THE JLAMP VUV/SOFT X-RAY USER FACILITY AT JEFFERSON LABORATORY

S.V. Benson, D. Douglas, P. Evtushenko, J. Gubeli, F.E. Hannon*, K. Jordan, J. M. Klopf, G.R. Neil, M.D. Shinn, C. Tennant, G.P. Williams, S. Zhang, Thomas Jefferson National Accelerator Facility, Newport News VA 23606

Abstract

Jefferson Lab (JLab) is proposing JLAMP (JLab Amplifier), a 4th generation light source covering the 10-100 eV range in the fundamental mode with harmonics stretching towards the oxygen k-edge. The new photon science user facility will feature a two-pass superconducting LINAC to accelerate the electron beam to 600MeV at repetition rates of 4.68MHz continuous wave. The average brightness from a seeded amplifier free electron laser (FEL) will substantially exceed existing light sources in this device's wavelength range, extended by harmonics towards 2 nm. Multiple photon sources will be made available for pump-probe dynamical studies. The status of the machine design and technical challenges associated with the development of the JLAMP are presented here.

INTRODUCTION

The science motivation for next generation light sources in the VUV and soft X-ray region indicates that there is a need for fully coherent emission, with very high duty cycle [1,2]. This will therefore require very bright, continuous-wave (CW) electron beam sources paired with high gradient continuous wave accelerators.

It is proposed to design and construct JLAMP; a light source operating in the 10 to 100eV photon energy range with sufficiently high repetition rate to provide users with several orders of magnitude higher average brightness than existing sources. This is shown in figure 1.

Jefferson Laboratory (JLab) already operates a fourth generation light source based on ERL technology. The primary photon source has been an IR oscillator FEL which can deliver up to 10kW of average power [3]. A second oscillator FEL, positioned in parallel to the first, is to become operational during 2010. This FEL is set to cover the UV range up to 4.0eV, with an estimated average power of 100W based on present electron beam performance. The IR capabilities of the present ERL FEL will be maintained in JLAMP.

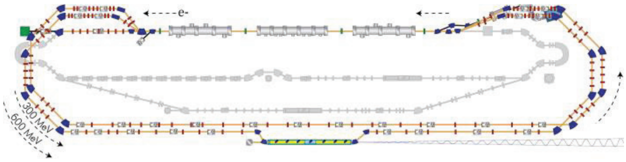

Figure 1: JLAMP superimposed on the ERL FEL accelerator.

Through a series of upgrades and reconfiguration of the present ERL accelerator with an additional arc containing a seeded amplifier FEL, JLAMP will provide world-leading photon capabilities in a region not covered by conventional lasers and operational light sources.

MACHINE LAYOUT

The layout of JLAMP will be predominately determined by the geometry of the present FEL vault. The dimensions of the vault are approximately 64 x 14 x 3m, with the additional constraint of support posts bisecting the width.

The present design comprises a 10 MeV injector and a 300 MeV SRF LINAC driving a two-pass up/two-pass down ERL. After acceleration to 300 MeV, the beam is recirculated, re-injected in phase with the LINAC RF fields, and further accelerated to 600 MeV. A second recirculation arc (displaced vertically from the first), then transports the beam to the FEL and provides bunch length compression and transverse matching. Following the FEL, the (degraded) electron beam is returned to the LINAC out of phase with the RF fields, and decelerated to 300 MeV, where it is again recirculated – with the 300 MeV transport common to that of the accelerated beam (e.g. CEBAF-ER experiment [4]). Given the selection of path length, RF phasing is maintained, so that when the beam is re-injected it remains out of phase with the LINAC accelerating field and is recovered to the injection energy [5].

The limited number of options for the layout of JLAMP is reduced further by the desire to avoid coupling in the beam by bending the various passes in more than one plane simultaneously. The 3 module LINAC is at a level of 0.7m from the floor and will be reused for JLAMP. This places some limitations on the location of the injector. Again to avoid coupling it is advisable to place the injector at the level of the LINAC, either directly inline or offset to one side. The choice of horizontal position will ultimately be decided by a combination of the merger type required to preserve the electron beam into the LINAC and the site of the components of the recirculation arcs.

It is suggested that the back leg of the high energy pass be at an elevation of 1.4m from floor level to accommodate 'standard' height insertion devices.

Given these constraints the optimal design would be to place the recirculation passes vertically on top of one another as shown in Figure 2.

---

*fhannon@jlab.org

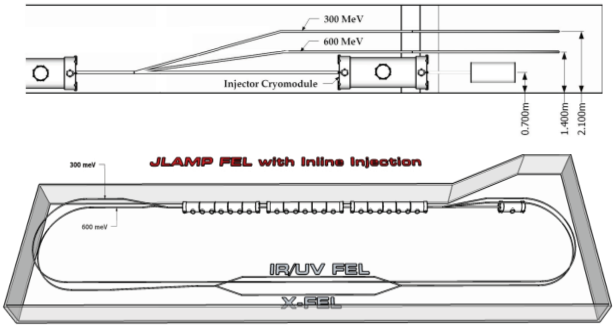

Figure 2 Conceptual Layout

BEAM PARAMETERS

Table 1 gives details of the electron beam properties required to operate the VUV/Soft x-ray FEL.

Table 1: Electron beam parameters 2010, compared with those required for JLAMP.

	2010	2012
Bunch charge (pC)	135	200
Bunch rep. rate (MHz)	75	4.68
Average current, max (mA)	10	1
Norm. transverse emittance at FEL (μm)	6	1
Longitudinal emittance at FEL (keV ps)	60	50
Energy spread at FEL (% rms)	0.4	0.1
Bunch length at FEL, rms (fs)	150	80
Bunch energy (MeV)	100	600

INJECTOR

The electron beam parameters required at the VUV/Soft X-ray FEL determine the quality of the beam that must be produced by the injector. The injector will be based upon using the VHF normal conducting cavity gun developed by Lawrence Berkeley Laboratory [6] operating at a sub-harmonic (187.5MHz) of 1.5GHz which is the fundamental frequency of the LINAC. The VHF gun is predicted to sustain a cathode gradient of 20MV/m which corresponds to a beam energy of 750keV, operating CW. The low frequency of the gun results in the electron bunches having similar properties to those from a DC. The experience at JLab operating a 350keV DC gun has guided the development of the subsequent injector components. The VHF gun is expected to produce a relatively long electron bunch that will require some velocity bunching in a 'buncher' cavity as in the ERL FEL injector. The electron energy will also need to be raised in a booster module before space charge forces within the bunch degrade the quality. Initial studies are concentrating on using single cell 750MHz cavities that can capture the low energy beam without distorting the electron bunches longitudinally before further acceleration to 10MeV.

BEAM TRANSPORT

The JLAMP beam transport system must meet three fundamental requirements: it must deliver a properly configured, high quality electron beam to the FEL, with 6D phase space "matched" to the FEL acceptance; the exhaust drive beam from the FEL must be energy recovered; beam loss must avoided throughout the machine, and instabilities and collective effects (such as beam break-up (BBU)) must be managed.

Longitudinal matching is a key feature of any system design meeting the requirements outlined above. JLAMP will inject a long, low momentum spread bunch to reduce charge density and avoid both space-charge and environmental wake driven beam quality degradation. A preliminary study [7] suggests that acceleration on the rising part of the RF waveform on both passes through the LINAC and recirculation through an isochronous transport system at 300 MeV provides adequate control of the beam. Bunch compression at full energy then generates the peak current needed for lasing; as in other systems [4] the return-transport momentum compactions may be used to properly set the beam longitudinal configuration for loss-free energy recovery.

PARMELA analysis of LINAC performance indicates that injection of a long, low momentum spread bunch and proper selection of transverse match at injection will avoid both significant beam quality degradation from space charge and lattice error sensitivities due to excessively strong focusing [8]. LINAC transverse optics are well described by single-particle models once the beam is through the first cryomodule, at about 100 MeV energy.

Beam quality preservation during transport, particularly during recirculation, bending and bunch length compression is of considerable concern. A very preliminary design study – in which the first pass of a JLAMP-class system is described and analyzed further supports this notion [9].

As with any SRF-driven system, BBU is of concern. The use of multiple recirculations allows some freedom in the choice of pass to pass phase advances, and thereby provides some control over BBU thresholds. An initial study indicates that JLab 12 GeV Upgrade SRF cavities will have a threshold well in excess of the anticipated operating current.

FEL CONFIGURATION

The FEL design is a balance between running high beam current and short FEL wavelength operation. Additional requirements are for variable polarization and the availability of THz or FIR radiation for pump-probe experiments, shown in figure 3.

To satisfy the requirement of high gain at short wavelengths and variable polarization the Delta wiggler design developed at Cornell University will be used [10]. JLAMP will use four segments of 100 periods each, the period being 2.1 cm for high gain at short wavelengths, a large bore (7mm) to reduce resistive wall heating, and a large tuning range so that the FEL can be tuned via the wiggler parameter rather than the energy. The shortest wavelength is about 11.5 nm, of which the fifth harmonic is the oxygen k-edge absorption line. The gain length over the JLAMP range of 11.5 nm out to 80 nm is shown in figure 4. For wavelengths shorter than 22nm the wiggler strength is adjusted. This increases the gain length due to the weaker coupling and focusing in the wiggler.

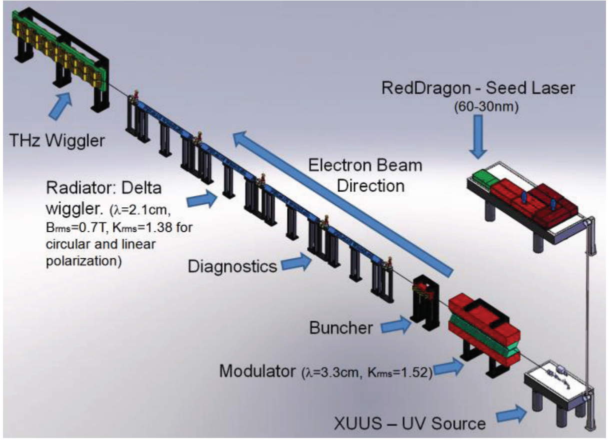

Figure 3: The FEL layout.

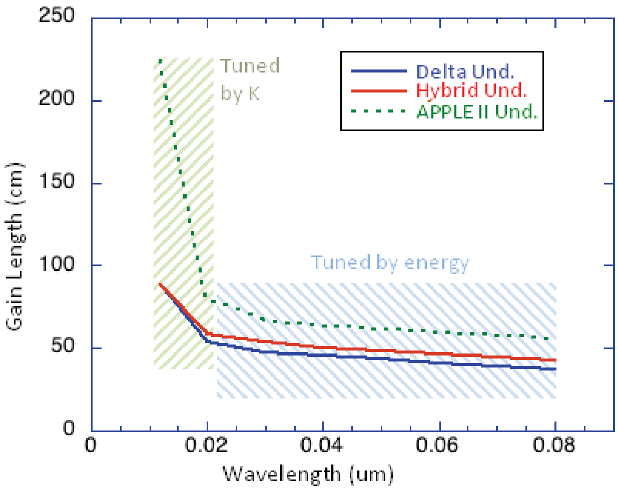

Figure 4: Gain length for three different wiggler designs calculated using the Xie gain length formulas.

At the shortest wavelength the gain length is about 88 cm, which corresponds to a gain of about 1000. With gain this small a seed laser is required and must have approximately 1 MW of peak power for saturation. This is possible at low repetition rates but higher repetition rates will have lower seed laser power. For this reason we will operate in an HHG/HGHG configuration for the shortest wavelengths (less than 20 nm). The seed laser will operate in the range of 60–30 nm and bunch the beam in a modulator wiggler. The beam will then be bunched in a dispersion section and sent into the Delta wiggler tuned to the third harmonic of the modulator. This will amplify the third harmonic up to saturation in main wiggler. For wavelengths longer than 20 nm the gain is sufficient to obtain saturation with only 100 kW of peak seed laser power. This is available at higher repetition rate.

An FEL with a gain of order 1000 is not very effective as an amplifier but may work as an oscillator. Mirrors are extremely poor in this wavelength range but with a factor of 1000 gain they do not have to be that good. If an oscillator could be made to work in a low Q configuration very high repetition rates could be achieved. The resonator also has the advantage of not being as sensitive to timing jitter. The first downstream mirror would have a hole in it, allowing harmonics to pass through to the users (for operation with linear polarization). For wavelengths longer than 50 nm it should be straightforward to obtain lasing with a resonator and extremely high average brightness should be achievable.

The THz probe pulse will be provided by a THz wiggler based on the successful design used at FLASH. To allow the THz pulses to be separated, steered and focused onto the target, a THz pulse preceding the pulse will seed the seed laser. A delay in the THz line will allow the pre-pulse THz to overlap the XUV laser pulse.

THE APPROACH TOWARDS JLAMP

In response to a request from the U.S. Department of Energy, a facility proposal [5] was submitted on 16 December 2009; it offers construction of JLAMP over a five-year period at a cost of 95.6M US$. A decision is anticipated in the near term.

ACKNOWLEDGMENTS

This work supported by the Office of Naval Research, the Joint Technology Office, the Air Force Research Laboratory, U.S. Night Vision Lab, the Commonwealth of Virginia, and by DOE Contract DE-AC05-060R23177.

REFERENCES

[1] DOE-BES Basic Research Needs Workshop www.science.dow.gov/bes/reports/list.html
[2] DOE-BES "Directing Matter and Energy: Five Challenges for Science and the Imagination" www.sc.doe.gov/bes/reports/files/GC_rpt.pdf
[3] S. Benson et al., "High power lasing in the IR Upgrade FEL at Jefferson Lab", Proc. FEL 2004
[4] C. Tennant et al., "CEBAF-ER", Proc. SRF Workshop 2003
[5] "The JLAMP VUV/Sorft X-ray User Facility", http://www.jlab.org/FEL/jlamp/JLAMP_Proposal.pdf
[6] F. Sannibale et al., NIM A 599, 9, 2009
[7] C. Tennant and D. Douglas, "JLAMP: Longitudinal Match v1.0", JLAB-TN-10-011, 26 March 2010.
[8] C. Tennant and D. Douglas, "JLAMP Linac Optics v1.0", JLAB-TN-10-012, 29 March 2010.
[9] D. Douglas and C. Tennant, "Use of Recirculation in Short-Wavelength FEL Drivers", JLAB-TN-09-046, 10 August 2009.
[10] A.B. Temnykh, Phys. Rev. ST Accel. Beams 11, 120702 (2008).