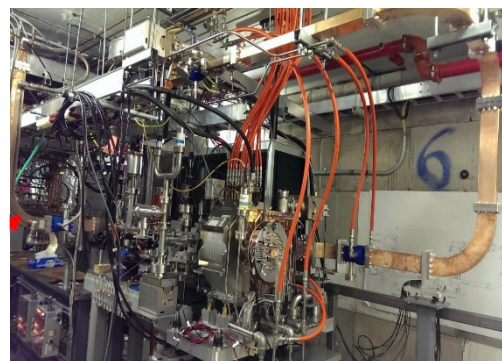


Figure 1: Image of PC Gun in Linac.

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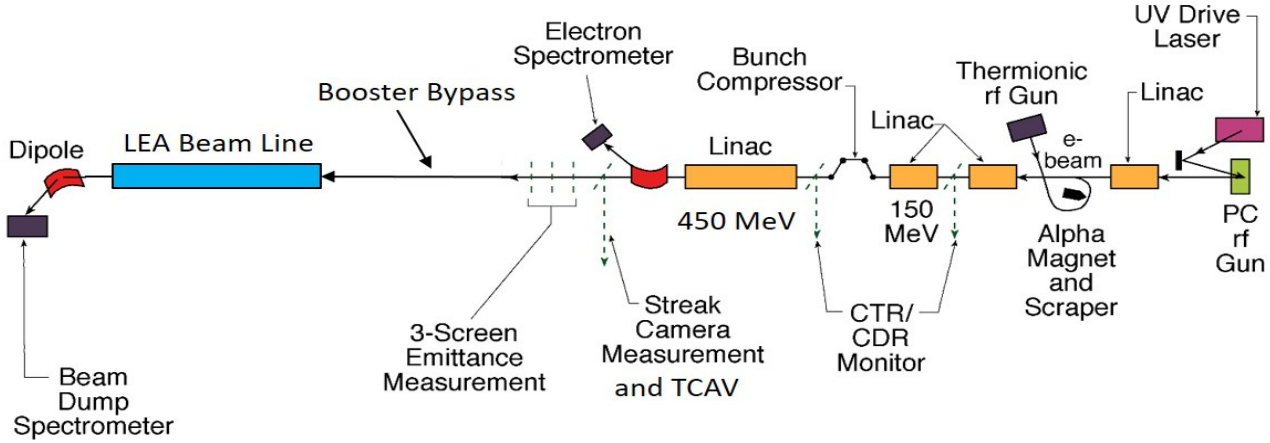


Figure 2: Injector configuration, beam transport and diagnostics.

LINAC EXTENTION AREA

LEA Overview

The LEA beamline provides a test platform electron beam line to accommodate accelerator research initiatives and hardware development scenarios. The building complex is separated from APS beam operations entry restrictions which allows for independent access to the LEA tunnel enclosure. The interior of the LEA tunnel is of sufficient size to allow for significant hardware additions, corresponding technical systems and infrastructure support. LEA was primarily established using a substantial number of hardware elements available from previous accelerator beam line installations.

LEA Beam Line Layout

The magnetic lattice design provides for a focused beam waist at the electron beam experimental interaction area with mirrored symmetry in order to efficiently analyse impacts and effects to the beam, see Fig. 3. An experimental chamber resides at the beam line lattice longitudinal mid-point which can accommodate in vacuum material and devices for manipulation and direct beam interaction [9]. Machine interlocks, fast acting gate valves, vacuum gauging and a local turbo pump protect the upstream beamline from outgassing effects. The beamline contains multiple YAG:Ce transverse profile imaging stations, integrating current monitors, beam position monitors and a vertical energy spectrometer dipole and beam dump.

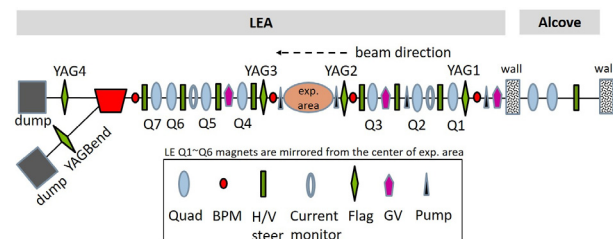


Figure 3: LEA beam line layout.

EXPERIMENTAL PLANS

Commissioning Experiment

Initial beam commissioning experiment is for dielectric tube wake field studies of the devices installed into the experimental test chamber. An in vacuum piezo driven stage is used to align a matrix of 1.5 mm diameter dielectric tubes, 6 cm in length, prepared by Euclid Techlabs (Bollingbrook) [10]. Each individual dielectric tube of the matrix can be adjusted remotely to be selected and aligned to the electron beam. Downstream YAG:Ce profile monitor image station diagnostics and the dipole energy spectrometer will be used to determine the transverse and longitudinal wake effects to the electron beam.

TESSA-266

Longer range plans are to implement the TESSA-266 undulator systems downstream of the existing LEA beamline, see Fig. 4. TESSA-266 is an initiative to study a high efficiency beam energy extraction scheme using tapered undulators [11]. Projected estimates of the energy transfer to the photon beam are by up to 50% compared to conventional SASE techniques. The LEA electron beam is well matched for the TESSA-266 program. The LEA complex offers a unique set of high quality electron beam delivery specifications combined with existing building infrastructure to support the TESSA initiatives. The primary system design

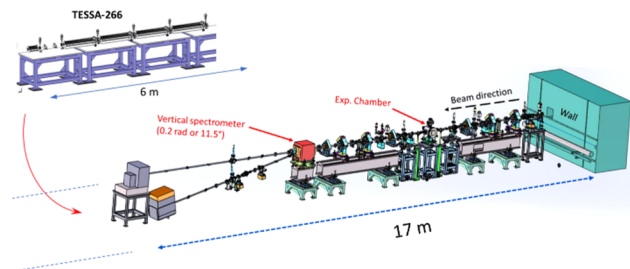


Figure 4: LEA beam line with TESSA-266 indicated.

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consists of a short prebuncher undulator followed by a small chicane section used to introduce a ultra-violet seed laser beam collinear to the electron beam. The seeded beam continues through a series of four strongly tapered undulators sections, each being two meters in length. The seed laser will be housed in laser room adjacent to the LEA tunnel with the laser beam transported through a UV compatible optical light pipe to the chicane injection point. RadiaBeam reported that the seed laser system has been specified and is in fabrication by the manufacturer. A downstream transverse deflecting cavity, energy spectrometer and other post TESSA-266 undulator diagnostics are in early conceptual design development.

STATUS AND CONCLUSIONS

The LEA beamline mechanical system is complete. The beam line is currently maintained under vacuum awaiting first beam. Cable plant, controls, beam diagnostics and the electro-magnet power supplies are to be addressed in the follow-up electrical systems phase of the project expected to begin in coming months.

Building infrastructure and support is on-going for the LEA beam line and other operational projects in the area. Anticipated obsolescence improvements in the APS injector RF systems in support of operational reliability requirements for the APS MBA upgrade will give rise to linac electron beam enhancements and jitter stabilization. Parallel planning and support with the TESSA-266 collaborating partners continues in earnest with first hardware delivery anticipated in the next year [12]. Administrative reviews, operating preparations and tunnel provisions leading to beam line commissioning are well underway.

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