MEASURING AND CHARACTERIZING ULTRASHORT BUNCHES IN THE JEFFERSON LAB FREE ELECTRON LASER

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Abstract

The characterization of ultrashort bunches is essential when dealing with free-electron laser driver accelerators. In such high-brightness accelerators, short bunch lengths are required to achieve the high peak current needed for high laser gain. Also, because of the high charge per bunch involved, the bunching process can potentially be altered via space-charge forces. In the high-power free-electron laser at Jefferson Lab, several methods are used simultaneously to monitor the longitudinal distribution. These methods include frequency-based devices that measure the bunch frequency spectrum by detecting coherent transition radiation, and time-based methods such as zero-phasing or M_{55} transfer map measurements using the "time-of-flight technique". In this paper we discuss measurements performed with the different devices and compare them with numerical simulations. We also present results of parametric studies of these various devices versus the RF phase of different critical elements in the machine.

1 GENERAL LAYOUT

Accurate beam instrumentation is essential for smooth commissioning of any accelerator. The diagnostics for Jefferson Lab's FEL accelerator have two main purposes: to allow set up of the accelerator and to monitor changes in beam conditions during production runs [1]. A diagram of the overall facility appears in Ref. [2]. 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 38 MeV. After passing through a 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. The main beam parameters are summarized in Ref. [2].

2 IR INTERFEROMETRY

The bunch length will be determined at several locations in the accelerator. The main measurement was completed at 38 MeV just downstream of the wiggler, i. e., at the location where one would like the bunch length to be minimized. Also, for beam verification purposes, a device at 10 MeV is installed. In the measurements, a polarizing Michelson interferometer and detector (Golay cell) are used to measure the power spectrum of transition radiation from a thin aluminum foil by autocorrelation [3]. An estimate of the bunch profile can be derived from the measured interferogram. The University of Georgia has build the interferometer and and the EPICs software to automatically perform the autocorrelation measurement. The range of the device is approximately 0.2-5 psec, and it is desired to have a result good to 0.1 psec.

An example from our first autocorrelation measurements is given in Figure 1. This interferogram clearly indicates that the rms bunch length is shorter than 250 μm. At this moment, the precision is limited because final alignment of the interferometer mirrors has not occurred; even a delta function bunch would have a finite indicated width of about 150 μm.

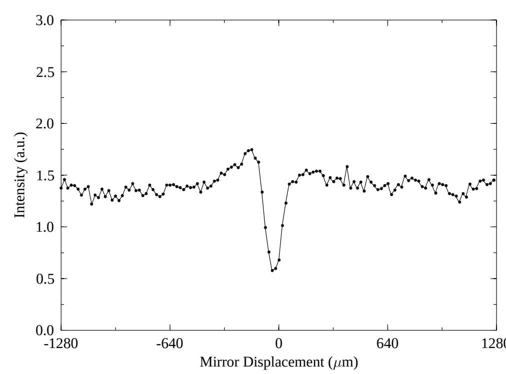

Figure 1: Interferogram measured at IRFEL wiggler

3 ZERO PHASING

The primary standard method used for precise determination of the longitudinal distribution is based on the zero-phasing method [4]. In the zero-phasing measurement, a longitudinal (accelerating) mode is phased to the zero-crossing of the accelerating wave. A linear energy ramp is induced front-to-back in the bunch. A distribution function is obtained by transversely diagnosing the beam at a dispersed location. Data from both zero-crossings, the positive and negative going crossings, are used to obtain an estimate of the slope of the longitudinal phase space. The measured slope is substantial when the rms beam sizes of the two crossings are different.

Examples of measurements taken at the Jefferson Lab IRFEL appear in Figures 2-4. Figure 2 is the profile on 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.

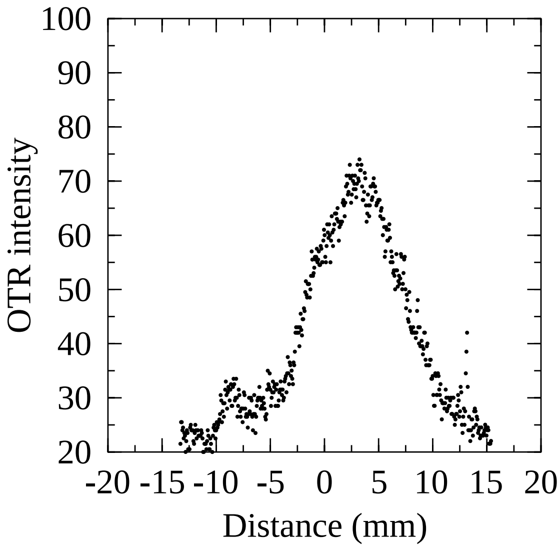

Figure 2: Profile on positive zero-crossing

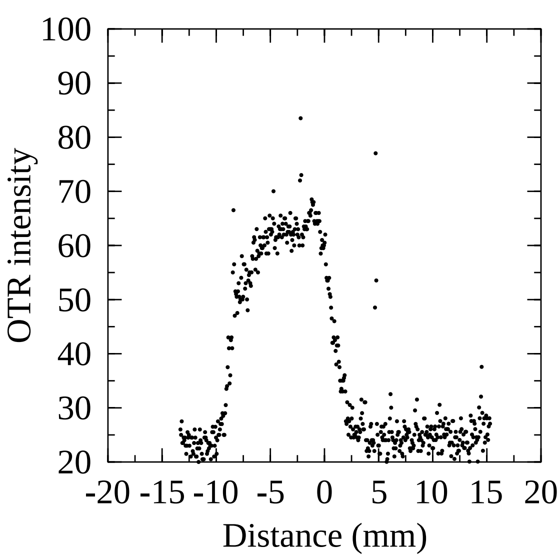

Figure 3: Profile with zero phasing cavity off

4 PHASE TRANSFER MEASUREMENTS

Measurements of the phase transfer function between the photocathode laser and two cavities placed at strategic lo-

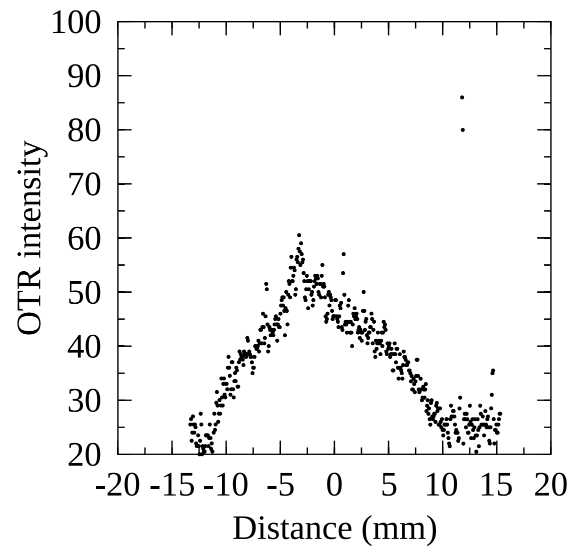

Figure 4: Profile on negative zero-crossing

cations 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-

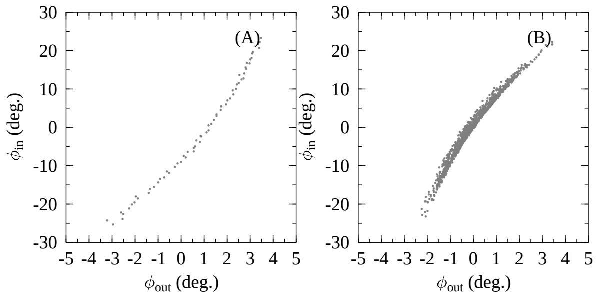

Figure 5: Comparison of measured M_{55} transfer map with the PARMELA calculated result for the second longitudinal pickup cavity.

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

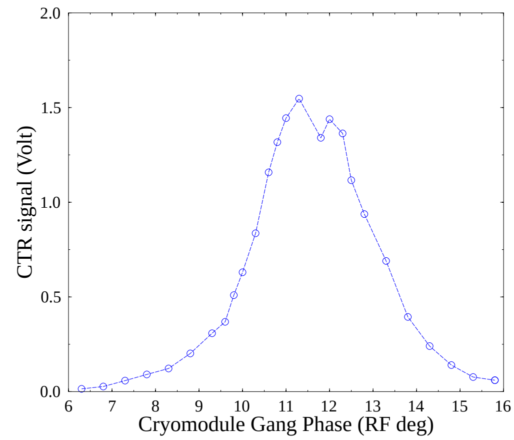

Figure 6: Coherent transition radiation signal measured by Golay cell vs. linac phase

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.

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