High Gradient Acceleration in a 17 GHz Photocathode RF Gun*

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Abstract

The physics and technological issues involved in high gradient particle acceleration at high microwave (RF) frequencies are under study at MIT. The 17 GHz photocathode RF gun has a $1\frac{1}{2}$ cell room temperature copper cavity with a peak accelerating gradient of about 250 MV/m. The anticipated beam parameters, when operating with a photoemission cathode, are: energy 2 MeV, normalized emittance 0.43π mm-mrad, energy spread 0.18%, bunch charge 0.1 nC, and bunch length 0.39 ps. The goal is to study particle acceleration at high field gradients and to generate high quality electron beams for potential applications in next generation linear colliders and free electron lasers. The experimental setup and status are described.

I. INTRODUCTION

To meet the stringent requirements set by future applications such as high-energy linear colliders and next generation free electron lasers, efforts have been made recently to create novel electron beam sources.[1] While existing RF guns operate 144 MHz to 3 GHz, a 17.136 GHz photocathode RF gun has been constructed and is currently under cold test at MIT.[2] The 17.136 GHz operation is very attractive despite potential technical difficulties and physics issues associated with high frequencies. It allows us to achieve a high accelerating gradient, to make the system compact, and to generate high brightness beams. In this paper, the status of the 17 GHz photocathode RF gun experiment is presented in detail. A general layout of the experiment is shown in Fig.1. It consists of three parts: (1) the RF gun cavity and the transport line (including the power source and the vacuum system), (2) the laser and timing system, and (3) the beam transport and diagnostic line. Each of these subjects is described successively in Sections 2, 3, and 4. Section 5 summarizes the status of the experiment.

II. RF CAVITY AND TRANSPORT LINE

A. RF Cavity and Waveguide Coupling

Figure 2 shows the vacuum assembly that houses the RF gun structure and the coupling waveguide. A vacuum of 10^{-9} Torr has been achieved inside the RF gun chamber. The peak accelerating gradient is chosen to be 250 MV/m, corresponding to a peak surface field around 300 MV/m.

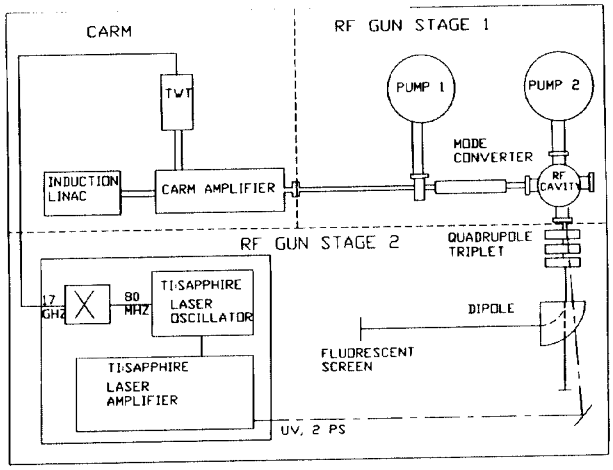

Fig. 1: Schematic of the 17 GHz photocathode RF gun experiment

The beam dynamics and the interplay between time-dependent RF forces, space-charge forces, and nonlinear RF forces have been studied using the simulation code MAGIC [3]. The main operating parameters at 17 GHz are summarized in Table 1.

Table 1: 17 GHz RFG Designed Beam Parameters

Peak accelerating gradient	250MV/m
Laser pulse length	1.4ps
Final bunch length	0.39ps
RF phase for laser pulse	12°
Current density	$6.7kA/cm^2$
Cathode radius	0.525mm
Bunch charge	0.1 nC
Emittance	0.43π mm-mrad
Energy spread	0.18%
Current	258A
Brightness	$1.43 \times 10^{14} \frac{A}{(mrad)^2}$

The TE_{10} waveguide mode is coupled to the cavity through two rectangular apertures, one on each cell of

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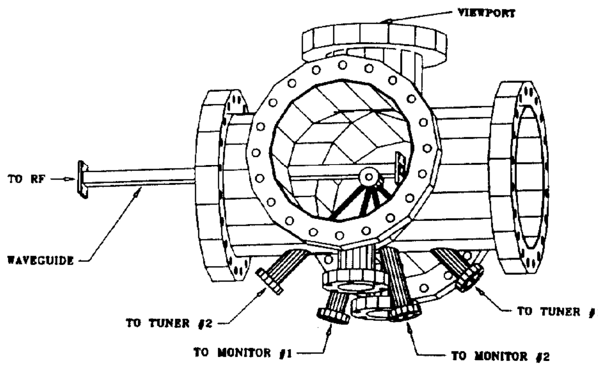

Fig.2: RF Gun Vacuum chamber. The gun structure is located at the center of the chamber.

the cavity, to excite the π mode resonance. An intensive study of this waveguide sidewall coupling scheme has been conducted both theoretically and experimentally.[4] We have cold tested both electroformed and machined/brazed OFHC copper cavities with similar results. The reflected power from the waveguide-fed RF gun cavities was measured using a network analyzer. Fig.3 shows the reflected power as a function of frequency of an untuned gun cavity. The two resonances are about 100 MHz apart and each cavity has a Q value of about 1000. Each cavity absorbs over 80% of the incident power.

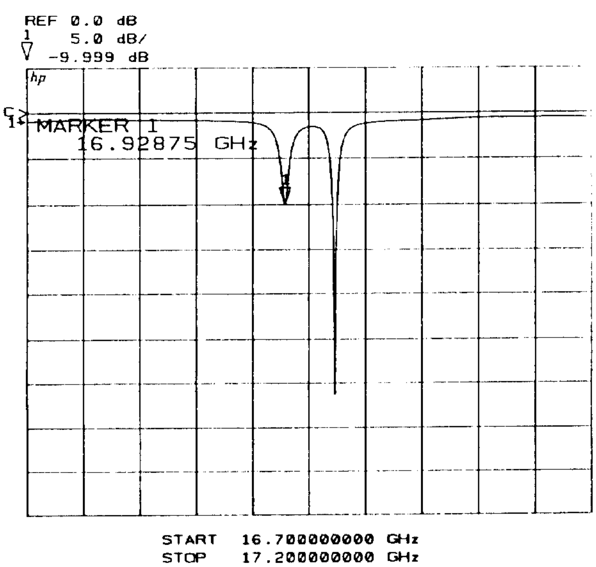

Fig. 3: Reflection as a function of frequency of an untuned gun structure

Figure 4 shows the reflection as a function of frequency after the gun cavities are tuned. The single resonance absorbs more than 90% of the input power. The theoretical modelling of the waveguide-cavity coupling is presented in a companion paper in this volume[4].

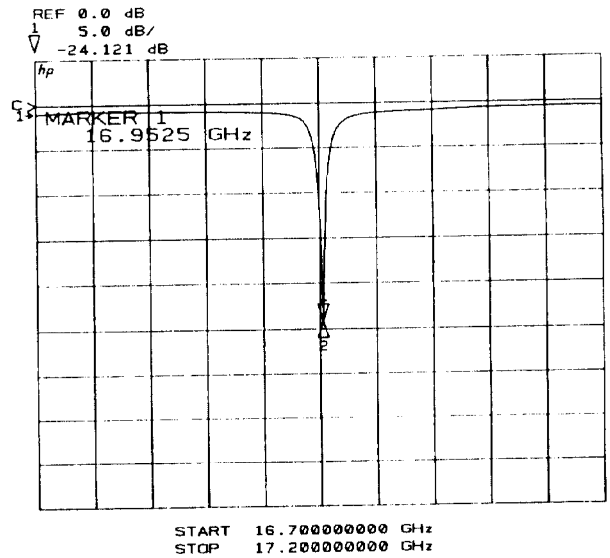

Fig.4: Reflected Power as a function of frequency of a tuned gun structure

B. RF Source and Transport

The power source used to feed the RF cavity is a gyro-amplifier under development at MIT [5]. The RF source will deliver 5-10 MW peak power in a pulse of 30 ns at a repetition rate of 10 Hz. The output RF is in a circularly polarized TE_{31} mode and must be converted to the TE_{10} mode in the rectangular waveguide that couples to the RF cavity. The RF transport line consists of a long overmoded 2" guide, a 2" to 1" taper, a TE_{31} to TE_{11} converter, a TE_{11} (rotating) to TE_{11} (linear) polarization converter, and a circular to rectangular transition. The line is followed by a dual directional coupler, a high-vacuum RF window, a flexible waveguide, and (optionally) an arc sensor. The TE_{31} to TE_{11} converter is under fabrication. The RF source is transit time isolated from the gun cavity by the 10 ft transport line.

The complete RF line, less the TE_{31} to TE_{11} converter, has been assembled and vacuum leak checked at 10^{-5} Torr. The VSWR for the flexible waveguide is 1.23. The VSWR for the high power window does not exceed 1.2 between 16.9 and 17.1 GHz. The efficiency of the mode converter is at least 98 %.

III. LASER AND TIMING SYSTEM

A. Laser

The parameters of the laser system are summarized in Table 2.

Table 2. Parameters of the Laser System

Wavelength	220-280 nm
Repetition rate	0-10 Hz (adjustable)
Energy	200 μJ
Energy fluctuation	$\leq \pm 10$ %
Pulse Length	<2 ps
Phase Jitter	<1 ps
Timing Jitter	<3 ns
Polarization	> 99 %
Beam Divergence	0.5 to 1 mrad
Beam Pointing Error	< 10 μrad
Mode-Lock Frequency	82 MHz

An Argon Ion pumped Ti:Sapphire laser oscillator produces a regeneratiely modelocked CW train of microjoule pulses which enter a pulsed Ti:Sapphire laser amplifier. The amplifier is pumped by a 1J Nd:YAG laser. The amplified IR pulse is then frequency tripled into the ultraviolet by an KDP/BBO combination and is directed into the RF cavity.

B. Timing

As shown in our simulation studies [3], the electron beam quality is strongly dependent on the RF phase of photoemission. The phase jitter is required to be less than 1 ps in our experiment. The highly stable Ti:Sapphire laser system serves as the system clock in the timing chain. The modelock frequency of 82 MHz is defined by the round-trip time of the laser cavity. The laser oscillator cavity mirrors are mounted on Invar tubes to minimize length variations. The 82 MHz signal is multiplied up by a solid state frequency multiplier (x 204) into 17 GHz to drive the RF amplifier chain.

IV. BEAM LINE AND DIAGNOSTICS

The beam line consists of a quadrupole triplet and a bending magnet. The 90° bend forms a point-to-point imaging system to be used for energy spread measurement. The position and the horizontal thickness of the fluorescent spot give the energy and the energy spread, respectively. The quadrupole triplet can also be used to measure the emittance: the bending magnet is switched off and the spot produced by the electrons on another screen positioned along the RF gun axis is observed. The gradient of one of the quadrupoles is varied in order to vary the spot size on the screen. A least-square analysis of the beam transverse dimension vs. the gradient in the quad gives the transverse emittance.

The program TRACE3d was used to obtain a preliminary design. Simulations of the same line with the program PARMELA show that the resolution of the spectrometer should be better than 0.1%. The charge will be measured with a Faraday cup. Several methods for measuring the bunch length are under investigation.

V. SUMMARY

A 17 GHZ photocathode RF gun experiment is under developments. The designed peak accelerating gradient on axis is 250 MV/m. The accelerating structure and the RF transport line have been fully cold tested. The first stage experiment involves powering the structure with high power 17 GHz microwaves. The goal of the initial experiment is to condition the cavity, and to study field emission and RF breakdown at 17 GHz.

The second stage of the experiment will integrate the laser system with the RF source and the gun system. Detail characterization of the beam property are planned The following systems will be integrated with the 17 GHz RF gun system in the second stage of the experiment. A UV laser system and the related timing system are being tested to generate picosecond electron bunches through photoemission from the cavity wall. Successful acceleration of these bunches under high field gradient will provide high brightness electron beams suitable for applications in next generation linear colliders and in short wavelength free electron lasers.

VI. REFERENCES

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