CHARGE AND WAVELENGTH SCALING OF THE UCLA/URLS/INFN HYBRID PHOTOINJECTOR*

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Abstract

The SW/TW hybrid photoinjector is being developed at UCLA, INFN/LNF, and University of Rome. The hybrid gun has SW cells and TW cells in one structure. It can produce the low emittance and high peak current beam. PARMELA simulation showed the emittance and the bunch length were 2.8 mm.mrad and 0.16 mm, respectively. With the charge and frequency scaling law of the photoinjector [1], low charge and higher frequency case were also calculated.

INTRODUCTION

The photoinjector with a BNL/SLAC/UCLA 1.6-cell RF gun has long been studied [2, 3], and now it became a standard of the low emittance beam production. The emittance is good, however, the bunch length is not short, and it is frequently required to be compressed. The hybrid gun can produce the low emittance and short beam in one structure.

The hybrid photoinjector consists of one accelerating structure which has both of standing and traveling wave cells (Figure 1). A standing wave structure is axially coupled to al traveling wave structure. It has a half cell and a full cell and acts as RF gun to produce low emittance beam. The beam is compressed in traveling wave structure by velocity bunching. Because the RF power is fed into the traveling structure, there is no reflection at the input port. Thus, it can omit a circulator which an RF gun generally requires. This feature enables to build a photoinjector at X-band frequency where no circulators at high power have been invented.

The study of the hybrid RF structure is detailed elsewhere [4, 5].

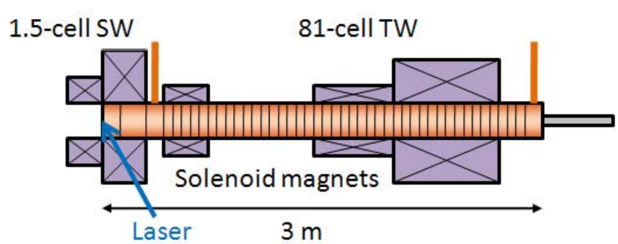

Figure 1: Schematic of the hybrid photoinjector.

S-BAND HYBRID PHOTOINJECTOR

The main parameters of the S-band hybrid structure are listed on Table 1.The standing wave (SW) section has a half cell and full cell, and it is operated at π mode. The length of the half cell is quarter of the RF wavelength, which is shorter than that of the 1.6-cell RF gun. This is because this guns accelerating field is as low as 60 MV/m and it takes more time to go through. The length of the input coupler is $(1/4+1/6)\lambda$ to put the beam at 0 degree for the velocity bunching as its phase is advanced by 90 degree to the full cell. The TW section has 81-cell 2π/3-mode structure, and the average accelerating gradient is 13.5 MV/m.

As shown in Figure 1, there are five solenoids, including the backing coil, at the hybrid structure. The first two solenoids stay around the SW section. The waveguide prevents to put one big solenoid. Due to the laser port, the first solenoid became relatively large to get sufficient field. The third and fourth solenoids keep the beam size small after the beam is focused by the upstream solenoids. They also control the position of the emittance minimum. The field of the latter solenoid have larger field as the beam is accelerated. Figure 2 shows the solenoid field along z axis.

Table 1: Main properties of the hybrid photoinjector

Resonant frequency	2.856 GHz
SW cavity mode	π mode
TW cavity mode	2π/3 mode
Peak Field in SW	60 MV/m
Average field in TW	13.5 MV/m
Cell number of TW	81 cells
Total length	3.m

BEAM DYNAMICS

PARMELA was used to calculate the beam dynamics. 10 k particles were used in each simulation.

The distribution of the input beam was uniform and rectangular in both of the radial and longitudinal direction. The radius was 1 mm, the length 10 ps, and the charge 1 nC. 0.98 mm.mrad of the cathode emittance was included.

Figure 3 shows the typical evolution of the rms beam envelope, the normalized emittance, and the bunch length. The beam was focused by the first solenoid and maintained its size under the field of the downstream magnets. The emittance had two minimum, and we usually look at the second one. The bunch length was

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initially spread by space charge force as other. Soon after the beam entered into the TW section, it began to bunching. Earlier injection makes stronger bunching. If the beam suffers the over bunching, the minimum emerged around 1 m. The beam parameters are listed on Table 2.

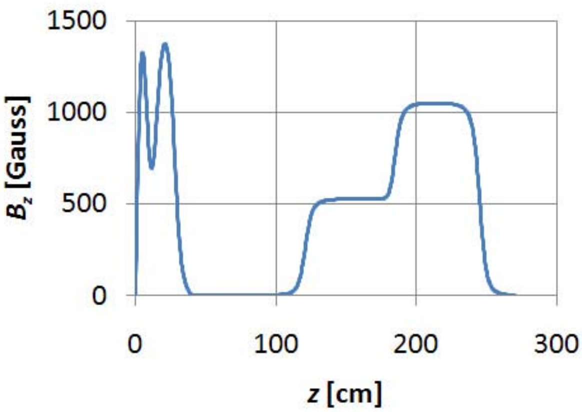

Figure 2: B_z along the axis calculated by using POISSON. The field was made by the solenoid around the hybrid structure.

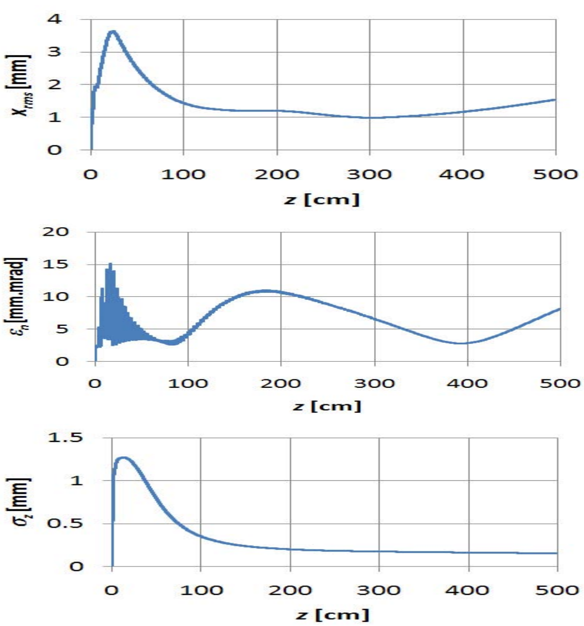

Figure 3: The evolution of the rms beam envelope (top), the normalized emittance (middle), and the rms bunch length.

Injection Phase Scan

The injection phase scan was made and the results are in the Figure 4. The emittance was picked at the second minimum while the bunch length was at 4 m of fixed position. The minimum bunch length was 0.10 mm at 46 degrees but the emittance was 6.5 mm.mrad. If you can guarantee the bunch length, 0.16 mm and 2.8 mm.mrad at 50 degrees may be better.

Table 2: Beam parameters of the hybrid photoinjector

Initial beam shape	Uniform, rectangular in r and z
Initial beam radius	1 mm
Initial beam length	10 ps
Injection phase	50 deg
Beam energy	21.1 MeV
Energy spread	2.3 %
Charge	1 nC
Bunch length	0.16 mm
Normalized emittance	2.8 mm.mrad

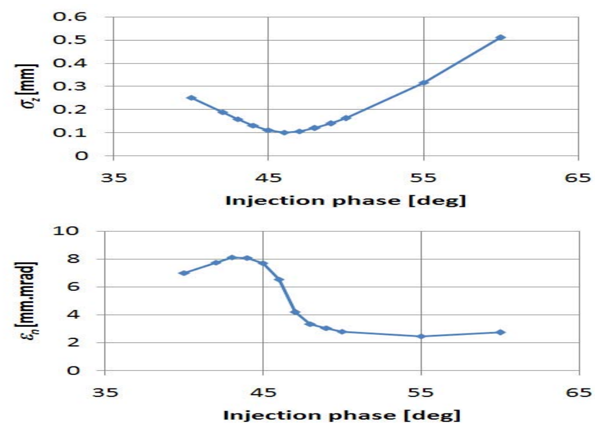

Figure 4: The rms bunch length (top) at 4 m and the normalized emittance at the second minimum (bottom) as a function of the injection phase of the beam at the cathode.

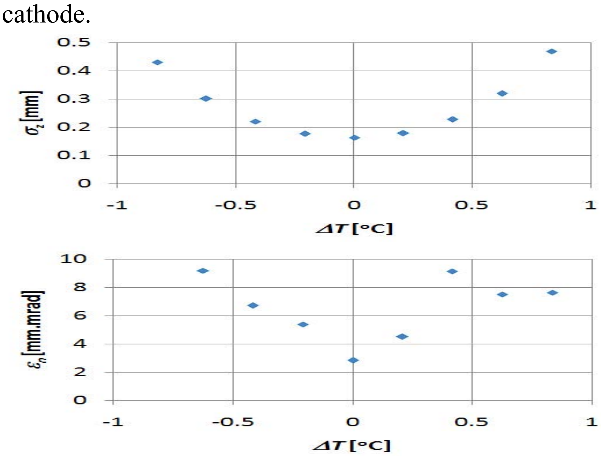

Figure 5: Temperature stabilities of the rms bunch length (top) and the normalized emittance (bottom). Both are the value at 4 m.

Temperature Stability

The amplitude and phase of the SW section are sensitive to the temperature as a high-Q cavity. Their variations were calculated by the HFSS as a function of the frequency, and they are converted at the rate of 48kHz/°C. Those values were put directly into the PARMELA simulation. Figure 5 depicts the effect to the

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beam dynamics. The emittance was more sensitive than the bunch length. The emittance became 4.5 from 2.8 mm.mrad by 0.2 °C rise while the bunch length was 0.16 to 0.18 mm.

Position Stability

The effect of the offset on the cathode was simulated. The bunch length did not show big change. The emittance degradation was 3.3 to 4.2 mm.mrad with 0.2 mm of the offset.

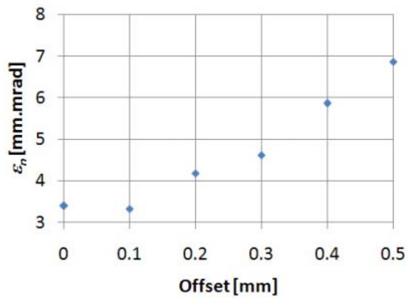

Figure 6: The effect of the beam position offset on the cathode. The normalized emittance was calculated at 4m.

Charge Scaling

The simulation of the various charges was performed according to the scaling law. The bunch size was scaled with $Q^{1/3}$. If the space charge is dominant in the emittance, the scaling factor is $Q^{2/3}$. The factor for the bunch length is $Q^{1/3}$. In Figure 7, PARMELA simulation and the simple estimation were shown. Although there is small deviation from the estimation, it shows good agreement with the scaling law. The emittance and the bunch length of 1-pC beam were 0.019 mm.mrad and 8.8 µm, respectively.

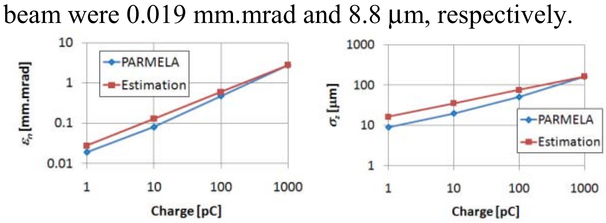

Figure 7: The charge scaling. Simple estimation was made by the factor of $Q^{2/3}$.

Frequency scaling

Frequency scaling was made with frequency scaling law. The field strength is proportional to the frequency, and the length and charge to the inverse of the frequency. They are well agreed with the law as shown in Figure 8. The emittance and the bunch length of 250 pC at 11.424 GHz were 0.79 mm.mrad and 43 µm, respectively. Coupled with charge scaling law, those of 0.25-pC beam were 0.005 mm.mrad and 2.2 µm.

SUMMARY

The beam dynamics of the SW/TW hybrid photoinjector was simulated by using PARMELA. The emittance and the bunch length of the beam with 1 nC were 2.8 mm.mrad and 0.16 mm, respectively. With 0.2 °C of temperature increase, they were 4.5 mm.mrad and 0.18 mm. Offset on the cathode did not affect the bunch length, but the emittance degrades by 0.9 mm.mrad for 0.2 mm of the offset. With 1-pC beam the emittance can be achieved as low as 0.0019 mm.mrad and the bunch length 8.8 µm. With frequency scaling law, X-band case are also calculated. The emittance became 0.79 mm.mrad and the bunch length 43 µm with 250 pC of the charge. When the charge was decreased down to 0.25 pC, the emittance and the bunch length were were 0.005 mm.mrad and 2.2 µm, respectively.

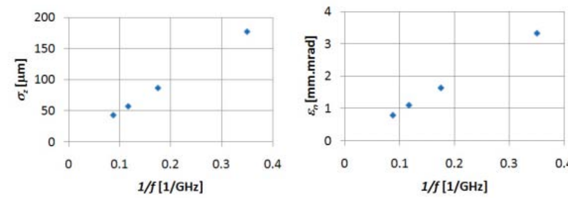

Figure 8: The frequency scaling. The frequencies are 11.424, 8.568, 5712, and 2.856 GHz from the left.

FUTURE WORK

Although the frequency scaling promised to produce good beams, it was still problems to realize it at X-band. The high field, which is four times higher than S-band, would be the problem. The heating and breakdown are the problem on the cavity design. As for the magnetic field, the conducting coils are no longer available because it requires too high current density. Permanent magnet is one of the solutions. It can produce higher field than conducting magnet.

In the S-band system, a shorter hybrid gun in combination with a TW structure is being considered for the normal injection of the driving laser. The laser ports on SW cells are obstacle to the solenoid as well as the emittance degradation problem.

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