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Performance of the Electron Beam Diagnostics at Jefferson Lab's High Power Free Electron Laser*

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Abstract

We describe the performance and current status of the electron beam diagnostic complement for Jefferson Lab's IR-FEL oscillator. In addition measurements for the driver-accelerator are presented. Beam diagnostics devices include optical transition radiation profile monitors, multi-slit beam emittance measurement, coherent transition and synchrotron radiation based bunch length monitors, both strip-line and button antenna BPM's and pick-up cavities for longitudinal transfer function measurement. All device are controlled via the EPICS control system.

1 OVERVIEW

Diagnostics in a high power FEL such as the JLab IR-FEL [1] were crucial to smoothly commission the driver-accelerator, measure and control the beam parameters. Among the parameters that must be thoroughly measured and controlled over the beam generation and transport, transverse emittance and longitudinal bunch length are probably the most important since their degradation can significantly affect the beam brightness and consequently degrade the laser gain. A generic diagnostic consists of a detector mounted on the beam line that is required to operate in the so-called "tune-up mode", a low duty cycle beam mode that can be used during machine setup without damaging any beamline components. The choice to perform most of the measurements at low duty signal is legitimate: in the Jefferson Lab's IRFEL the beam physics is dominated by single bunch effects (the inter-bunch distance cannot be smaller than $\simeq 4.02$ m). The signal from the detector is treated with a appropriate system (digitizer, ADC, etc...) and pre-processed on an input-ouput controller (IOC) operating under the VxWorks environment. The generated data are sent on the local network and can be accessed from any application running on one of our HP-9000 workstations connected to the local network. In parallel to the EPICS system it is possible to access some of the data using the Cdev protocol. For many purposes, especially during commissioning activities, we have developed high level applications based on the Tcl/Tk scripting language or the MATLAB package.

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2 BEAM POSITION

The beam position monitoring system consists of two types of detector: stripline detectors that provide a low RF-impedance so that no beam degradation due to wakefield occurs and the button antenna detector which are used in large aperture vacuum chambers required in the resonator bypass chicanes and the recirculation arcs. Two different electronics are used for processing the signal: the 4-channel electronic is used since it offers a high reproducibility. This electronic consists of 4 detectors for each of the 4 antenna. In the wiggler region, the switched electrode electronic [2] is used: it switches the signal between each pair of the four antenna and offers a higher dynamics range compared to the 4 channels electronics. The most stringent requirement on the BPMs concern the six BPMs located in the wiggler insertion region: the demand on position measurement accuracy is 45 μm. During the commissioning of the driver accelerator we have been able using saved value of the reading from the BPM's to routinely achieve a very reproducible orbit which significantly expedites the startup of the laser. It has also been used to test the lattice first order transfer matrix using the difference orbit method. The SEE electronics also provides a "B-scope" feature which consists of acquiring and recording for off-line analysis the beam position at higher frequency (e.g. 30 Hz). This feature enables the operator to quantify beam jitter and identify potential frequency dependent beam motion.

3 MOMENTUM COMPACTION & COMPRESSION EFFICENCY

One must carefully set up the bunching elements to achieve ultrashort bunch length at the wiggler insertion. We characterize the compression efficiency of the lattice by measuring the transfer function $<\phi_{laser}|\phi_{out}>$. The phase of the photocathode drive laser ϕ_{laser} is modulated and the output phase ϕ_{out} after a section of the transport is measured using a stainless pill-box cavity by detecting the fundamental mode TM_{010}. The signal is processed with a precise phase detector: the signal is phase shifted and mixed with the reference master oscillator signal. Before the measurement the phase shifter is set to insure the cavity is at zero-crossing. An example of measurement of $<\phi_{laser}|\phi_{out}>$ transfer map is presented in figure 1. There are four pickup cavities in the driver-accelerator: located downstream of the 10 MeV cryomodule in the injector, at the linac front end, at the exit of the first and second recirculation Bates-type arcs. The three latter cavities are also used to measure the positive zero-crossing. Figure 3 is the profile when the zero-phasing cavities are off, and Figure 4 is the profile on the negative zero-crossing. The indicated bunch length extracted from the data is an rms bunch length of 500 μm (1.7 psec). The maximum compression is not at this location, but at the wiggler.

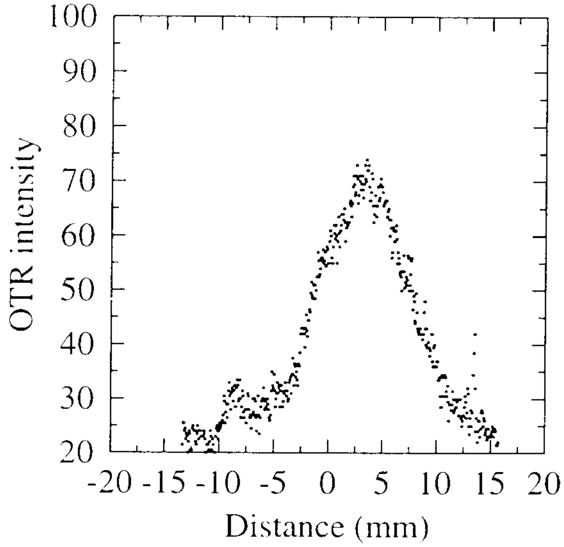

Figure 2: Profile on positive zero-crossing

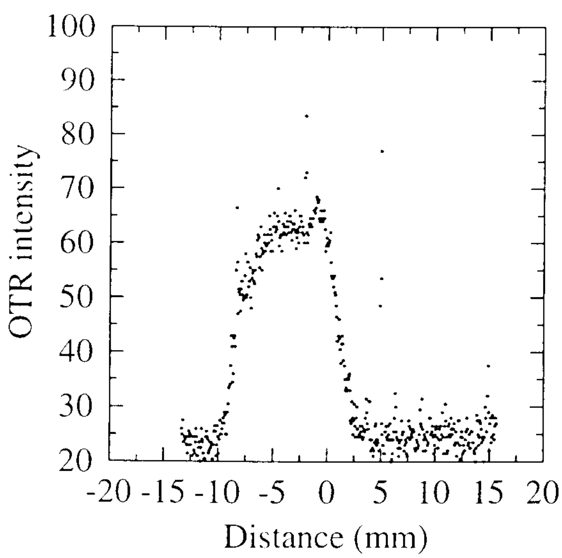

Figure 3: Profile with zero phasing cavity off

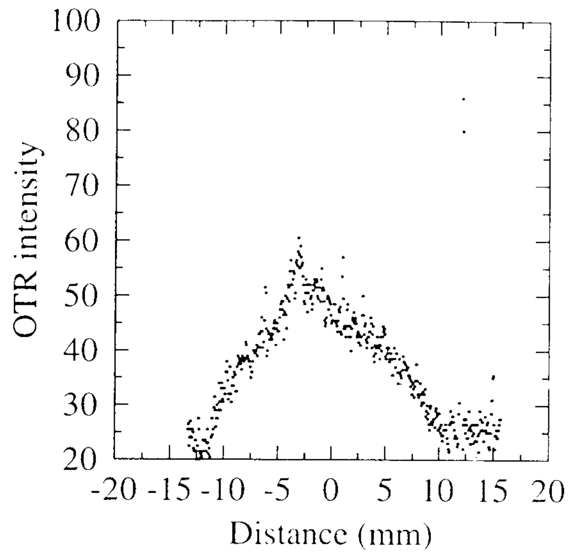

Figure 4: Profile on negative zero-crossing

4 PHASE TRANSFER MEASUREMENTS

Measurements of the phase transfer function between the photocathode laser and two cavities placed at strategic locations in the accelerator, provide a convenient and rapid method to diagnose problems in the settings of the RF cavities in the FEL. The first pickup cavity is located on the injection beam line just prior to the final bend onto the linac beam line. Measurements on the first cavity are used to establish proper injector setup, which can be nontrivial because of the bunching that occurs there. The second pickup cavity, located just downstream of the cryomodule, is used to establish that the proper bunching slope is established going into the first optical chicane prior to the wiggler. This chicane has non-zero M_{56}, which is used for a final bunching into the wiggler region. Phase transfer measurements follow the method that is currently employed at the nuclear physics accelerator at Jefferson Lab [5]. In this method, a precision phase detector is used to measure the phase difference between a RF reference signal and the output of tuned pickup cavities. Adjusting the slopes (bunching) is accomplished by adjusting the phases of (1) the second SRF cavity in the injector cryounit for the first pickup, and (2) an offset phase which changes the phases of all the cavities in the linac cryomodule for the second pickup. Results from the first cavity appear in another contribution to this conference [6]. Results of measurements on the second cavity appear in Figure 5 below. Although the slope of the phase transfer is precisely as predicted by PARMELA, the curvature in the distribution is obviously incorrect. Presently, it is believed that the setup of the injector has not been rigorous enough that the PARMELA calculations should be reproduced.

5 BUNCH LENGTH CONTROL

The Golay cells in the interferometer are also being used for bunch length monitoring by measuring the total volt-

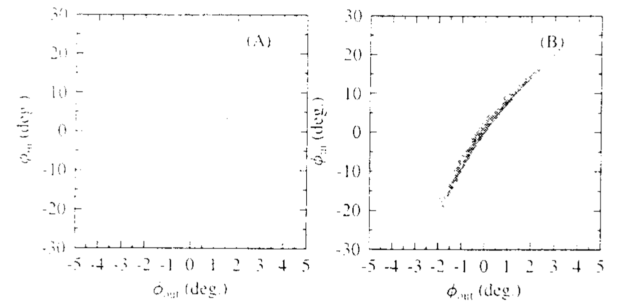

Figure 5: Comparison of measured M_{55} transfer map with the PARMELA calculated result for the second longitudinal pickup cavity.

age fluctuation from the cell when the beam is pulsed. This voltage increases with the power deposited in the Golay cell. Neglecting some subtleties that should be discussed in a more thorough presentation, by maximizing the collected power, the bunch length of the emitting beam is minimized, because shorter bunches emit more coherent transition radiation than longer bunches. This diagnostic is already routinely used to optimize conditions for lasing. At our FEL, when the first beam was produced after the wiggler for the laser was installed, the beam emission was at power levels consistent with spontaneous emission. After an adjustment was made to maximize the power indicated by the Golay cell by changing the bunching voltage in the linac, lasing in the free electron laser was observed.

That the bunching can be systematically varied is demonstrated by Figure 6, where the overall coherent transition radiation collected by the Golay cell is plotted against linac phase. The clear maximum at 11.3° corresponds to the minimum bunch length, as the beam transitions from overbunching to optimal to underbunching. Also, it should be noted that the technique is highly sensitive to changes off nominal in the RF parameters. Changes in the overall phase at the 0.1° level are discernable off crest. The range of phases in which lasing occurs has been determined experimentally. It has been demonstrated experimentally that this range is much wider than the region of response of the Golay cell to coherent transition radiation. The conclusion is that the Golay cell provides a better bunch length optimization tool than the laser itself.

6 CONCLUSIONS

We have completed and are substantially finished commissioning the electron beam longitudinal diagnostic set. The various devices have supported commissioning to lasing, provided raw data for comparisons to design, and through EPICS interfacing, made condensed data available to operators in easily understood screens. We are not yet to the stage that detailed agreement exists between design and measurement; it is thought that the disagreement resides not in the diagnostics, but in the lack of precision in

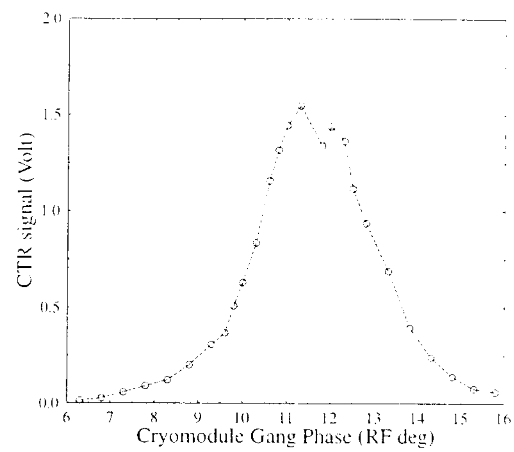

Figure 6: Coherent transition radiation signal measured by Golay cell vs. linac phase

the machine setup procedures used up to now. This work was performed under the auspices of the US-DOE contract #DE-AC05-84ER40150, the Office of Naval Research, the Commonwealth of Virginia, and the Laser Processing Consortium.

7 REFERENCES

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