ELECTRON-BEAM DIAGNOSTICS FOR JEFFERSON LAB'S HIGH POWER FREE ELECTRON LASER

G. A. Krafft, K. Jordan, D. Kehne, S. Benson, J. Denard, E. Feldl,
P. Piot, J. Song, and R. Ursic, TJNAF, 12000 Jefferson Ave., Newport News, VA 23606

Abstract

In this paper the current plans for the diagnostic complement for Jefferson Lab's IRFEL are presented. Diagnostic devices include optical transition radiation beam viewers, both stripline and button beam position monitors, multislit beam emittance measuring devices, coherent synchrotron and transition radiation bunch length monitoring devices, and synchrotron light cameras for measuring the beam profile at high average power. Most devices have update rates of order 1 sec or shorter, and all are controlled through an EPICS control system.

1 DIAGNOSTIC REQUIREMENTS

Accurate beam instrumentation is essential for smooth commissioning of any accelerator. The diagnostics for Jefferson Lab's FEL accelerator [1] have two main purposes: to allow set up of the accelerator and to monitor changes in beam conditions during production runs. Setup of the accelerator will proceed in a low-beam-power mode with significantly reduced average micropulse repetition rates to limit the beam loss and activation of accelerator components. The production runs will occur in a high-average-power CW mode. The diagnostic requirements for the FEL are similar in many respects to that of other electron accelerators. There are, however, a few parameters that require additional emphasis. One would like to obtain short bunch lengths (0.5 psec rms), low average beam loss, and precise steering and beam envelope matching in the wiggler.

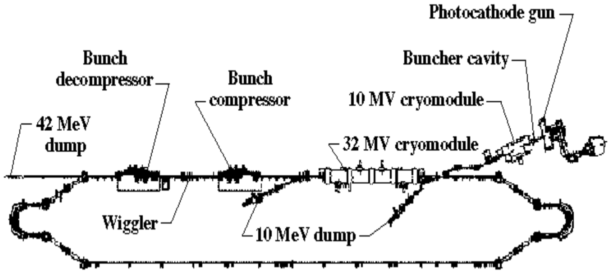

Figure 1: IR Demo Layout

A diagram of the overall facility appears in Fig. 1. Beam, originating in a 350 kV high-average-current injector, is accelerated to 10 MeV, merged onto the main linac beam line, and accelerated to 42 MeV. After passing through the wiggler, the used beam is recirculated to the beginning of the accelerator and its energy recovered, thereby reducing the overall demand on the linac RF systems. In Ref. [1], the main beam parameters are summarized. In Table 1, the performance of the various diagnostic techniques and measurements is summarized.

All of the beam diagnostics devices are to be controlled by EPICS, employing UNIX workstations for executing high-level applications.

2 DIAGNOSTIC SYSTEMS

2.1 Beam Position Monitors

There are thirty Beam Position Monitors (BPMs): one in the injector, nine in the linac straight section including the wiggler, thirteen in the recirculation straight, two each in the recirculation bends, and three in the dump lines. The most stringent requirements are given by the BPM systems in the wiggler region. The required relative resolution through the wiggler is 45 μm rms with a bandwidth of about 10 Hz. During startup the general accuracy should be 500 μm based on aperture restrictions; we are demanding 100 μm resolution on startup. A typical BPM system consists of a beam electrode mounted to the beamline and time domain electronics to resolve the signal.

Two types of beam electrodes are used in the IRFEL: stripline detectors and button detectors. The stripline detector design is modeled after work done at the SSC. It is about 15 cm long, and its principal advantage is the smooth RF transition from the vacuum feed-through to the stripline. The button detectors are identical to those purchased for the B-factory at SLAC. Such detectors are used in regions where, for beam-dynamics reasons, the vacuum chamber is wider than normal. Examples are the recirculation bend regions and the chicanes.

There are two types of BPM electronics, based on those of Jefferson Lab's nuclear physics accelerator. The older first type, called four-channel electronics, detect the output from each stripline in a separate channel [2]. They are principally located on the straight sections of the machine, and are always attached to stripline BPMs. The second type, based on VXI standards, are the so-called switched-electrode electronics (SEE) [3]. In these electronics alternate electrode outputs are switched onto the same detector channel, eliminating one potential source of error compared to a four-channel device. These electronics have relatively high dynamic range in current compared to the four channel systems. They are attached to all the button-type monitors and to the two stripline monitors near the wiggler, to help insure greater reproducibility of the orbit through the wiggler. It is already known that these systems will meet the requirements, given that the

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beam current is so much higher in the FEL than in the nuclear physics accelerator.

2.2 *Bunch Length Monitor*

The bunch length will be determined at several locations in the accelerator. The main measurements will be done at 42 MeV near the wiggler, although, for beam verification purposes, several devices at 10 MeV are planned. Two types of devices are planned: ones based on a destructive coherent transition radiation interferometer used for calibrating and optimizing the bunch length, and devices based on "narrowband" coherent synchrotron radiation detectors which noninvasively monitor bunch length changes.

In the first device, a Michelson interferometer and Golay cell detector are used to measure the power spectrum of transition radiation by autocorrelation. An estimate of the bunch profile can be derived from this spectrum. The University of Georgia is building the interferometers and Golay cells, which are similar to one installed and tested at Vanderbilt. The range of the device is approximately 0.2-5 psec, and it is desired to have a result good to 0.1 psec. Two interferometers will be installed. The first is at the injection point into the main linac and the second is just downstream of the wiggler, i. e., at the location where one would like the bunch length to be minimized.

The second device uses coherent synchrotron emission to monitor the bunch for any changes in the longitudinal distribution while running at full beam power [4]. The device is a replica of previous work at Jefferson Lab, modified for the longer bunch length of the IRFEL bunches as compared to the nuclear physics machine. Three devices are planned for installation. One is in the injector region, one is in the wiggler region, and one is in the recirculation beamline, to check that the bunch length does not grow on recirculation.

2.3 *Beam Viewers*

Optical transition radiation (OTR) viewers will be used to measure beam profile and position throughout the machine. Resolution of the viewers is 50 μm. Charge Injection Device (CID) cameras will be used to image the screen. The only area where there might be a problem is at 10 MeV where the emitted light level is low. If necessary, these can be replaced with fluorescent viewers and harps.

2.4 *Synchrotron Light Monitors*

The critical wavelength for synchrotron emission from a typical 42 MeV bend is about 7.5 μm. We have chosen to use image-intensified CCD cameras to monitor the synchrotron emission. The camera sensitivity is high enough that low-power, pulsed, tune-up beam is observable. Attenuators will be used to prevent camera saturation during high-power running. The cameras are located near each bend of the recirculation dipoles, at the 90° point of the 180° bends, and in the chicane regions. These latter cameras will allow us to monitor the energy spread generated by the laser as the laser turns on.

2.5 *Emittance*

The size of the beam emittance will be determined at three different locations using three distinct methods. In a set of gun characterization experiments [5], a variant of the "two slit" method is used. After the beam is accelerated to 10 MeV, the large space charge in the beam makes envelope measurements questionable. Therefore, we have developed a multislit device for such measurements [6]. Finally, we measure the emittance by envelope fitting for energies of 42 MeV, i. e., after acceleration to full energy.

The nominal value for normalized rms emittance at the 10 MeV injection point is 4 mm mrad. The requirement for first light lasing is about 8 mm mrad. It is desired to measure emittance to within ± 1 mm mrad, covering the range 4-20 mm mrad. Because space charge dominates the beam optics at 10 MeV, it is necessary to reduce the beam intensity to perform a significant measurement. A multislit device was chosen based on the results obtained at UCLA on a similar design. The multislit provides information on α and β for tuning purposes. The device was recently tested with beam. It performs measurements of the required accuracy in real time.

Downstream of the main accelerator, the emittance will be measured by fitting to beam envelopes. Two prominent examples of such measurements are the wiggler emittance measurement, which can involve either three or five OTR viewers in the straight section containing the wiggler, and the back-leg emittance measurement, which involves varying a quadrupole magnet and observing the beam profile on a downstream OTR foil. Profiles may be obtained at six locations in the recirculation straight. The measurements will be analysed using high-level software previously developed for the nuclear physics machine at Jefferson Lab. Eventually, we will use the OTR radiation to obtain the emittance directly as this process is more rapidly completed operationally.

2.6 *Beam Current*

The requirements impose a limit of 2% peak-to-peak fluctuation for current stability. The beam current will be measured by collecting the beam in the dumps. Such measurements give the average current over time scales greater than 1 μsec. The average current is sampled and reported to the control room on a time scale of order 1 sec. Fast measurements are possible by directly monitoring collected current signals. There are six possible dump locations; only three of the dumps are able to handle full beam power.

Also, the stripline BPMs may serve as fast current monitors. Should the need arise, amplitude detecting the 1497 MHz signal on the BPM wires provides a precise measure of the average current at a high speed ($\approx$100 kHz

Parameter	Nominal Value	Span	Technique	Resolution	Bandwidth/ Time scale	Number
Position	Centerline	±5 mm	BPM	100 μm	60 Hz	30
Profile	5 mm	0.1-20 mm	OTR Foil	50 μm	>10 Hz	24+13
Divergence	30 μrad	10-1000 μrad	OTR	1 μrad	1 Hz	
Emittance	9mm mrad	3-25mm mrad	Quad Profile/OTR	3mm mrad	0.1 Hz	2
Charge	135 pC/bunch	10-270 pC	Faraday Cup	5 pC	2 kHz	6
Energy	42 MeV	20-45 MeV	High η OTR	0.01%	1 Hz	3
Energy Spread	280 keV		High η BPM	0.05%	0.01 Hz	3
Bunch Length	0.4 psec	0.2-5 psec	CSR or CTR	0.1 psec	0.01 Hz	3+2
M_{56}	0 cm	±100 cm	RF Phase	1 cm	0.1 Hz	3

Table 1: Requirements for the Accelerator Diagnostics

bandwidth).

2.7 Path Length/M_{55}/M_{56}

Measurements of path length are required to set the proper RF phase of the second pass through the linac and to measure M_{56} in the arcs. Path length measurements will be done using the method that is currently employed at CEBAF [7]. In this method, a precision phase detector is used to measure the phase difference between a RF reference signal and a tuned pickup cavity located at the end of the linac. Adjusting the path length will be done by antisymmetrically exciting two correctors before and after the 180° bends in the recirculation arcs. The M_{56} value will be determined by measuring path length differences through the arc at two slightly different beam energies. Path length at CEBAF has been measured to within 50 μm, while M_{56} has been measured to within 1.8 cm.

2.8 Beam Loss

The electron beam in the driver accelerator for the FEL has enough power rapidly to burn through the vacuum chamber if it is not adequately protected. The protection system in use for the nuclear physics machine at Jefferson Lab will be adapted for use in the FEL. It is based on fast photomultiplier tubes which rapidly shut the beam down when beam loss is detected. Experience on the nuclear physics machine indicates that losses as low as 100 nA (20 ppm) are detectable by these methods. It is not clear at present whether the continuous beam loss of the full-power beam will exceed this level. If so, an installed beam scraper will be used to localize the loss, allowing loss monitors not in this region to be active without being blinded. The response time of the electronics systems attached to the tubes is of order 1 μsec. Shutdowns within 10 μsec of beam loss detection are anticipated.

3 STATUS AND RESULTS

Presently, the beam diagnostic complement is on schedule to be installed by 30 September, 1997. All hardware choices and most hardware procurements are out. To the extent we are able, early checks of the diagnostics have been undertaken. As summarized in Ref. [6], the multislit emittance device has successfully passed its first tests, measuring emittances down to 0.5×10^{-6} m rad with 250 kV beam. More standard emittance measurements using envelope fitting have been used at Jefferson Lab over a number of years, and they present no problems for application to the 42 MeV FEL beam. Our first interferometer is complete, and plans to test the device at Vanderbilt or at Jefferson Lab are proceeding. The path-length system is complete, except for the longitudinal pickup cavity which will be complete in two months. This work supported by U. S. DOE Contract No. DE-AC05-84ER40150, the Office of Naval Research, the Commonwealth of Virginia, and the Laser Processing Consortium.

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