Optimization of FAST Electron Gun Beam Parameters

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Introduction

The FAST (Fermilab Accelerator Science and Technology) Facility includes a superconducting RF linear accelerator. This accelerator's test beamlines downstream will provide venues for advanced accelerator R&D (AARD) and future planned experiments like IOTA [1].

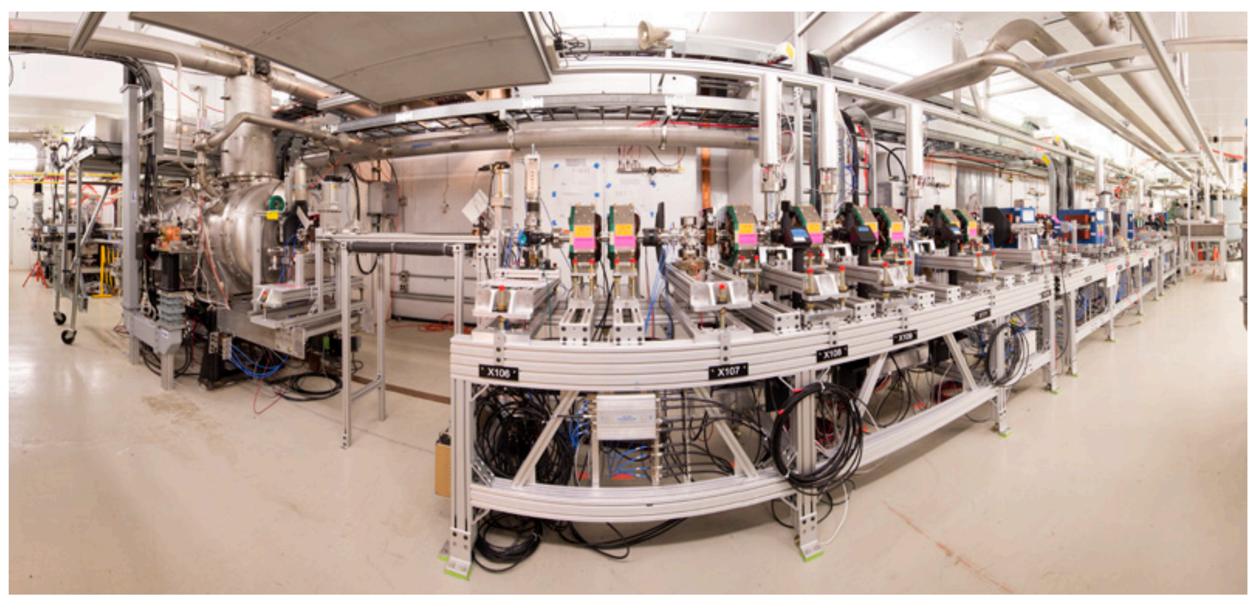

Figure 1: Image of Cyro Module and beam line, ASTA Cave Configuration at NML (FAST). Photocathode electron gun and toroid monitor to the left, beam travels to the right.

Photoinjector Gun

The RF photocathode electron gun is identical to the gun developed at DESY Zeuthen (PITZ), and is a normal-conducting 1½ cell 1.3 GHz gun.

The electron gun is routinely operated at peak gradients of 40-45 MV/m, with an output beam energy of ~5 MeV. Additionally, it utilizes a feedback system to regulate temperature to better than ±0.02 °C for beam and phase stability.

The photocathode is a 10 mm diameter polished molybdenum disk coated with Cs_2Te with 5 mm diameter photosensitive area. It is illuminated by 263 μm wavelength laser light directed onto the photocathode downstream of the RF coupler [1].

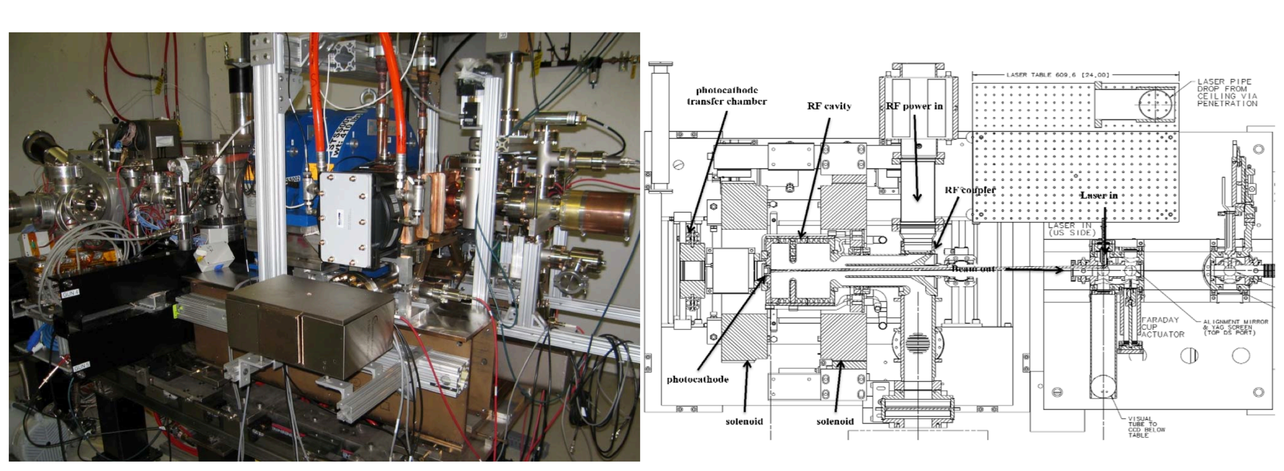

Figure 2: (a) Photograph of the gun installation in the ASTA enclosure on August, 2012. Photocathode preparation chamber is to the left, and beam exits to the right. RF waveguide connection is towards the viewer (white blank-off). Solenoids are blue [1]. (b) Cross section of gun, solenoids, transfer chamber, and downstream instrumentation [1]. Toroid monitor placed before the Faraday Cup to measure beam intensity/charge.

The Problem

To measure beam intensity, a toroid monitor was utilized to conduct a phase scan (accelerated charge measured as a function of launch phase). In order to optimize gun operation, the RF phase of the gun was varied with respect to the laser across various phase scans (See Figure 4).

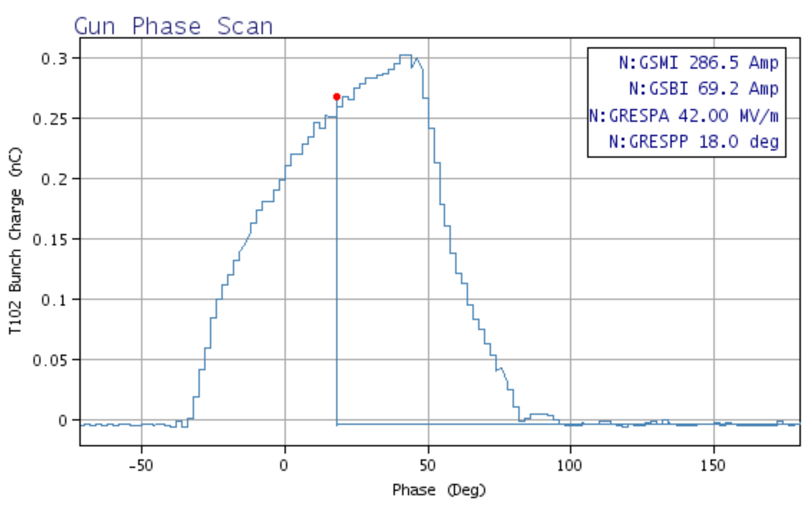

Figure 4: Measured phase scan from the electron gun in FAST. Data taken from a toroid monitor placed 1.186 m downstream from the gun. Plateau in charge is characterized by a significantly steeper slope than was observed at PITZ, which may be caused by a secondary emission of electrons.

Faraday Cups and integrating current transformers (ICT) had been used at PITZ to measure the electron beam charge.

However, the phase scans from FAST did not match those from PITZ despite the identical nature of the guns. This is an issue, since there is no explanation for why the phase scans from FAST would be so different.

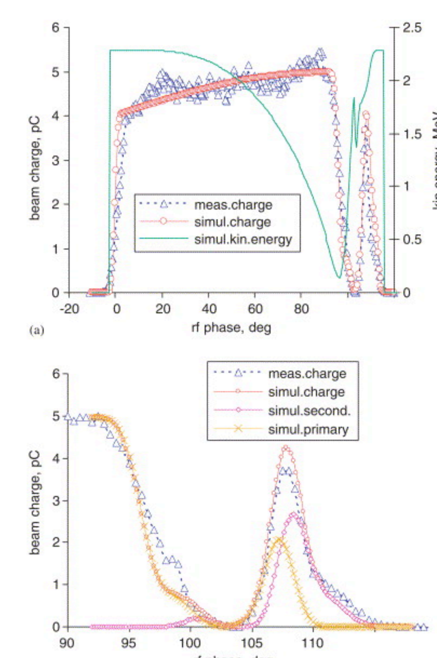

Figure 3: (a) Measured and simulated phase scan (beam charge vs. RF phase). (b) Detailed phase scan for RF phase range ~100–115° [2].

One possible explanation for the discrepancy in the recorded data is a Schottky-like effect manifesting itself in the Cs_2Te photocathode.

The Schottky effect describes the lowering of the work function or the potential barrier of a metal by an external electric field, which leads to an increased electron emission from the metal. This phenomenon may explain the unexpected results observed in the phase scan above. The charge of a bunch is determined at the time of emission as:

$$Q = Q_0 + SRT_{Q_{Schottky}} \cdot \sqrt{E} + Q_{Schottky} \cdot E$$

where E is the combined longitudinal electric field in the centre of the cathode. The charge Q_0, is the charge of the macro particles as defined in the input distribution (rescaled to fit Q_{bunch}) [3].

Parameter Optimization

ASTRA (A Space Charge Tracking Algorithm) is written in Fortran 90 by Klaus Floettmann (DESY).

A program was developed that allows for the simulation of the FAST beam through a Monte-Carlo approximation utilizing *ASTRA*, as well as real-time manipulation of parameters, and regression analysis, to try to explain our recorded data with the consideration of secondary emission.

Using this, a set of parameters was found that relatively accurately describes the behavior of the accelerator, and hints towards a potential hardware scaling factor. The program also began shedding some light on the problem of secondary emission, though arriving at a conclusion may warrant more investigation in the future.

Figure 5: The optimization program, first written in Python, was translated to C in order to more efficiently process the large amounts of raw data that ASTRA outputs per simulation. Now, it acts as an environment in which bash script and analysis can be run side-by-side.

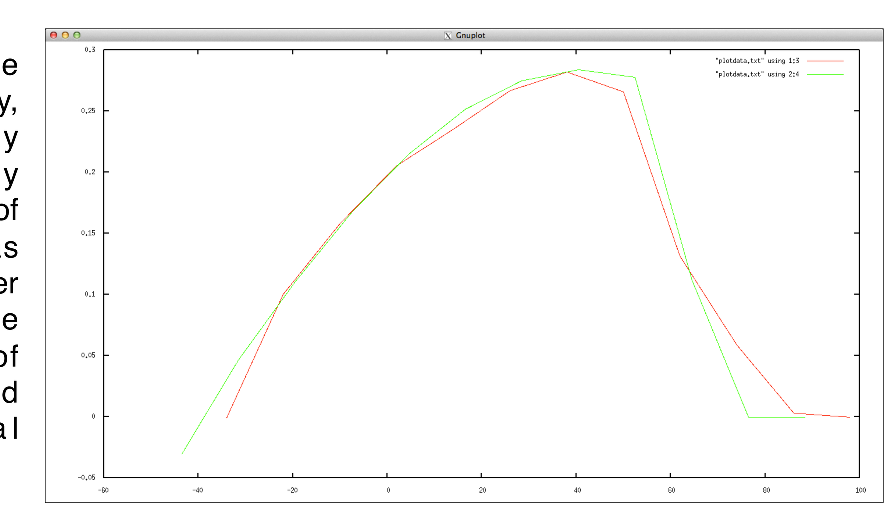

Figure 6: Through the tuning of gun geometry, charge, and Schottky parameters, a relatively accurate approximation of our recorded data was achieved. This lends further evidence towards the hypothesized impact of secondary emission, and hints at a potential hardware scaling factor.

Future Work

The program above, as well as the parameters it found, will continue to predict future experimental readings and diagnose issues. As FAST strives for higher intensities and more bunches, this work will set the stage for future optimization.

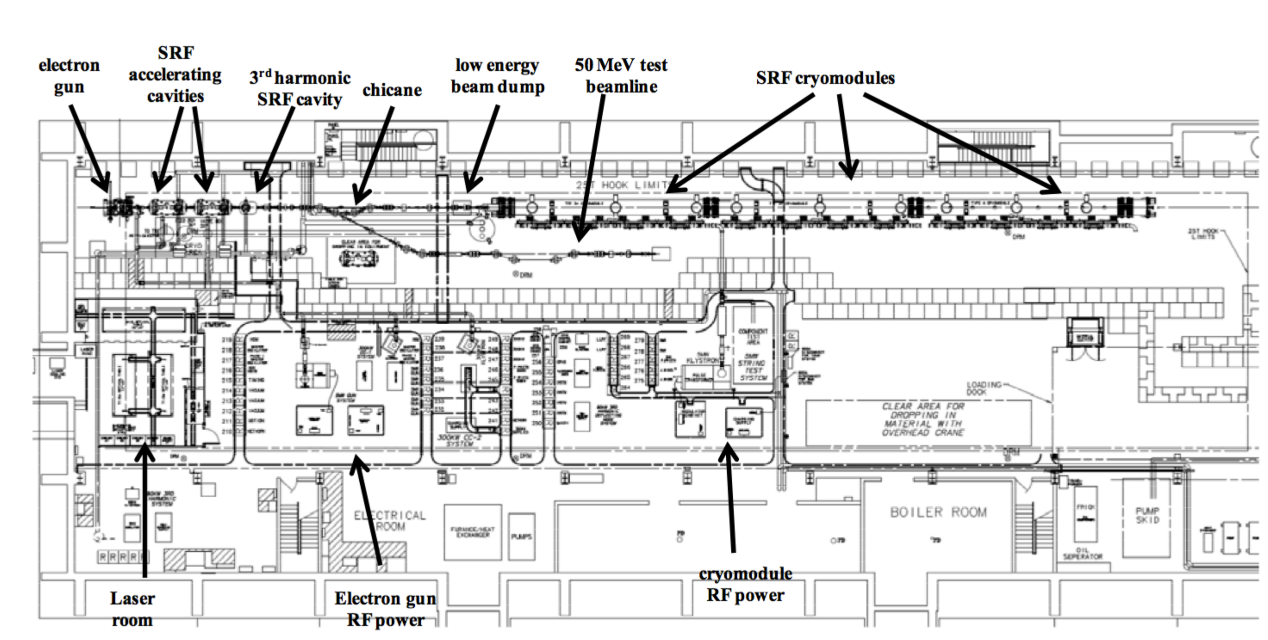

Figure 7: Upstream floor plan of the ASTA photoinjector and 3 SRF cryomodules in the original building footprint. The beamline is 1.2 m above the floor, the floor is 6.1 m below grade, and the building length is 74 m [1].

References

1. Mike Church, et al. 2012. *Design of the Advanced Superconducting Test Accelerator.*
2. K. Abrahamyan, et al. 2006. *Experimental characterization and numerical simulations of the electron source at PITZ.* Nuclear Instruments and Methods in Physics Research, Volume 558, Issue 1.
3. J. Li, et al. 2012. *Emission Study of Photocathode RF Gun at PITZ.* Proceedings of ICAP2012.