

MEASUREMENTS OF THE ELECTRICAL AXES OF THE CEC POP RF CAVITIES

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Abstract

It is common knowledge that every mode in an SRF cavity has a so-called electrical axis, and only in an ideal cavity would this axis align exactly with the geometrical axis of the device. The misalignment of the electrical axis creates an additional undesirable transverse kick to the beam, which has to be corrected to achieve the designed beam parameters. In this paper we present the two methods which have been used in order to determine the electrical axes in the RF cavities of the Coherent electron Cooling (CeC) Proof of Principle (PoP) accelerator [1, 2]. The electron accelerator for the CeC PoP consists of the three main RF components: the 113 MHz SRF gun, the two normal-conducting 500 MHz bunching cavities, and the 704 MHz SRF 5-cell elliptical cavity. We discuss, in detail, the specifics of the measurement for each cavity and provide the corresponding results. In addition, we describe the influence of the field asymmetry in the 500 MHz bunchers on the beam dynamics, which was observed experimentally and confirmed by simulations.

CEC POP SRF ACCELERATOR

In the CeC PoP accelerator, electron bunches are generated from a CsK₂Sb photocathode by the 532 nm green laser and then accelerated by the 113 MHz SRF gun up to 1.25 MV. Primary focusing of the beam is provided by the solenoid located at the minimal acceptable distance from the cathode. Two 500 MHz normal-conducting cavities and the low energy beam transport (LEBT) section are utilized to achieve a desirable ballistic compression of the beam before it is accelerated to the full energy in the 704 MHz SRF linac. The LEBT section shown in Fig. 3 consists of 5 solenoids and several pairs of dipole trims which provide a successful beam transportation. The beam line is equipped with an integrating current transformer (ICT) for the beam current measurements, two beam profile monitors (yttrium aluminium garnet (YAG) screens), three beam position monitors (BPMs), and a set of vertical and horizontal slits for the beam emittance measurements.

113 MHz SRF PHOTOINJECTOR

The 113 MHz SRF photoinjector (see Fig. 1) is based on Quarter Wave Resonator (QWR) and operates at 1.25 MV of accelerating voltage. The gun is generating high charge electron bunches (up to 10 nC per bunch) and low transverse emittances with the cathodes operating for months without significant loss of quantum efficiency. The detailed description of our gun and its successful performance can be found in [3].

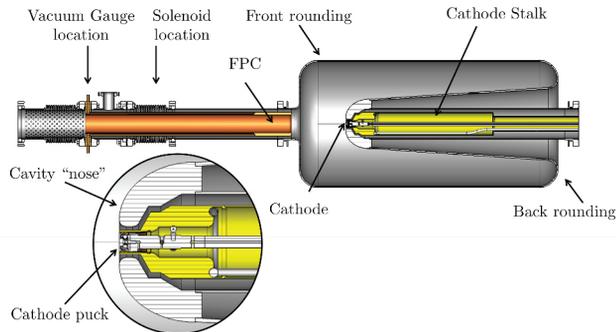


Figure 1: Simplified geometry of the CeC PoP SRF photoinjector.

Throughout the operation of the CeC PoP we encountered a few very specific features about the gun performance which we would like to discuss in detail. Specifically, we will address two procedures which have been used in order to determine the electrical axis of the gun and location of the cathode puck relative to the “nose” of the cavity.

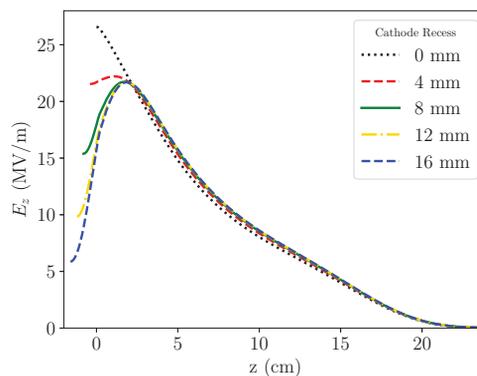


Figure 2: Electric field distribution along the gun axis for various values of the cathode recess.

Cathode Location

As one can see from Fig. 2, longitudinal field profile along the beam path and the peak field at the cathode surface strongly depend on the position of the cathode stalk relative to the nose of the cavity. Since the cathode is located in the area of the highest concentration of the electric field in the gun, any local changes in the geometry caused by the cathode recess will introduce a dramatic change in the field distribution, and hence, the initial focusing of the beam.

In order to determine the exact location of the cathode, we performed a series of measurements to calculate the magni-

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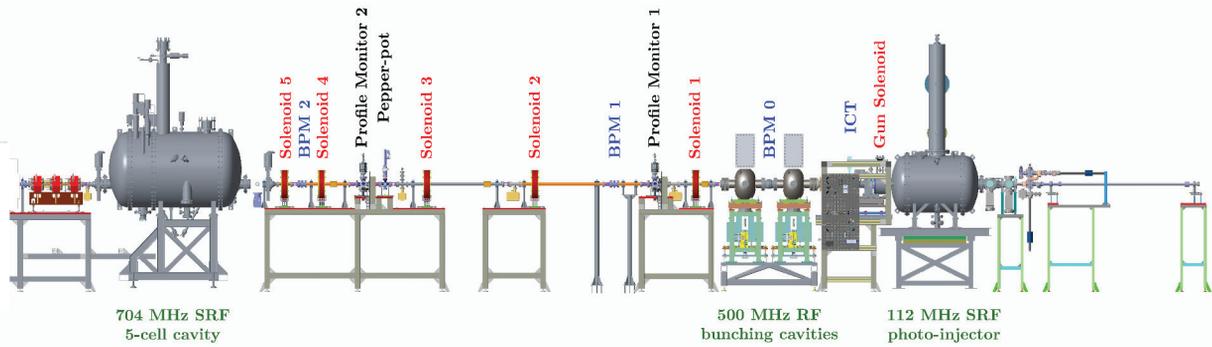


Figure 3: Low energy beam transport (LEBT) line.

fication of the gun. By moving the laser spot on the cathode, and measuring the position of a very small low-charge beam on the YAG screen, we found that the magnification (ratio of the beam position at YAG and the laser spot position) by the gun is approximately -4.

This experiment was then simulated using the field profiles in the gun corresponding to the various possible locations of the cathode. One can see from Fig. 4 that the simulations were performed using several well-known codes for the beam dynamics calculations: PARMELA, ASTRA and GPT [4–6]. This experiment completely excludes the effects of the space-charge, so we can conclude that these codes have a very good agreement for the simulations without the space charge. According to the simulations, the cathode recess of -10.5 mm relative to the nose of the cavity provides the measured magnification of -4 (see Fig. 4).

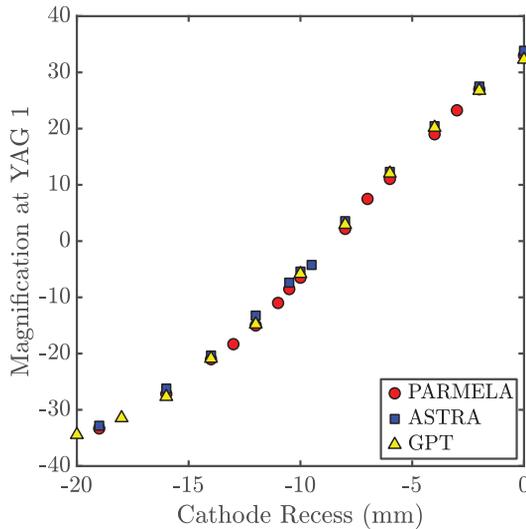


Figure 4: Magnification by the gun as a function of the cathode recess.

Electrical Axis

In order to determine the electrical axis of the gun, we changed the beam rigidity by scanning the voltage of the gun, and measured the position of the beam center at the first profile monitor. For these measurements all of the solenoids

between the gun and the YAG screen were turned off. To guarantee that the beam stays on the YAG screen throughout the experiment, we split the scan in three parts and changed position of the beam using the dedicated set of trims.

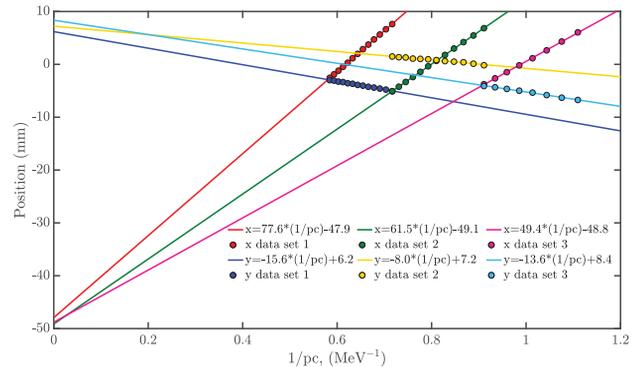


Figure 5: Dependence of the beam position at the YAG 1 on the inverse rigidity.

Position of the beam center was then plotted as a function of the inverse beam rigidity, which has a linear dependence (see Fig. 5). The y-intercept here gives the direction of the gun axis for an infinitely rigid beam. Taking into account the distance between the cathode and the YAG screen of 4.267 m, one can conclude that the gun is aiming with a horizontal angle of -11.1 ± 0.1 mrad (away from the RHIC beamline), and vertical angle of $+1.6 \pm 0.2$ mrad (upwards) with respect to its external fiducials. This measurement was later confirmed using the beam-based alignment.

500 MHZ BUNCHING CAVITIES

The ballistic compression of the CeC electron beam is provided by the set of two normal conducting 500 MHz RF cavities, which are loaned from the Daresbury laboratory (UK). As shown in Fig. 6, the fundamental power coupler utilized for these cavities is of a waveguide type coupled to the cavity via an aperture (port) at the cavity top. This choice of the waveguide design introduces an undesirable transverse component of the electric field, which could be negligible for a proton beam, but provides significant vertical kick to the electron beam of the CeC. Fig. 7 shows the displacement of the vertical beam position on YAG 1 traveling through the

bunchers with initial offset of -6, 0, and +6 mm for various phases and voltages of the cavities.

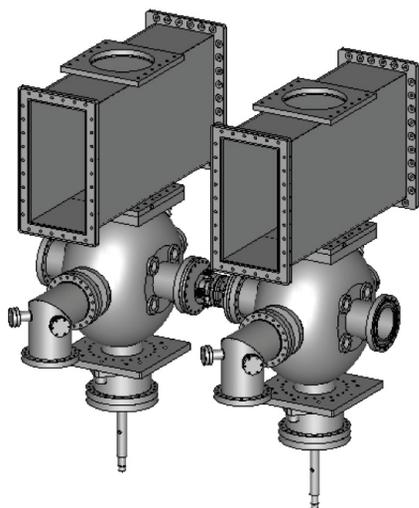


Figure 6: Geometry of the buncher assembly.

Using the BPM located between the two bunching cavities, we determined that their electric axis is displaced from the geometrical center by 3 to 4 cm and is located outside of the physical aperture.

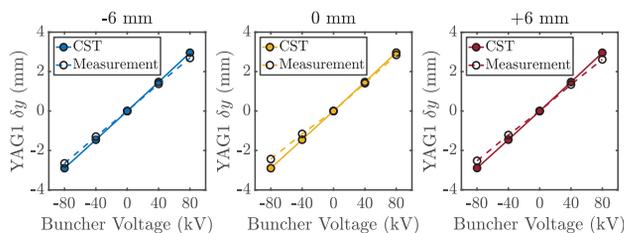


Figure 7: Displacement of the vertical beam position at YAG 1 as a function of the voltage of the bunching cavities for various initial displacement.

704 MHZ 5-CELL SRF LINAC

The geometry of the 704 MHz 5-cell SRF linac and its cryostat is shown in Fig. 8. Elliptical cavities, such as our linac, are well known and widely used for beam acceleration. However, when utilized for a non-relativistic beam, it leads to a non-periodic dependence of the accelerating voltage on the phase of a cavity. Electron beam enters the CeC 5-cell linac with the energy of 1.25 MeV, which limits stable regime of operation within ± 20 degrees around the crest of the cavity voltage (see Fig. 9).

The measurement of the electrical axis of the 5-cell cavity (see Fig. 10) showed that the linac has an axis aiming approximately 3 mrad upward.

CONCLUSION

The CeC PoP accelerating system has shown a great performance during the last years of commissioning. We achieved

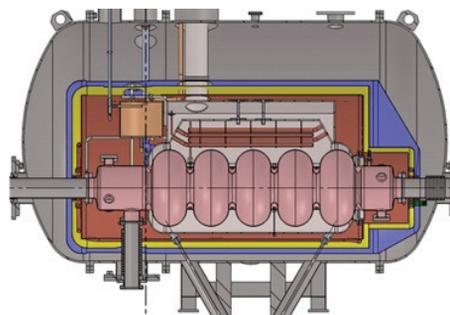


Figure 8: Geometry of the 704 MHz 5-cell cavity.

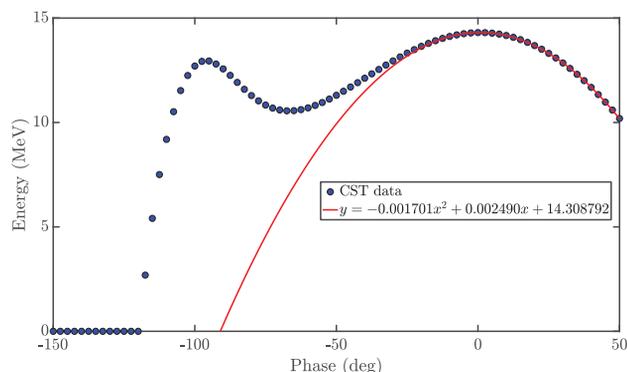


Figure 9: Energy of the electron beam after the 5-cell linac as a function of the cavity phase.

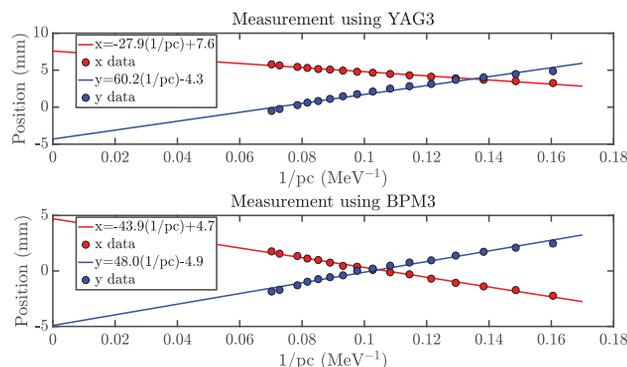


Figure 10: Dependence of the beam position at YAG 3 and BPM 3 on the inverse rigidity.

a better understanding of beam dynamics in the system, and developed convenient and precise methods of finding the electrical axes of the cavities, and the cathode location in our SRF gun.

ACKNOWLEDGMENTS

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