THE FINDER PHOTOINJECTOR*

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Abstract

The FINDER photoinjector was developed for the inverse Compton scattering experiment under UCLA-LLNL collaboration. The improvements of this gun from SPARC gun [1, 2] at INFN-LNF (Frascati) and previous UCLA versions of the 1.6 cell S-band photoinjector are detailed here. The gun is designed to have large mode separation to suppress 0 mode excitation which may be a cause of the emittance degradation. In an effort to reduce the RF quadrupole effect the full cell tuners are replaced by vacuum ports. The laser ports are also omitted. Two openings of the solenoid shield are added to top and bottom of it where there were only two openings on the sides. S_{11} of the cavity was presented. The on-axis electric field was measured by the bead drop method to show the good field balance. The magnetic field in the emittance compensation solenoid was measured and the quadrupole components were derived.

INTRODUCTION

In the FINDER project, an inverse Compton scattering experiment is planned to be performed which produces a narrow-band spectrum of gamma rays in the MeV range. It requires high quality beams to produce the desired narrow-band and high-brightness photons. A BNL-SLAC-UCLA 1.6-cell RF gun [3] is a solution to provide such beams. A new version of such a gun has been developed witin the context of the UCLA/LLNL collaboration. UCLA has developed a multitude of previous versions of this type of RF gun − for SLAC GTF and E163, BNL ATF, LLNL PLEIADES, Univ. Maryland, UCLA Neptune (2 versions), and SPARC (INFN-LNF). The current generation gun for FINDER calls for continued to upgrades to the design. The improvements on this new gun, some of which are echoed in the LCLS photoinjector design, are the following:

- The frequency separation between π mode and 0 mode is increased up to 12.33 MHz from ~3.2 MHz.
- The full cell tuners are removed.
- The laser ports on the half cell are removed.
- Cooling system was enhanced with wider water path and thicker outer wall.
- Support rings are not brazed to the cavity.

These improvements are discussed in this paper. The detailed beam dynamics and commissioning of the gun will be discussed elsewhere [4]. The measurement of the emittance compensation solenoid will also be presented in the conference [5].

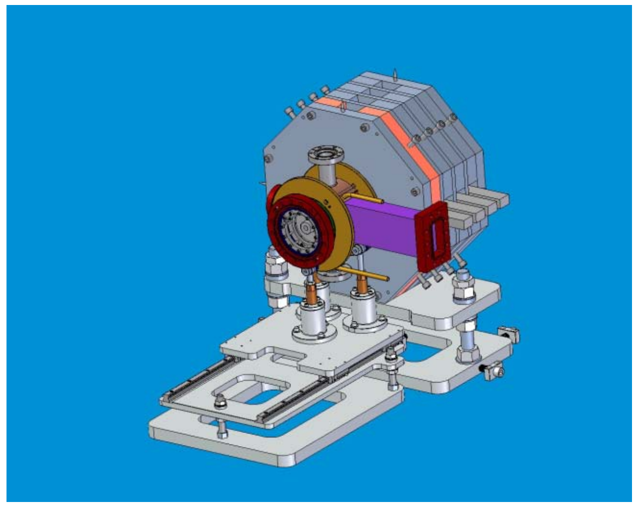

Figure 1: Finder Photoinjector RF gun and its emittance compensation solenoid.

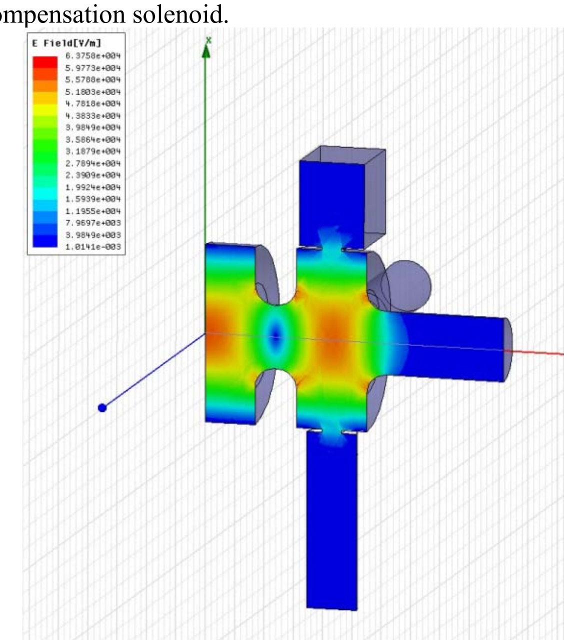

Figure 2: Amplitude of the electric field in the FINDER gun cavity simulated by HFSS.

FINDER GUN OVERVIEW

The design of the FINDER gun is based on immediate preceding design developed for the gun employed in the SPARC project [1, 2]. The cathode plate can be deformed

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slightly by pushing or pulling it to tune the half cell frequency around 6 MHz. The resonant frequency is at 2854.5 MHz due to the peculiarities of the S-band RF systems used at LLNL. The HFSS RF simulation program was used for the 3D design of the structure (Figure 2). In terms of fabrication, the cells were machined at UCLA, brazed at SLAC, and the final measurement took place in LLNL.

The solenoid has four coils with a large cooling manifold sandwiched between solid conducting coil layers. Each position of them is adjustable in the transverse direction by the four bolts. Separate powering of the coils allows flexibility in choosing the magnetic center of the emittance compensating solenoid lens.

IMPROVEMENTS

Large mode separation

The biggest improvement of the new gun is the large mode separation $\Delta f_{\pi-0}$ between π mode and 0 mode. The gun with wider mode separation can produce lower emittance beam than that with narrower one [4]. The 0 mode can be excited at the same time as π mode due to the finite Q-width of the unwanted resonance; the relative field amplitude excited in the 0 mode is approximately $f_0 / \Delta f_{\pi-0} Q$. The field component excited in the 0 mode may introduce excessive momentum spread in the beam in the post-gun region, and degrade the beam emittance. The field can be obviously suppressed by placing the 0 mode frequency far from the driving frequency.

To obtain large mode separation, the diameter of the half cell iris was increased from 24.99 mm to 34.28 mm, and the iris thickness was also decreased by 2 mm.

The reflection response S_{11} of the cavity was measured by a vector network analyzer to identify the mode frequencies during the tuning and brazing process. The final mode separation obtained was 12.33 MHz, as shown Figure 3.

Other measured properties of the FINDER RF gun cavity are listed on Table 1.

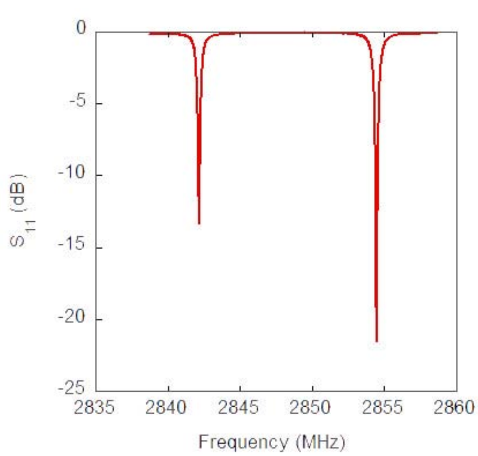

Figure 3: Mode separation of the Finder gun.

Removal of the full cell tuner

Two problems arise from the scheme of penetrations employed in the initial versions of the 1.6 cell gun. First the coupling slot/opposing dummy slot are accompanied by tuners rotated by 90 degrees azimuthally. This produces an RF quadrupole which can degrade the emittance, as it is coupled to the solenoid field. The resulting skew coupling is the obvious source of emittance growth. Further, the tuners have been shown to unequivocally result in breakdown problems. A direct test of this at UCLA showed that such breakdown, observed at 4 MW in the original Neptune gun, could be immediately mitigated to allow 10 MW operation by making changes that resulted in tuner removal [6].

The tuners on the full cell are now replaced by vacuum ports and now it has three vacuum ports and one RF feeding slot. This makes the field inside the full cell symmetric reducing the quadrupole components, and also improves vacuum speed of the cavity. As a result of removing the tuners, the full cell can no longer be tuned except for the temperature control. We paid special attentions on the machining of the full cell. The field along the axis was measured by bead pull method [7], after the resonant frequency was tuned to the operation frequency by the cathode deformation and the temperature control. The cavity tune was achieved at 42 °C without full cell tuners.

Table 1: RF cavity measurement

Resonant frequency	2854.5 MHz
Mode separation (0 to π mode)	12.33 MHz
Q	13,500
VSWR	1.14
Running Temperature	42 °C
Full cell probe coupling	-65.2 dB

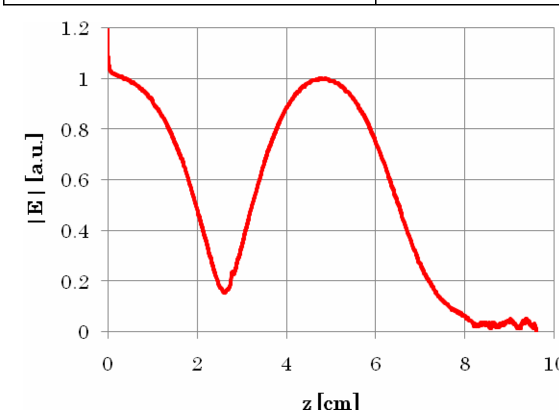

Figure 4: Normalized electric field along the beam axis measured by the bead drop method.

As shown in Figure 4, the field balance was very good. The initial jump of the field occurred by the bead touching the cathode. The ratio of the half cell field to the full cell field is almost unity.

Other modifications on the gun

The two laser ports in the half cell are also removed to achieve both laser and RF symmetry. In this case the photocathode drive laser is injected nearly normally.

The diameter of the cooling path was increased to enhance the cooling capability, thus enabling 20 Hz repetition rate with a 3 microsecond RF fill and a power of > 8 MW. The thickness of the outer wall is also increased to obtain a higher thermal capacity.

We do not braze the gun support rings to avoid the possible deformation of the cavity, which was experienced during brazing attempt in a commercial shop. The new gun support is composed of a mechanical ring clamp. Rings are made of stainless steel while the cavity is made of OFE copper. This scheme was introduced to address potential problems in brazing that arise due to the difference of thermal properties of the radiation dominated rings, and the more compact Cu gun body. These two pieces may have temporarily differential thermal expansions or contractions, which could lead the SS rings to squeeze the cavity thus deforming it.

Symmetrize the openings of the solenoid shield.

The symmetry of the emittance compensation solenoid is also improved. The previous solenoid has only dipole symmetry, but new solenoid has quadrupole symmetry. The measured skew and the normal quadrupole focal lengths for 5.6 MeV are -230 m and -30 m, respectively [5]. The SPARC solenoid was measured to have a skew focal length of 8 m, assuming that the normal quadrupole focal length is infinite (i.e. it has the perfect symmetry to the normal quadrupole.).

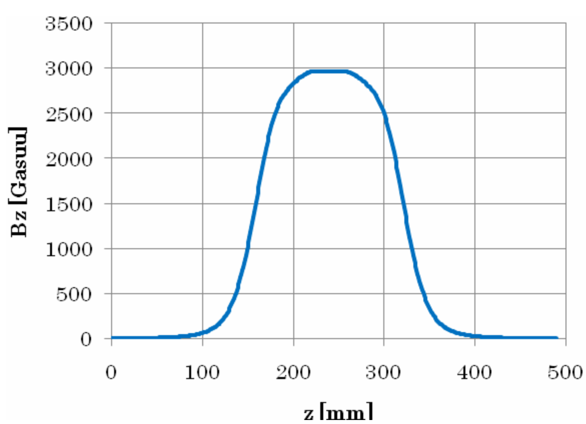

Figure 5: Magnetic field of the FINDER solenoid measured by Hall probe.

The B_z profile of the solenoid was measured by a single-axis Hall probe at the solenoid current of 150 A. The scan was made at 8 points over 20.0 mm for x, 7 points over 17.14 mm for y, and 50 points over 490 mm in z, and thus the total scanned points were 2800. The local center position was determined as the maximum or minimum on each x-y plain at every measured z position. After a set of measurement, the coils position was tuned by the tuner bolts to adjust the field center. B_z along the center of the solenoid is shown in Figure 5. The maximum was 3000 Gauss. The skew and normal quadrupole components were also derived from the measured data [6]. The focal lengths for 5.6 MeV beam for the skew and the normal components, derived from this measurement indicate a contribution to the transverse emittance of less than 1 mm-mrad

SUMMARY

The FINDER gun has developed to have a large mode separation. The aperture of the half cell iris was increased and the measured separation was 12.33 MHz. The symmetry of the cavity has been improved by removing the full cell tuners and the laser ports in the 0.6 cell. The field balance of the full cell and the half cell was tuned to near unity without the aid of full cell tuners. Added cooling has given the option of 20 Hz operation, which is a significant advantage for an electron source dedicated to ICS radiation production. The symmetry of the emittance compensation magnet is also improved by adding the openings on the iron yoke. The resultant focal lengths of the skew and the normal quadrupole components are -230 m and -30 m, respectively.

FUTURE PLANS

The FINDER photoinjector has been installed in the beam line at LLNL, and high power commissioning has been carried out [4]. Cathode illumination by the drive laser to give beam, and then first ICS light, is planned by October 2007.

In the future, we are moving to develop a 100 Hz gun in the as the next step. To operate high repetition rate, pulsed heating on the coupling iris to the waveguide is one of the big problems. It requires changing the iris shape, perhaps adopting the LCLS injector Z-coupling scheme [9].

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