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SINGLE-SHOT LONGITUDINAL PHASE-SPACE MEASUREMENT OF THERMIONIC-CATHODE GUN BEAM AT THE APS LINAC*

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Abstract

Advancements in particle accelerator technology hinge on our ability to precisely measure and understand the behavior of high-brightness beams. Following the installation of the new photo-cathode gun (PCG) laser at the front-end of the Advanced Photon Source (APS) linac, commissioning studies are needed to understand and bring the new PCG beam up to operational standard. In the present work, we present initial measurements characterizing the longitudinal phase-space of the thermionic-cathode gun (TCG) electron beam using a transverse deflecting cavity (TCav) located at the end of the APS linac. Downstream of the TCav, which deflects the beam vertically, lies the B1 horizontal bending magnet and three Chromium Oxide screens placed at three different locations where the beam is intercepted and imaged. Measurements of the TCG beam longitudinal phase-space are discussed and compared to previous measurements of the PCG beam longitudinal phase-space.

INTRODUCTION

Longitudinal phase space studies were initiated to explore the capabilities of the RG2 electron gun in conjunction with the TCav diagnostic system in preparation for PCG comissioning. These studies follow the foundation established by Sun's study in 2021 [1]. The primary goal was to refine the operational parameters (e.g. TCav RF phase, magnet strengths) and assess the beam characteristics under parameter variations.

For these studies, the beam energy selected was 425 MeV. RF conditioning was performed bringing the TCav to approximately 19 MW which correlates to a deflection strength of 3.8 MV [1]. A diagram showing the relevant components of the APS linac is shown in Fig. 1.

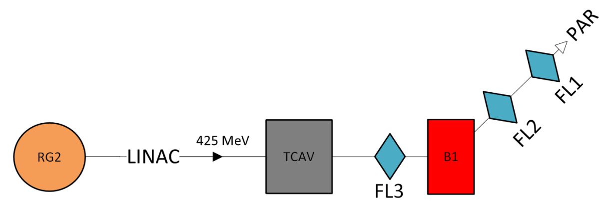

Figure 1: APS linac diagram.

INITIAL SETUP

First, the Particle Accumulator Ring (PAR) triple stop is closed to prevent injection into the storage ring. Before making changes, a save compare restore (SCR) file is created. Then, initial measurements establish the image calibration and confirm normal operation of RG2 beam to FL1, FL2, and FL3 (see example in Fig. 2). Before changing B1 current values, the control law feedback for corrector magnets is turned off to avoid railing correctors. Lastly, necessary camera, klystron, and timingResets GUI panels are opened for parameter control.

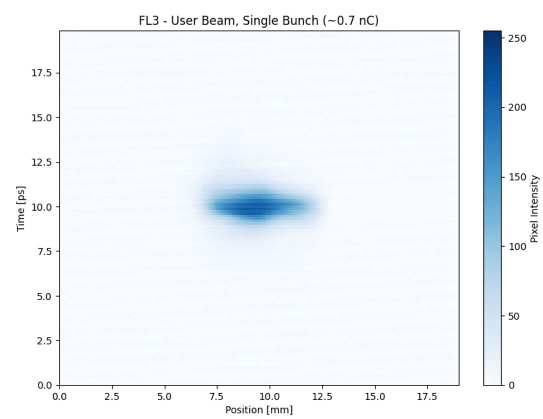

Figure 2: Example of normal TCG beam without TCav deflection showing on FL3.

LATTICE OPTIMIZATION

The APS linac lattice was optimized to minimize the beta functions and maximize the horizontal dispersion at FL1 using elegant [2,3]. The resulting magnet strengths from the simulation in physics units were converted to engineering units (Amps) using a scaling factor derived from the nominal linac lattice parameters. After adjusting the magnets, an image was taken to confirm the beam was minimized and showing on FL1. Note that the lattice optimization was only applied to FL1 measurements.

TCAV TIMING

Under the low level RF GUI panels are RF control and RF measurements panels. Through the RF measurements panel, we can launch the other panels to vary the klystron trigger settings such that the timing of the TCav's deflection

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and the timing of the bunch traveling through the cavity overlap (beam is deflected) or do not overlap (beam is not deflected). It is also possible to vary the RF phase through the panels thereby changing the bunch's position on the RF wave. Changing the phase past a lower or upper bound will cause the beam to be "lost" by the screen. Changing the phase by a larger amount will cause the beam to be "found" again though the shape of the beam will be reflected about the y-axis.

LONGITUDINAL PHASE SPACE MEASUREMENTS

FL1

After performing the initial setup, GUI panels were utilized to vary the triggers and timing for klystron and the TCav. For calibration of the vertical axis, the TCav phase was varied (ϕ = 40.6°, 51.4°, 58.6°, 65.8°, 76.5°) and images were saved. Contrary to our expectation, the centroid of the beam did not move much in the vertical direction as the phase was varied which affected the phase calibration factor. To obtain the phase calibration factor, the centroid was tracked and plotted versus the phase values giving a factor of 50.0 deg/mm (Fig. 3).

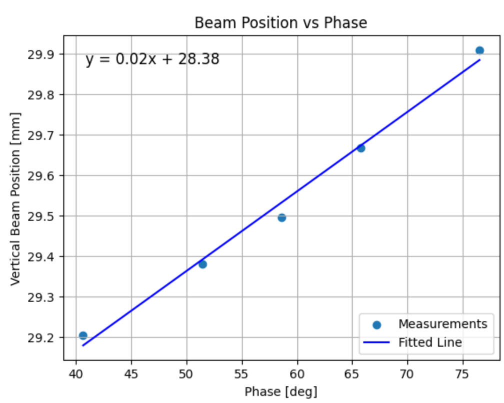

Figure 3: Vertical phase calibration for FL1.

The full width at half maximum (FWHM) vertical bunch length with deflection (Fig. 4) was measured to be 1.14 mm. Alternatively, the bunch lengths can be converted using a calibration factor of 0.97 ps/deg at 2856 MHz giving 55.3 ps [1]. Next, the TCav phase was returned to ϕ = 58.6°. For calibration of the horizontal axis, the current on the B1 magnet was varied (I = 155.3 A, 156.3 A, 157.3 A, 158.3 A, 159.3 A, 160.3 A, 161.3 A) and images were saved. To obtain the energy calibration factor, the beam centroid was tracked and plotted versus the energy variation corresponding to the small variation in current giving a factor of 0.76 MeV/mm (Fig. 5). Following the completion of our measurements, we returned magnet strengths and klystron timings to the original values and confirmed beam was still showing on FL1.

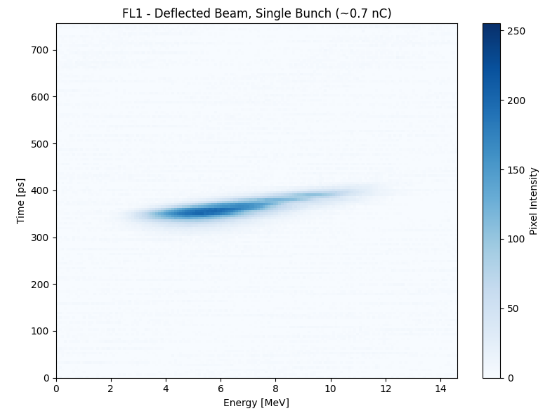

Figure 4: TCG beam is shown on FL1 with TCav deflection.

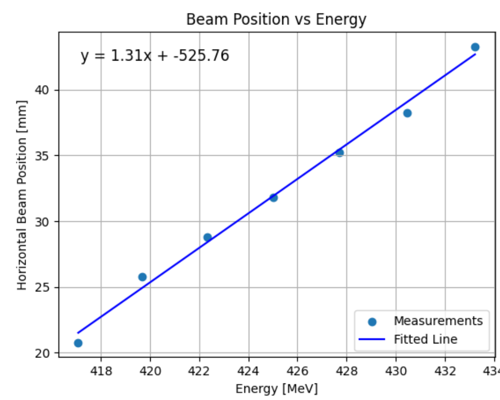

Figure 5: Horizontal energy calibration for FL1.

FL2

Similar to the FL1 measurements, the calibration of the vertical axis followed the same procedure except the TCav phase was set to ϕ = 240° (lower bound) and ϕ = 244° (upper bound) before "losing" or clipping the beam on the screen. This resulted in a calibration factor of 1.25 deg/mm (Fig. 6). The vertical bunch length with deflection (Fig. 7) was measured to be 5.60 mm or 6.79 ps. For calibration of the horizontal axis, we followed the same procedure as before resulting in a factor of 0.64 MeV/mm (Fig. 8).

FL3

Following the measurements on FL2, we switched to the camera on FL3. For calibration of the vertical axis, we followed the same procedure except the TCav phase was set to ϕ = 51.8° (lower bound), ϕ = 59.0°, ϕ = 69.8°, ϕ = 80.6°, ϕ = 89.5°, and ϕ = 100° (upper bound) before "losing" or clipping the beam on the screen. The resulting vertical calibration factor was 1.33 deg/mm (Fig. 9). The vertical bunch length with deflection (Fig. 10) was measured to be 7.06 mm or 9.11 ps. Since FL3 is located directly downstream of the TCav and before the B1 dipole magnet, the beam is not deflected on the horizontal axis eliminating the need for an energy calibration factor.

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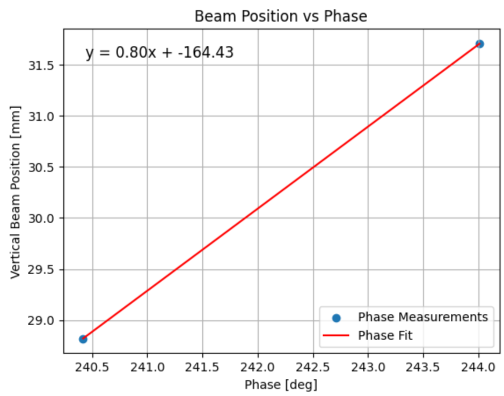

Figure 6: Vertical phase calibration for FL2.

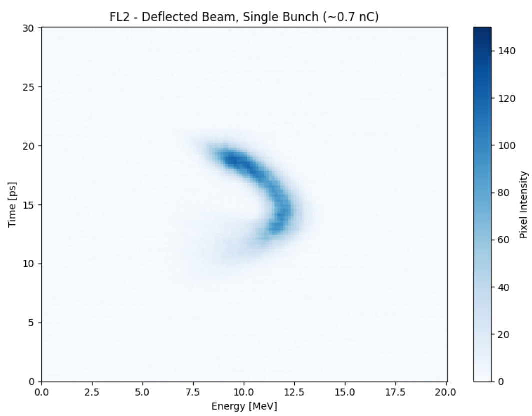

Figure 7: TCG beam is shown on FL2 with TCav deflection.

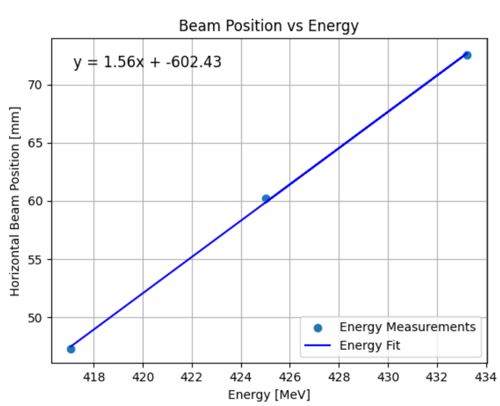

Figure 8: Horizontal energy calibration for FL2.

CONCLUSION

Reflecting on the studies, we can conclude that minimizing the beam using lattice optimization negatively impacted the TCav deflection resulting in an inaccurate vertical calibration factor. Hence, further improvements to the lattice optimization are needed. After establishing a proper calibration and measurement procedure, we were able to achieve similar results as Y. Sun when comparing our FL2 bunch lengths and Y. Sun's FL1 bunch lengths shown in Table 1.

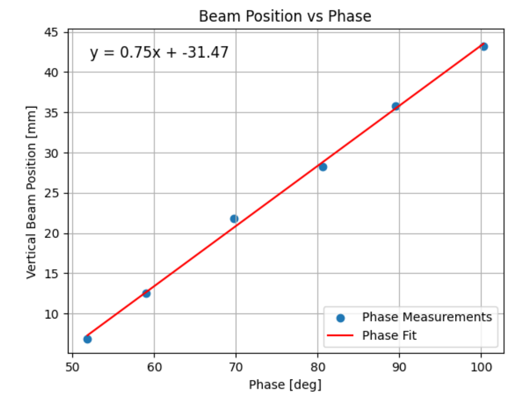

Figure 9: Vertical phase calibration for FL3.

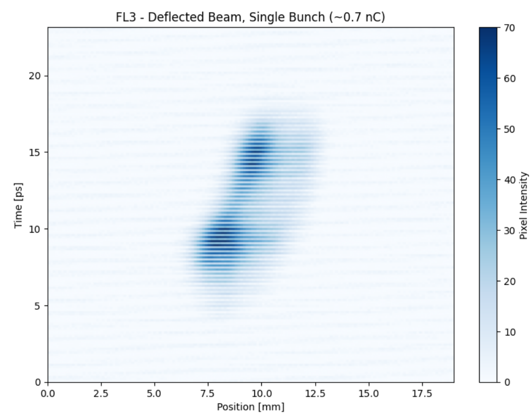

Figure 10: TCG beam is shown on FL3 with TCav deflection.

As a result of the lessons learned in prior studies, the subsequent study was successful in meeting our expectations for the beam's behavior while providing a comparison between the three diagnostic flags downstream of the TCav. Adjustments to various parameters led to improved understanding and control of the TCav beam dynamics establishing a solid foundation for future studies.

Table 1: Bunch Length Comparisons

Flag	**TCG**	**PCG** [1]
FL1	55.3 ps	6.4 ps
FL2	6.79 ps	-
FL3	9.11 ps	-

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