OPERATION AND COMMISSIONING OF THE JEFFERSON LAB UV FEL USING AN SRF DRIVER ERL*

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Abstract

We describe the operation and commissioning of the Jefferson Lab UV FEL using a CW SRF ERL driver. Based on the same 135 MeV linear accelerator as the Jefferson Lab 10 kW IR Upgrade FEL, the UV driver ERL uses a bypass geometry to provide transverse phase space control, bunch length compression, and nonlinear aberration compensation necessitating a unique set of commissioning and operational procedures. Additionally, a novel technique to initiate lasing is described. To meet these constraints and accommodate a challenging installation schedule, we adopted a staged commissioning plan with alternating installation and operation periods. This report addresses these issues and presents operational results from on-going beam operations.

INSTALLATION PLAN

The machine installation plan involved three distinct phases. Phase 1 was the installation of all beamline components sans wiggler followed by an accelerator run period to check out the magnets, vacuum, diagnostic and control systems. After this verification and setup stage was complete, the plan was to stop beam operations and install the wiggler chamber and ancillary optical hardware in Phase 2. This was followed by a second beam operations period when the wiggler would go through an initial checkout and in which a machine setup with a clean transmission through the narrow gap wiggler could be finalized prior to attempting to lase. Phase 3 was intended to lase and then characterize the FEL, followed by normal FEL operations.

Phase One, Accelerator Installation and Test

Phase 1, installation of the magnets, vacuum chambers and diagnostic systems, was completed in the spring of 2010 as planned. The initial test run was not scheduled until mid-June in order to finish a series of User THz experiments on the IR FEL line. Once this series of experiments was completed, the machine was reconfigured to put beam through the UV bypass. In order to economically operate the two separate FELs, a system was implemented which switched a single set of power supplies' output between the two beam lines magnets. It allowed EPICS control of the switchover between the lines while minimizing the additional hardware, racks and foot print needed in the already crowded equipment galleries. Complete switchover was accomplished in a week and included the remapping of the control signal names to allow a single physical power supply to appear with two distinct magnets and names in the EPICS control pages and, more importantly, in the Save and Restore utility. It became possible to Save or Restore unique IR and UV setups although common control nodes are used.

This goal of this run was to check out all the systems in the accelerator line. The process was known to involve deliberate steering of the electron beam, for example to check quadrupole alignment and magnet calibrations, which would result in downstream beam loss. The wiggler being used is the prototype APS Undulator A and is a permanent magnet design. The pole pieces are very susceptible to radiation and thermal damage. In order to minimize the radiation the wiggler would experience and relax the beam aperture during this operation period, the wiggler jaws were opened completely and a three inch pipe installed to replace the wiggler chamber.

The subsequent run was very successful and provided a great deal of hot checkout information concerning operation of the hardware systems. The beam operations also allowed the testing of the lattice performance. The lattice of the line is very complicated, utilizing a seven quadrupole four cell FODO dispersion management module and six quad telescope leading into the wiggler, followed by a symmetric telescope and dispersion management module used to recover the exhausted electron beam, [1] this conference. During accelerator operations beam images and difference orbits in the new beam line allowed assessment of the magnets' strength and alignment. It also allowed corrections to the design optics solution to be inserted into the model to account for errors in the real magnetic elements. This meant that corrected machine model solutions could be calculated for completely different beam conditions with some degree of confidence. Nevertheless, the scheduled run period was over before all the machine check out could be completed leaving Beam Loss Monitor (BLM) commissioning for Phase 2.

Phase Two, Wiggler Installation and Test

Phase 2, wiggler and optics hardware installation, was hampered by a shortage of parts and one of the key

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components, the wiggler chamber, was delayed during fabrication and vacuum leak check. This delay would mean that Phase 2 would only be completed one week prior to the milestone for Phase 3. This would leave little time to sort out the remaining diagnostic systems, find a good transport setup to the dump, align the e beam and cavity and lase. To give the best chance of achieving Phase 3, lasing, prior to the milestone, it was decided to take advantage of the delay in the wiggler chamber fabrication by completing as much of the installation as possible and then running beam for two weeks to improve the machine setup. We also wanted to demonstrate the ability to transport the electron beam, without loss, through the small vertical gap produced by the wiggler chamber. To simulate the aperture constraints of a wiggler chamber, a mock-up was produced by installing the water cooled apertures meant as halo scrapers at the front and rear of the re-installed three inch pipe.

The Phase 2 ‘bonus’ experimental run provided the time to develop a much better optics solution. This solution enabled calibration of the BLMs on the UV line culminating in a 2 mA average CW run and saved settings which could be restored for later use in Phase 3. Additionally, time was made to tighten the step size of the modified Martin-Puplett interferometer diagnostic and perform phase transfer (M55) measurements from the injector to the wiggler. Results of these measurements are presented in [2], this conference. We had operated all of the systems in the machine except the wiggler. Armed with the knowledge we could run enough current with electron bunches that had the correct measured phase space properties to lase we prepared to complete Phase 2 and install the wiggler chamber.

Phase Two, Completion

The wiggler chamber was installed with one week left prior to the milestone for lasing. Since this beamline was designed from the start to take advantage of the third harmonic produced by the FEL, a set of mirrors optimized for a 700 nm fundamental had been installed (233 nm third harmonic). The large quantity of new beamline hardware loaded the vacuum system heavily and delayed the start of beam operations by 24 hours for pump down to be completed. Electron beam was rapidly established to the recirculation dump and the optical cavity aligned and the real task of scanning the cavity length for lasing was started once the beamline vacuum reached valve open thresholds.

The electron beam/optical cavity alignment procedure used has two steps. In the first, the electron beam is aligned to holes in the up and downstream wiggler viewers. At that point the electron beam is shut off and an optical device for injecting a HeNe laser along the optical path is inserted into the beamline. An upstream aperture is inserted and the HeNe steered to center the diffraction pattern produced on the center wiggler viewer. This aligns the HeNe to the optical path. Then the aperture and wiggler viewer are retracted and the HeNe is retro-reflected from the cavity mirror onto the backside of a viewer with a hole, Figure 1. The cavity mirror is then tilted to steer the reflection to the center of the viewer. The alignment procedure is then repeated with a laser at the other end of the optical cavity, thus setting the tilt of both optical cavity mirrors [3].

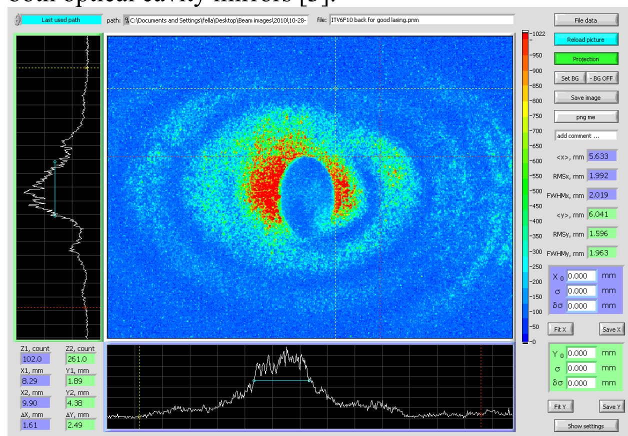

Figure 1: Retro-reflected HeNe used in alignment procedure.

Phase Three, Lasing

After alignment, the optical and electron beam paths are aligned transversely. To lase however, the optical and electron bunches must overlap longitudinally also. To do that the cavity length is adjusted by moving the cavity mirror along the beam axis in small steps of a few microns each in order to find the spot at which the electron and optical bunch overlap. Imperfections in the translation mechanism force the operator to stop and check the transverse alignment between the beams every hundred microns or so of longitudinal travel. To allow the cavity mirror to be scanned relatively quickly, the electron beam was set to produce 1 millisecond long macropulses at a 60 Hz repetition rate with a bunch micropulse frequency of 4.68 MHz. Using this technique, the cavity length was scanned ±2.5 mm in 50 micron steps over the course of the next 12 hours, stopping to realign the e beam and optical cavity every few steps without enhancement being observed.

To speed the search, a different cavity technique was tested. After the cavity was transversely aligned as described above, the synchrotron light from the wiggler was transported to a fast diode used to measure the laser turn on time. The presence of enhancement in the signal was checked for by closing a shutter in the laser cavity and looking for a reduction in the diode signal level. The cavity mirror alignment was then optimized against the amplitude of the spontaneous emission. Finally, the cavity length was then adjusted to maximize the diode signal until lasing occurred. This technique <u>only</u> works because the optical and electron beam axes are co-linear from the initial alignment procedure. If the two axes were not co-linear the synchrotron light would follow the electron beam axis and tuning the mirrors to increase it would simply point the electron beam and /or the optical cavity at the diode detector with no possibility of enhancement.

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When coupled to the initial alignment procedure however, this technique proved to be a robust and repeatable method to start the FEL lasing. Using this technique, lasing was achieved in less than 8 hours. Total beam operations time to commission the accelerator and lase was less than 40 hours from completion of the installation of the wiggler chamber.

With initial lasing at the 700 nm fundamental complete, the configuration of optical cavity mirrors and wiggler gap was changed to lase at 400 nm. With the new technique for searching the FEL parameter space in hand, one day was spent setting up the accelerator again on the 700 nm mirrors and then switching to the UV mirrors and wiggler gap. Within 4 hours of the time we switched from 700 nm to 400 nm optics, we had 100 watts of 408 nm light, Figure 2, on the optical power meter.

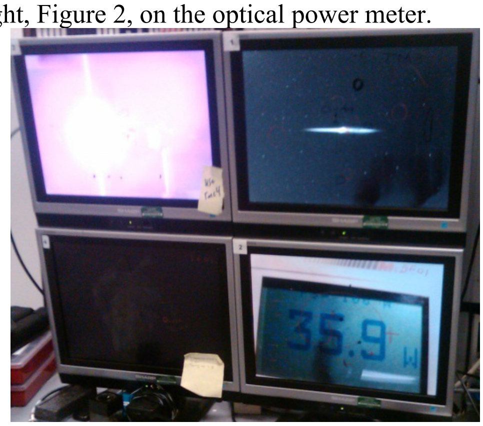

Figure 2: Initial FEL lasing at 400 nm as seen at out coupler.

The subsequent two and one half months were spent characterizing the FEL. Operation at wavelengths as short as 370 nm was common. A great deal of data on the FEL was taken and is presented in [4], this conference.

VUV Lasing

Following the extensive runs to characterize the FEL, the program moved to demonstration of third harmonic production and out coupling from the UV FEL. To out couple the radiation, a 'holey' mirror was installed in the out coupler vacuum tank which would allow the third harmonic mode to escape while still reflecting enough UV light to lase. For details of the experimental setup and technique, see [5]. Operationally, the procedure followed previous run schedules. The optical cavity and wiggler gap were set to 372 nm. The accelerator was optimized and aligned to produce lasing. The FEL turned on rapidly after the vacuum installation work using the above alignment and tune up procedure. The experimental chamber contained three different detectors; a sodium salicylate coated fluorescent viewer, a separate Ce:YAG viewer and an Al2O3 metal NIST traceable diode. Because the predicted magnitude of the 124 nm radiation was 1000x smaller than the 372 nm fundamental, it was difficult to map the shape of the 124 nm photon beam and be sure that the image was not produced by the fundamental. Fortunately, several upstream valves were windowed. By closing these, the 10 eV photons could be prevented from entering the detector chamber and a measure of the fundamental's contribution to the detector signal could be made.

Once lasing on the fundamental was achieved and transported to the diagnostic chamber, 124 nm photons were immediately seen on the metal diode which was 'blind' to the fundamental. A further test was the closure of the upstream windowed gate valves which completely shut off the diode signal. Sodium salicylate is commonly used as a solar blind fluorescent coating for viewers in synchrotrons, but the magnitude of the fundamental required installation of a optical passband filter centered at 120 nm in the optical beamline to allow images to be made of the 10 eV beam on the screens.

Transport to User Lab

Installation of the optical transport system from the UV FEL to the User laboratories is in progress, with different photon energies requiring different optical elements and beam paths. First 700 nm light from the UV FEL to a User Lab occurred on Feb. 28, 2011 in preparation for a busy summer schedule of User experiments. 10 eV photons are scheduled to be delivered to a User lab in March.

SUMMARY

The JLAB UV/VUV FEL used an alternating installation/commissioning plan to meet incremental milestones. By keeping the size of the installations and the goals for any run period to a manageable size, corrections to the plan could be kept small and constant progress is being made. In the process, a new procedure which dramatically shortens the time spent scanning the multi-dimensional interaction space for initial FEL lasing was developed allowing more time to be spent doing experiments. Finally, new optical transport systems which will take UV and VUV light to User labs are being installed and commissioned in preparation for a summer schedule of User experiments.

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