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Progress on the hybrid gun project at UCLA

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Abstract

UCLA/INFN-LNF/Univ. Rome has been developing the hybrid gun which has an RF gun and a short linac for velocity bunching in one structure. After the cavity was manufactured at INFN-LNF in 2012, tests of the gun was carried out at UCLA. The field in the standing wave part was 20 % smaller than the simulation but the phase advance was fine. The cavity was commissioned successfully up to 13 MW. The beam test was performed at 11.5 MW and demonstrated the bunch compression.

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Keywords: RF gun; hybrid photoinjector; bunch compression; high brightness beam.

1. Introduction

To obtain a high brightness beam, the beam must be low emittance and high current, because the beam brightness is defined as $B \propto I / \varepsilon_x \varepsilon_y$, where I is the beam current and ε_x, ε_y the beam transverse emittance. To achieve this, RF-based electron accelerators usually consist of a photocathode RF gun and bunch compressors, for example, LCLS at SLAC [1]. A photocathode RF gun can produce low emittance beams with proper emittance

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compensation [2-4]. The bunch compression is achieved by either magnetic chicane [5] or velocity bunching [6] to produce high current beams. Thus, high brightness beams can be obtained at photoinjectors.

The typical BNL/SLAC/UCLA 1.6-cell RF gun has two standing wave cells in it and requires about 6 MW at S-band to operate at 100 MV/m peak accelerating field. Because the standing wave structure causes large RF reflection at the start and after the end of filling, it is important to prevent the reflection from damaging the klystron and RF windows. A circulator is usually installed between the klystron and the gun. However, there are no high power circulators at higher frequency, such as X-band. If the higher frequency photoinjector is needed, this problem must be resolved. The hybrid gun is one of the solutions.

The hybrid gun has a traveling wave structure axially coupled with 1.55-cell standing wave RF gun. The image of the gun cavity is shown in Fig. 1. The structure is fed through the dual feed coupler at the input coupler. The majority RF power goes to the traveling wave section and only 8 % or -11 dB of that is delivered to the standing wave section. As a result, the RF property of hybrid gun is almost the same as a pure traveling wave structure. Therefore, there is no typical RF reflection at the hybrid gun. To serve as the high brightness beam source the length of the coupling cell is designed to put the beam at a zero-crossing in the linac so that the beam can get the energy chirp for the ballistic bunch compression. There are a lot of applications of this compact high brightness beam source, and one example is the relativistic, ultra-fast electron diffraction [7].

UCLA, INFN-LNF, and Univ. Rome have been developing the hybrid gun [8, 9]. The S-band cavity was manufactured at INFN-LNF in 2012, and the tests of the structure have been performed at UCLA. In this paper, we report our most recent results.

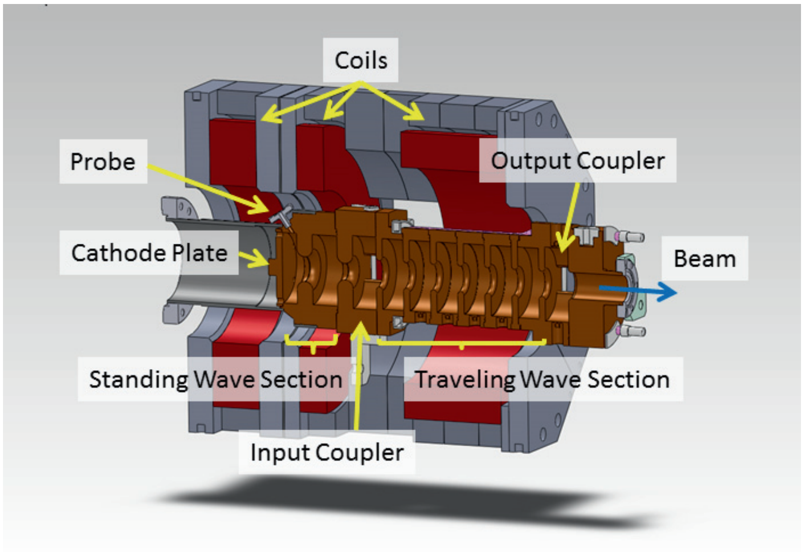


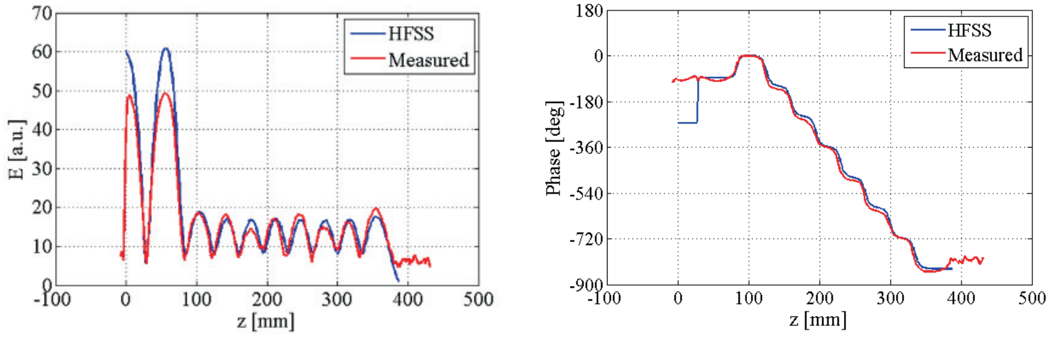
Fig. 1. CAD image of the hybrid gun and its solenoid.

2. Cold Test

The field along the axis was measured with Steele method [10]. In Fig. 2(a). the measured field amplitude was normalized so that the amplitude at the input coupler is equal to that of the simulation result. The amplitude in the standing wave part was about 20 % smaller than that of the simulation from HFSS [11]. To understand this discrepancy, the loaded Q was measured on a network analyzer. The measured loaded Q was found to be 11,000 while the simulation used 13,000. The unloaded Q calculated using SUPERFISH [12] was 15,400. There are two possibilities. One is the coupling error. This structure, however, increase the field with lower Q. So, this is not the reason. The other is the higher resistivity of the cavity. The difference in the loaded Q can be translated as 18 %

larger surface resistivity. This happened due to the oxidation of the cavity, because the cavity was exposed to air for several months.

The phase advance (Fig. 2 (b)) agreed with the simulation well, because it demonstrated the 90-deg phase advance between the second standing wave cell and the input coupler.



(a) (b)

Fig. 2. The electric field measurement along the beam axis. a) The field amplitude. b) The phase advance.

3. Beam Test

The high power test and the beam test were held at Pegasus Laboratory at UCLA. Although limited by an aging klystron The commissioning was successful up to 13MW with a 3.5usec pulse width operating at 1 Hz.

We built a short beamline (Fig. 3) at Pegasus Laboratory at UCLA and operated at 11.5MW RF input power. The drive laser is third harmonic of a Ti:Sapphire laser and we have a pulse stretcher in UV.

The beam charge was measured with the faraday cup at the straight end of the beamline. The available charge in the experiment was limited by laser power and UV optics, and we could obtain about 1 pC in this experiment. There were two known problems in UV optics. Limits to the laser power were also due to the pulse stretcher transmission efficiency of 20% and the limited aperture for the cathode imaging. Resolving these problems will increase the charge available. A typical result of the charge measurement is shown in Fig. 4.

The beam energy and the energy spread was measured at the 45-degree bend round dipole and shown in Fig.5. The positive slope in Fig. 5 (a) means that the beam got energy chirp to compress the bunch as the particle in the head has less energy than those in the tail.

The bunch length was measured by using the 9.6-GHz deflecting cavity which was located at 1.5-m downstream from the cathode. The resolution of this monitor was about 100 fs in this experiment. As shown in Fig. 6, we can see the bunch compression at different launching phases.

Some simulations were performed to understand those results. The beam dynamics was simulated by using PARMELA [13]. The bunch charge was 1 pC. The initial bunch length was assumed to be 1.5 ps. The peak electric field in the standing wave section was 29 MV/m. The average acceleration in the traveling wave part were varied by 7.6, 7.8, 8.0 MV/m, while 8.3 MV/m was expected from the measurement at the low level as shown in Fig. 2. The simulation and the measured data roughly agreed, although there were small difference in the energy measurement and expected accelerating field in the traveling wave structure.

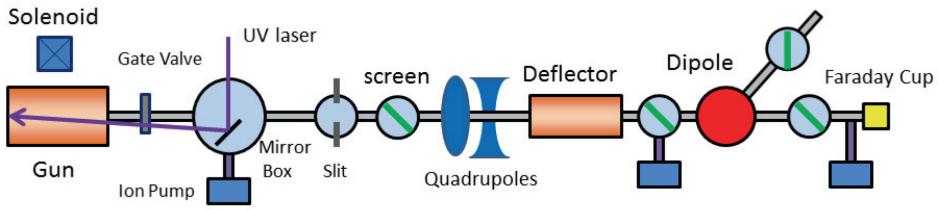


Fig. 3. The schematic view of the beamline.

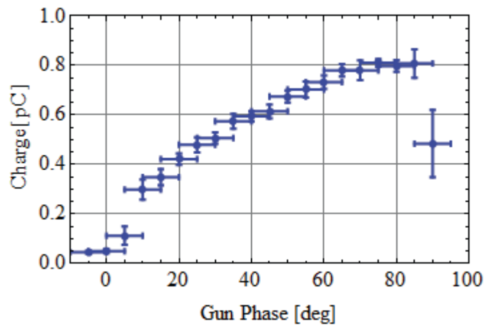
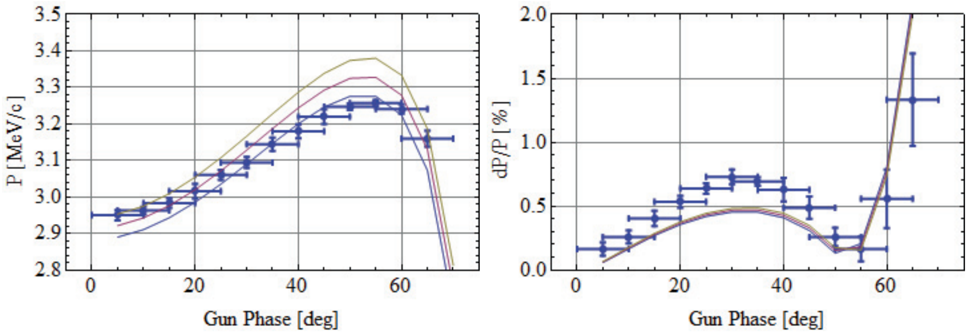


Fig. 4. The charge measurement as a function of the gun phase.



(a) (b)

Fig. 5. The measurement and PARMELA simulation of (a) the energy and (b) the energy spread as a function of the gun phase. The measured data are displayed as points with error bars. The three lines are simulation results with different accelerating field 7.6, 7.8, 8.0 MV/m from the bottom in (a) in the traveling wave section while the peak field in the standing wave section was fixed to 29 MV/m. There are also three lines in (b) but no clear difference can be seen.

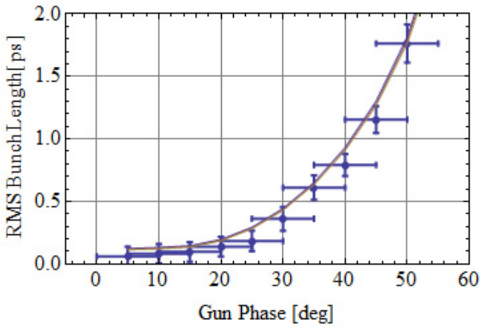


Fig. 6. The bunch length measured as a function of the gun phase. The points with error bars are the measured data and the line is the result of the simulation. The simulation results were obtained under the same condition as Fig. 5. The line actually consists of three lines but seems identical.

4. Summary

The results of the tests of the 'Hybrid Gun' which UCLA/INFN-LNF/Univ. Rome has been developing are reported The measured field strength in the standing wave structure was 20 % smaller than expected but the phase advance was good. The gun was commissioned up to 13 MW 3.5 μs at 1 Hz. The bunch compression was demonstrated with sub-pC beams.

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