JLAMP: A NEXT GENERATION PHOTON SCIENCE FACILITY AT JEFFERSON LABORATORY

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Abstract

Jefferson Laboratory is proposing to construct a next generation light source that capitalizes on the existing infrastructure of the Energy Recovery Linac (ERL) based Free Electron Laser (FEL) that has been operational since 1998. The new user facility, called JLAMP, will feature a two-pass superconducting linac to accelerate the electron beam to 600MeV with the possibility of energy recovery. The photon source will be a seeded amplifier FEL that covers the 10 to 100eV energy range, capable of providing up to seven orders of magnitude increase in average brightness over existing sources. At longer wavelengths the device will also have the option of operating as a high gain resonator for users who desire a higher repetition rate. The design options and technical challenges associated with the development of the JLAMP machine 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 3]. This will therefore require very bright, continuous-wave (CW) electron beam sources paired with high gradient continuous wave accelerators.

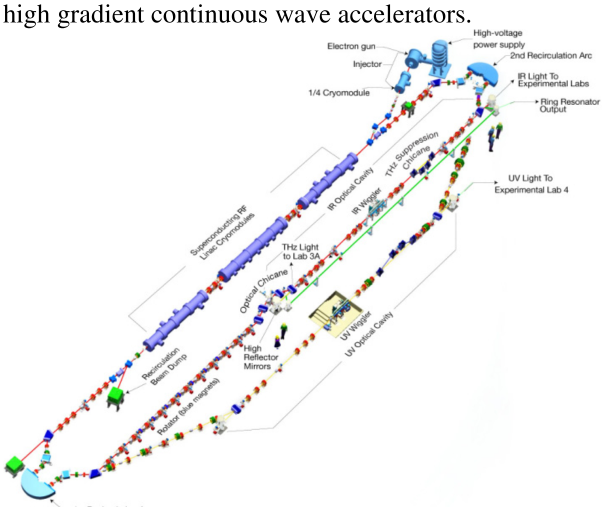

Figure 1: The Jefferson Laboratory ERL FEL accelerator

Jefferson Laboratory (JLab) already operates a fourth generation light source based on ERL technology, see figure 1. The primary photon source has been an IR oscillator FEL which can deliver up to 10kW of average power [4]. However, a second oscillator FEL, positioned in parallel to the first, is to become operational during summer 2009. 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.

It is proposed to design and construct 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. Through a series of upgrades to the ERL accelerator and an additional arc containing a seeded amplifier FEL, JLab will provide world-leading photon capabilities in a region not covered by conventional lasers and operational light sources.

CHALLENGES

The cutting edge nature of such a proposal naturally has some development challenges associated. Presently the accelerator technology does not meet required goals of this project; however the required advances are within reach of modest research.

To date, amplifier FELs have been limited in average power primarily due to the average current available from driver accelerators. ERL accelerators are perceived as a way of offering high average current without degrading electron beam properties. The challenge at JLab is to extend the spectral scale from 1000nm to the 100 - 10nm range without losing the present capability in the IR and UV region. One method of achieving this is to increase the electron beam energy.

JLab currently operates the ERL at ~100MeV, limited by the gradient available from the 3 cryomodules in the linac. The dominant constraint for any modification to the ERL layout is the size of the building, in which the accelerator is a snug fit. As there is no space for additional accelerating cryomodules, the only options available to increase the electron beam energy are to use higher gradient modules with a similar footprint and having multiple passes through the linac. Replacing the cryomodules with a high gradient design that can deliver 100MeV per module will raise the beam energy from the ~100MeV to 600MeV with one re-circulation. Such a module has been developed by JLab for the 12GeV upgrade of the CEBAF accelerator [5]. Two beam transport systems will therefore be required to first circulate a 300MeV back into the linac, and secondly the 600MeV beam to the FEL and possibly back to the linac for energy recovery. This accelerator architecture results in an extremely flexible research and user-facility due to

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the multiple FEL sources and electron beam energy range, see figure 2.

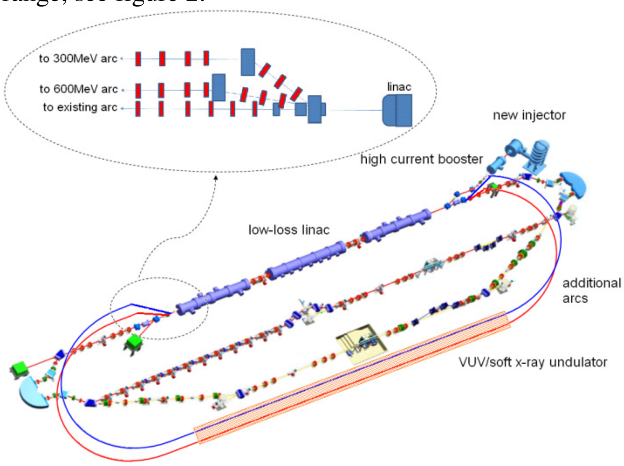

Figure 2: Schematic of JLAMP

Table 1 gives details of the electron beam properties that are generated in the ERL now compared with those required to operate the VUV/Soft x-ray FEL.

Table 1: Electron Beam Parameters 2009, Compared with Those Required in 2012.

	2009	**2012**
Bunch charge (pC)	135	270
Bunch rep. rate (MHz)	75	1
Average current, max (mA)	10	0.27
Normalized transverse emittance at FEL (μm)	10	1
Longitudinal emittance at FEL (keV ps)	60	50
Energy spread at FEL (% rms)	0.4 (at IR FEL)	0.1
Bunch length at FEL, rms (fs)	150	80
Bunch energy (MeV)	100	600
Gamma	197	1175

FEL Design and Electron Beam Requirements

With a fixed electron beam energy the resonant wavelength of the radiation from the FEL is defined by the undulator period and peak on-axis field. The field is determined by the strength of the permanent magnet material and the undulator gap. However, the gap must be large enough to not destroy wiggler through radiation degradation and resistive wall heating on vacuum chamber.

Spectral brightness is dependent on the number of periods and the percentage of the bunch contributing to the longitudinally coherent emission. As with the linac, the length of the undulator is limited by the building. It is required that the undulator be long enough for the FEL radiation to become saturated. The requirement for this is typically 20 times the gain length for SASE FELs. For a seeded FEL, 10 times the gain length is needed, which therefore must be short to fit in the allocated space. Gain length is proportional to the undulator period and inversely proportional to the FEL parameter. Taking these factors into consideration assumptions can be made for the design of the undulator, see table 2.

Table 2: Undulator Parameters

	VUV	soft x-ray
Undulator period (m)	0.025	0.025
Deflection parameter, K	~1.2	~0.6
Beam Energy (MeV)	280	600
Fundamental wavelength (nm)	100	10
Gain Length (cm)	~100	~40

The brightness from such a FEL over the range of photon energies is shown in figure 3. The average brightness is several orders of magnitude greater than that from existing facilities, largely due to the average current available from the injector.

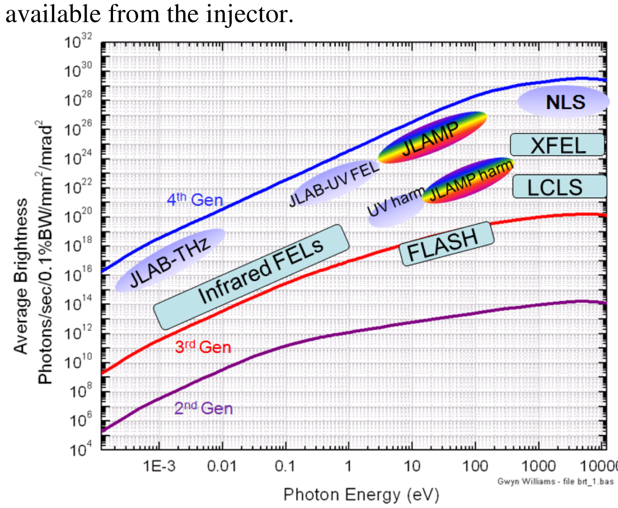

Figure 3: JLAMP spectral brightness in comparison to other FEL machines.

As there are currently no amplifier FELs in an ERL machine there are some unknowns as to how it will behave. For example the gain mechanism, saturation efficiency, optical mode quality, wakefields and resistive wall effects, output divergence, energy spread induced on the electron beam, and harmonic intensity are not fully understood.

The FEL will be seeded via high gain harmonic generation at long wavelengths and high harmonic generation from conventional lasers at short wavelengths so that the output will be fully coherent longitudinally.

New Injector

Photoinjectors have become the preferred method of electron production for next generation light sources for numerous reasons. They produce electron bunches with high peak current due to the ability to shape the bunch longitudinally and transversally with the laser and have low thermal emittance. The injector must provide beam brightness comparable to that of copper cavity injectors but with continuous beams. JLab operates a world leading DC photoinjector that produces up to 10mA true CW current [6]. The demand for shorter wavelength photon production requires that the injector transverse emittance be improved by an order of magnitude.

An improved DC electron gun is under construction as a first step to a brighter injector [7]. The new gun will operate at a higher voltage of 500kV, and has electrostatic focusing geometry to control transverse divergence. For optimized performance the injector layout will be reconsidered with a new booster linac designed for high current operation.

RF Cavities

The booster linac in the present injector has some limitations associated with the maximum current that can be accelerated, and some asymmetric fields around the fundamental power coupler and higher order mode dampers that degrade the beam emittance. A high current cell shape has been designed at JLab for use with up to 1A electron beams [8]. Given that the footprint of the booster cryomodule must be similar in size, there is some flexibility to the combination of cells used inside. For example two 5 cell cavities could be used, as in present booster, or some variant which could include beta matched cells to compensate for the non-relativistic beam from the gun.

A low-loss RF cavity design has been implemented for the 12GeV upgrade of CEBAF [5]. In each cryomodule are 8 7-cell cavities, which combined will deliver 100MeV. Replacing the FEL linac with 3 of these modules will increase the beam energy to 300MeV total per pass. The higher gradient cavities required modifications to the CEBAF cryomodule that included increased filling factor, more precise tuning control, higher power input couplers, and modified HOM damping schemes [9].

Transport

Transporting the electron beam at 300MeV and the recirculated beam at 600MeV will be challenging. The 300MeV must be transported back to the linac with the correct phase to be interleaved with the low energy beam from the injector during CW operation. If the 600MeV beam is to be energy recovered there will be 4 beams in the linac to consider.

The transport up to the undulator at 600MeV must preserve the electron beam properties. A study will be required to investigate the limitations of coherent synchrotron radiation during transport and the effects of longitudinal space charge on the bunch properties.

THE APPROACH TOWARDS JLAMP

As part of ongoing research projects at JLab, several upgrades will be made to the ERL accelerator over the next few years that complement the JLAMP programme. The new DC electron gun will be installed into the Gun Test Stand for high voltage tests and electron beam measurements this year. This will eventually be moved into the FEL, replacing the 350kV gun. Work is also under way to replace the booster linac with one of a new design. When this occurs there is the opportunity to optimize the injector layout to produce a lower emittance electron beam while also giving more room for magnets in the transport line to the main linac.

In the linac one of the three cryomodules will be removed to install a low-loss module, which will increase the nominal energy to 150MeV in 2010. With this increase in energy it will be possible to investigate lasing the UV FEL below 100nm using the 3rd harmonic. With this set up the optical limits of mirrors can be investigated.

Construction specific to JLAMP will be an additional two linac modules, a 300MeV arc and a 600MeV arc with the VUV/Soft x-ray undulator. This is scheduled to begin in 2012.

ACKNOWLEDGMENTS

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