A HIGH GRADIENT 17 GHz RF GUN FOR THE PRODUCTION OF HIGH BRIGHTNESS ELECTRON BEAMS

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Abstract

We report on the design and construction of a new, tuneable, 1.5 cell 17 GHz RF gun and improved beamline. Emittance compensation in the new beamline is achieved with a 6.5 cm long, 0.5 T solenoid placed immediately after the RF Gun. Simulations predict a normalized rms emittance of 0.5 πmm-mrad for a 1 ps, 0.1 nC, 2.4 MeV beam. Emittance measurement diagnostic slits have also been designed and constructed. This gun will operated with 50 ns, approximately 5 MW, pulses from a 17.13 GHz klystron amplifier built by Haimson Research Corp. Initial cold tests of the new gun have been performed. The on axis field profile of the RF gun has recently been measured using a "bead hang" technique developed at MIT to forgo the need of a hole in the cathode as required by the more conventional "bead pull" measurement. A balanced field profile was obtained.

1 INTRODUCTION

The MIT 17 GHz photocathode RF gun is a 1.5 cell electron accelerating structure consisting of two coupled TM_{010} like cavities excited by side wall coupled microwaves from a WR-62 waveguide (Fig. 1). The goal of the MIT 17 GHz RF gun experiment is to examine the advantages of operating an electron source at high frequency, and thereby produce an ultra-high quality electron beam capable of meeting the demands of future applications such as short wavelength free electron lasers. The scaling with RF frequency of the quality of the beam from an RF gun has previously been derived [1]. This study suggests that the emittance of the beam will scale inversely with RF frequency provided the charge and size of the beam are also scaled inversely with RF frequency (constant peak current) and the accelerating gradient is increased proportional to frequency. This implies a quadratic increase in the beam brightness.

Initial experiments demonstrating beam production have been completed at MIT and are summarized in the next section. This was the first RF gun experiment to operate above 3 GHz. In order to demonstrate an ultra-high brightness electron beam, a new emittance compensated RF gun and beamline with emittance diagnostics will begin operation in the near future.

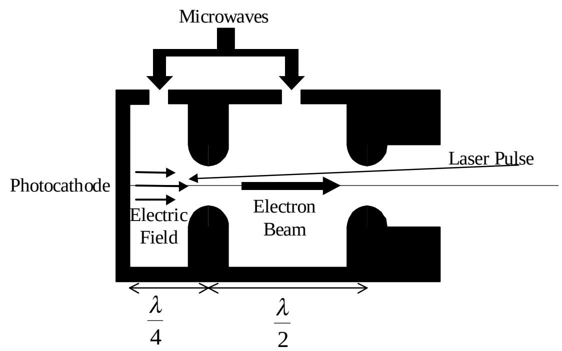

Figure 1: Schematic of RF Gun

2 OPERATION OF ORIGINAL GUN

The original MIT 17 GHz RF gun consists of 3 pieces of OFHC copper which are clamped together and attached to WR-62 coupling waveguide. Cold tests of the gun revealed a π mode frequency of 17.145 GHz, a coupling coefficient β = 1.56, and an ohmic Q = 2700. More recent field profile measurements (see section 4) showed that the electric field strength in the half cell is about 15-20% larger than that in the full cell. In high power tests, the gun was driven with up to 8 MW of RF power from the 17 GHz relativistic Klystron Amplifier built by Haimson Research Corporation [2], corresponding to peak accelerating fields of 300 MV/m. Breakdown in the RF gun occurring on some shots with incident power exceeding 5 MW, however, usually limited operation to a lower incident power and peak fields of 200-250 MV/m. The electron beam was produced by 1 ps, 20 μJ, 0.5 mm radius UV laser pulses created by frequency tripling 2 ps, 1.0 mJ, 800 nm pulses produced from a Ti-Sapphire regenerative amplifier.

2.1 Experimental Results

Results of beam measurements are listed in Table 1. These results have previously been reported in greater detail [3]. The bunch charge measurements (yielding values up to 0.1 nC) were made with a high speed Faraday cup placed downstream of the gun. The laser was injected into the gun with a prism placed inside the collector portion of the Faraday cup. The energy measurements were made with a Browne-Buechner [4] style magnetic spectrometer placed about 30 cm away from the RF gun. The measured rms energy spread at the position of the spectrometer is in good agreement with PARMELA [5] simulations of the RF gun and beam transport, and is consistent with an rms energy spread of about 1.5 % at the RF gun exit.

Table 1: Beam measurement results

Parameter	Measurement
Bunch Charge	0.1 nC
RF Injection Phase	10 - 40 °
Initial Bunch Length	1 ps (Laser Measurement)
Initial Bunch Radius	0.5 mm (Laser)
Cathode Electric Field	≈ 200 MV/m
Beam Energy	1.05 MeV
Energy Spread (rms)	2.5% (at Spectrometer)

3 NEW GUN AND BEAMLINE

A new RF gun and beamline are in development in order to provide an emittance measurement demonstrating an ultra high brightness beam. The new RF gun is a 1 1/2 cell structure similar to the original gun, but is equipped with tuners in order to optimize field balance, allowing for maximum electron beam energies. The tuners consist of small plungers which retract from or fill up a small hole in both the half and full cells, but fall short of actually protruding into the cavity. This provides about 10 MHz of tunability.

The gun will be installed into the beamline shown in Fig. 2. Emittance compensation is performed with a 6.5 cm long, 5 kG peak field solenoid. The edge of the magnet will be placed 2.0 cm from the RF Gun cathode, resulting in a maximum magnetic field at the cathode of about 25 Gauss. The additional normalized emittance resulting from this magnetic field at the cathode is only 0.04 πmm-mrad for a 0.5 mm radius beam. The emittance will be measured by breaking the beam into individual beamlets using an emittance mask, made from laser drilled 70 μm slits in a thin (0.125 mm) tantalum foil placed about 200 μm apart The beamlets will then be imaged downstream of the mask in order to reconstruct the phase space.

It is expected from PARMELA simulations that a 0.1 nC, 1 ps, 2.4 MeV beam with a normalized rms emittance of 0.4-0.6 πmm-mrad can be produced with this experiment. For a 1 1/2 cell gun, peak accelerating fields of 350 MV/m will be required to obtain these parameters. In order to alleviate the necessity for such high fields, a 2 1/2 cell gun could be easily be inserted in the beamline, bringing the needed peak field value down to 218 MV/m. The normalized rms brightness of the beam, defined by

$$B = \frac{I_{peak}}{\varepsilon_n^2} , \tag{1}$$

can reach values of about 500 A/(πmm-mrad)^2. If this value is achieved, it will represent a significant improvement over previous high current electron injectors.

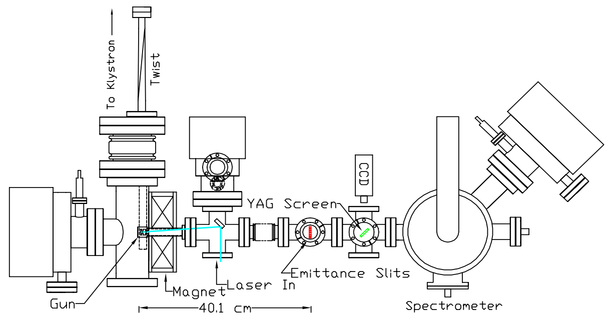

Figure 2: Schematic of New Beamline.

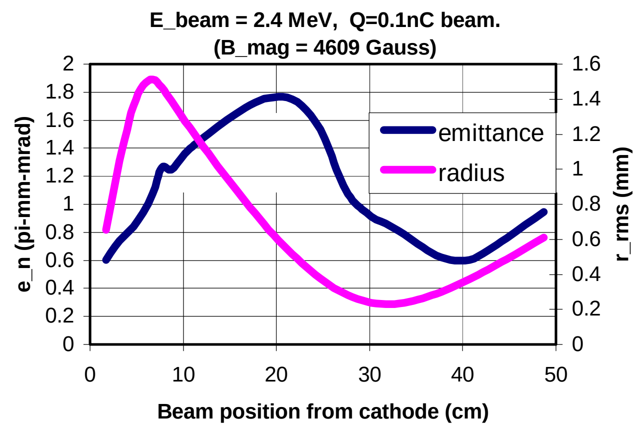

Figure 3: PARMELA Simulation of emittance compensation for 1 1/2 cell gun.

4 FIELD PROFILE MEASUREMENTS

In order to perform field profile measurements of the excited mode in the MIT RF gun, a "bead hang" method was developed. This is similar to "bead pull" measurements [6], but has a key difference in that the perturbing element is simply hung down into the RF cavity as opposed to being pulled all the way through it. The advantage of this method is that there is no need to have a hole in the cathode, allowing for the exact structure used in high power experiments to be measured. Ideally, the axial electric field profile in the gun can then be determined by mapping out the perturbation in the resonant frequency of the excited mode as a function of the position of the bead, i.e.

$$|E(z)|^2 \propto \frac{\Delta f(z)}{\alpha_{bead}} . \tag{2}$$

where α_{bead} is the electric polarizability of the bead.

In reality, the line used to hang the bead into the cavity also has a position dependent effect on the resonant frequency as a result of the fact that the bead is simply being hung as opposed to pulled all the way through. This non-local perturbation, which can be expressed as,

$$\Delta f_{line}(z) \propto \int^{z} \left|E(\xi)\right|^{2} d\xi \tag{3}$$

where the integral is along the length of the support line up to the position of the bead, should be subtracted out of the measurement in order to obtain accurate results. This is especially necessary for smaller, high frequency structures like the MIT 17 GHz RF gun in which the line will have a more significant effect. The measured value for the electric field profile is then given by

$$\left|E(z)\right|^{2} \propto \frac{\left(\Delta f(z) - \Delta f_{line}(z)\right)}{\alpha_{bead}} \tag{4}$$

Results of a bead hand measurement of the new cavity are shown in Fig. 4. The bead used in the measurement was a 0.5 mm long, 0.2 mm diameter piece of copper wire. The support line used in the measurement was a short piece of 76 μm diameter fishing line (1.5 lb. tensil strength). As expected, at the position of the iris between the half and full cell, the frequency perturbation due to the bead is zero.

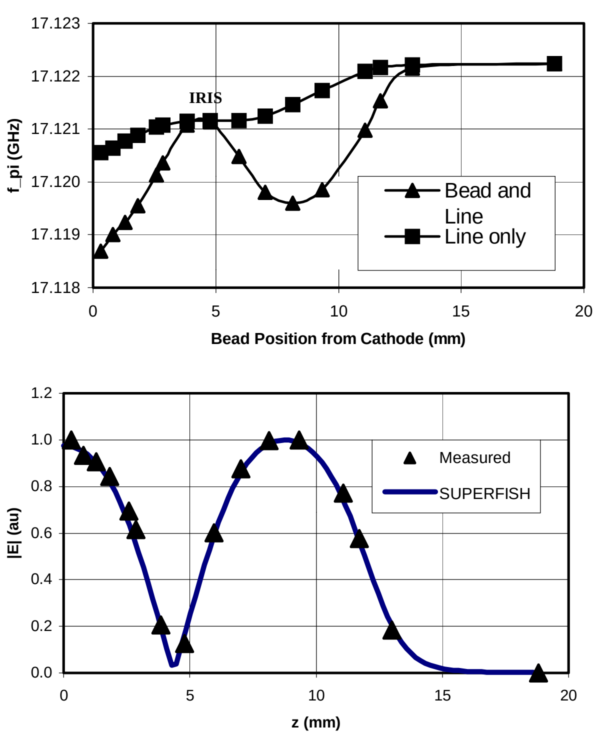

Figure 4: Measurement of the on axis field profile of the new RF gun.

Eventually, we plan to perform measurements of the azimuthal asymmetry of the field caused by the coupling holes. Initial measurements yield qualitative agreement with numerical simulations, with the value of E_z being slightly larger off axis at the azimuthal position of the coupling holes. Quantitative results, however, have proven difficult to obtain since a very large perturbation in the fields has been required in order to resolve the variations in the azimuthal dependence of the field.

5 CONCLUSIONS

A first round of experiments on a 17 GHz 1 1/2 cell RF Gun have been completed, demonstrating 1 MeV electrons with peak accelerating fields greater than 200 MV/m. A new, tunable, RF Gun has been designed and built, and the on axis field profile has been measured using a "bead hang" technique, demonstrating good field balance between the half and full cells. This gun will be installed in a new and improved beamline which includes an emittance compensating solenoid and a slit based emittance measurement scheme. We hope to demonstrate a record high quality electron beam with an rms normalized emittance $\varepsilon_n \approx 0.5\ \pi mm\text{-}mrad$ and peak current $I_{peak} \approx 100A$, corresponding to a rms normalized brightness of about 500 A/πmm-mrad. Operation will begin by June, 1999.

6 ACKNOWLEDGEMENTS

This research is supported by the U.S. Department of Energy.

7 REFERENCES

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