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**FIRST MEASUREMENTS OF ELECTRON-BEAM TRANSIT TIMES AND
MICROPULSE ELONGATION IN A PHOTOELECTRIC INJECTOR AT
THE HIGH-BRIGHTNESS ACCELERATOR FEL (HIBAF)***

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ABSTRACT

Key aspects of the dynamics of a photoelectric injector (PEI) on the Los Alamos High-Brightness Accelerator FEL (HIBAF) facility have been investigated using a synchroscan streak camera. By phase-locking the streak camera sweep to the reference 108.3 MHz rf signal, the variations of micropulse temporal elongations (30 to 80% over the drive-laser pulse length) and of transit times (25 ps for a 16° -phase change) were observed for the first time. These results were in good agreement with PARMELA simulations.

I. INTRODUCTION

The characteristics of the electron beam from a photoelectric injector (PEI) depend critically on the first accelerating cavity. We have investigated the dynamics of the PEI-generated beams on the Los Alamos High-Brightness Accelerator FEL (HIBAF) Facility using a synchroscan streak camera. Because the electron-beam micropulse elongation depends on the balancing of space-charge effects by the rf field gradients present when the electrons are released from the photocathode, drive-laser phase is a critical parameter. Similarly, the transit time of the electrons through the first cell also depends on the accelerating fields present at their release, and thus the time it takes to

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reach relativistic velocities. These dynamic aspects can serve as important tests of the modeling of the PEI.

Because designers prohibited instrument diagnostics in the accelerator tank, we have utilized the fact that these initial first cell dependencies are preserved in the accelerations up to 17 MeV. By phase-locking the streak camera sweep to the reference 108.3 MHz rf signal the variation of elongation and transit time with respect to the drive-laser injection phase were measured. Both the path lengths for the drive-laser signal and the electron-beam signal (Cherenkov light) were adjusted in such a way that they appeared in the same streak sweep. Experimental results were in good agreement with PARMELA simulations as discussed in Section III.

II. EXPERIMENTAL CONSIDERATIONS

The HIBAF facility is described in more detail elsewhere in these proceedings [1], but in our initial test configuration there was only the photoinjector (see Fig. 1) tank and a second accelerating tank. The ND:YLF laser oscillator was mode locked to 54.1 MHz, pulse compressed, its wavelength doubled in frequency in a KTP crystal, and pulse selected to provide a few microjoules per micropulse at 21.6 MHz (1/60th of the fundamental 1300 MHz rf frequency). This drive-laser beam, after mode shape preparation and transport, irradiated a CsK₂Sb photocathode located in the first accelerator cell. Basically no beam line diagnostics were allowed until after accelerator B. Energies at that point were 15-17 MeV.

Figure 2 shows a schematic of the beam line diagnostics that are addressed also in reference [2]. In these experiments, however, we relied principally on the aluminized fused silica screen #3, 7-meters downstream of the photocathode. The screen was

oriented at 45° to the beam direction so that the Cherenkov light exited almost normal to the screen surface but through an exit port at 45° to the beam line. The streak camera was located a few meters from the beam line. Transport optics were used to place the image on the entrance slit of the streak camera. Additionally, a fraction of the drive-laser beam was transported to the entrance slit along a path that approximated that of the electron beam plus Cherenkov light path.

A Hamamatsu C1587 streak camera with the synchroscan plugin phase locked to 108.3 MHz was used to detect the two signals. With the optical paths adjusted, both the e-beam and laser beam micropulse were observed in the same sweep of the camera. The system could track single micropulses or the synchronous sum of hundreds of pulses. A NARDA phase shifter in the drive laser rf side and in the line to the streak camera allowed tracking of the relative rf phase changes (Fig. 3).

III. RESULTS AND COMPARISON TO SIMULATIONS

The initial experiments were performed in January 1990. Figure 4 shows two streak images of the drive-laser micropulse and the electron beam pulses at two different drive laser phases. An approximately 30° (60 ps) phase change between the upper and lower figures shows a narrowing of both micropulse length and the change in separation between the micropulses on the time axis. This latter effect is attributed to the change in transit times through the first cell.

A series of such images was taken as a function of the phase shifter on the rf to the drive laser. The full-width at half-maximum intensity (FWHM) values and peak position values for both e-beam and drive-laser micropulses were tracked. Figure 5 shows the measured micropulse length variation in picoseconds versus phase. The

drive-laser micropulse length was monitored through an autocorrelator on the $1.05\ \mu\text{m}$ radiation as well as in the doubled frequency via the streak camera ($\text{FWHM} = 11 \pm 2\ \text{ps}$). The variation of e-beam micropulse of 30 to 80% is indicated. The solid curve shows a curve calculated from the PARMELA description of the injector was in good agreement with experiment. In Fig. 6, the transit-time phase dependence is shown. One of the interesting features is at higher fields in the cell (larger phase #), the transit time effect saturates so arrival times all fall in a 25 ps window.

Within the course of these streak camera experiments, we turned off the drive laser to establish backgrounds. We actually were able to synchronously integrate the field emission electrons from the photocathode. In Fig. 7, beam transport was not optimized, but the two doublets result from electrons generated at 1300 MHz arriving phase locked to both sides of the sinusoidal streak sweep. A 42-ps variation of the NARDA phase shifter in line to the streak unit rf causes the motion of the two doublets in opposite "time" directions. Figures 8a-d, then show the strong, nonlinear dependence of the beam images (viewed via OTR signals) versus accelerator A fields. A factor of five decrease in electrons for only a 20% decrease in field at the photocathode was observed. The rf tank probe reading of 300 mV corresponds to about 26 MV/m at the photocathode. Further experiments and results on these field emission electrons will be reported elsewhere.

IV. SUMMARY

In summary, by phase-locking the synchroscan streak camera sweep to the reference 108.3 MHz rf signal, the variations of e-beam micropulse elongation and transit time with drive-laser injection phase were measured. These two phenomena have been

observed for the first time in a PEI, and their phase dependencies have been shown to agree with PARMELA simulations. This understanding can also be applied to the unexpected field emission electron source. These techniques can be used then in optimization of the PEI performances.

V. ACKNOWLEDGMENTS

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FIGURE CAPTIONS

Fig. 1. Schematic of photoinjector accelerator.

Fig. 2. Schematic of HIBAF beamline diagnostics.

Fig. 3. Schematic of Dual Sweep Streak Technique.

Fig. 4. Simultaneous synchroscan streak images of e-beam (Cherenkov converter) and drive laser.

Fig. 5. Micropulse length variation with drive.

Fig. 6. Transit time effects vs. drive laser phaser in the photoinjector.

Fig. 7. Synchroscan streak images of field emission electrons vs. input RF phase shifts.

Fig. 8. Field emission electrons imaged at 17 MeV versus accelerator A field with probe readings in mV: a) 300, b) 280, c) 260, and d) 240.

REFERENCES

1. D. W. Feldman, et al., "Performance of the Los Alamos HIBAF Accelerator at 17 MeV," Proceedings of the 12th International Free-Electron Laser Conference, Paris, France, September 16-21, 1990.
2. A. H. Lumpkin, et al., "Initial Observations of High-Charge, Low-Emittance Electron Beam at HIBAF," These Proceedings.

**CHARACTERISTICS DEPENDENT UPON
PHYSICS OF E-BEAM IN THE FIRST
ACCELERATING CAVITY: CRITICAL FOR
INEX VALIDATION AND ENHANCEMENT**

NEW DIAGNOSTICS ALLOW MEASUREMENT OF CRITICAL BEAM PARAMETERS ON HIBAF

E-BEAM MEASUREMENTS:

- SPOT SIZE
- DIVERGENCE
- μ PULSE WIDTH
- TRANSIT TIME
- μ PULSE CHARGE
- ENERGY SPREAD

SCHEMATIC OF DUAL SWEEP STREAK TECHNIQUE

SIMULTANEOUS SYNCHROSCAN STREAK OF E-BEAM/DRIVE LASER (DL) (D. L. PHASE EFFECT)

LASER PHASE

" $\Delta\phi$ " = 0 ps

FWHM $\approx$ 16 ps
(E-BEAM)

TIME $\longrightarrow$

LASER PHASE

" $\Delta\phi$ " = -60 ps

FWHM $\approx$ 12 ps
(E-BEAM)

TIME $\longrightarrow$

AUTO CORR.
~ 13 ps

MEASURED μ PULSE LENGTH VARIATION
WITH LASER PHASE IN INJECTOR
AGREES WITH INEX PREDICTION

MEASURED ELECTRON-TRANSIT-TIME VARIATION WITH LASER PHASE IN INJECTOR AGREES WITH INEX PREDICTION

SYNCHROSCAN STREAK IMAGES SHOW PHASE EFFECTS ON FIELD EMISSION ELECTRONS

(3-20-90)

NARDA
= 09#
 $\Delta\phi = 0$

NARDA
= 24#
 $\Delta\phi = 42 \text{ ps}$

— TIME (ps) —→

FIELD EMISSION ELECTRONS
VARY WITH TANK-A FIELDS

(3-20-90)

Accel. A:
Ampl. = 300 mV

$I_{pk} = 1.0$
Box Average
of x-Profile

a)

Ampl. = 280 mV

$I_{pk} = 0.8$

b)

————— **x** —————→

FIELD EMISSION ELECTRONS VARY WITH TANK-A FIELDS

(3-20-90)

Accel. A:
Ampl. = 260 mV

$I_{pk} = 0.4$
Box Average
of x-Profile

c)

Ampl. = 240 mV

$$\frac{A_4}{A_1} = 0.80$$

$I_{pk} = 0.2$

d)

END

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