A HYBRID STANDING WAVE-TRAVELING WAVE PHOTOINJECTOR

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Abstract

We present here the RF aspects and beam dynamics study of a hybrid photoinjector, where the cathode section is standing wave, and the section downstream of the third (coupling) cell is traveling wave. This device has strong RF advantages: there is a single feed, mitigating expense, and there is a nearly complete suppression of reflected power during the SW section fill. This, critically, allows one to scale these devices to higher field and frequency, which should dramatically improve beam brightness. Further, the beam dynamics are fundamentally changed, as the TW section acts as a velocity buncher. Thus one may produce low emittance, >kA beams at 20-30 MeV from such a device. We discuss here results of detailed beam dynamics simulations, and RF design and initial cold-testing.

INTRODUCTION

A standing wave / travelling wave hybrid photoinjector is being developed at UCLA/INFN/Roma Univ. The concept is to produce a short bunch by velocity bunching scheme with normal 1.6 RF gun and to make it a compact system. From the point of view with RF system, this is near a travelling wave structure, then there is almost no reflection at the input port. This enables to remove an isolator which is required for standing wave structures to protect the RF system from the reflected RF. This is very important when we consider making a high frequency, such as X-band, structure where no high power isolator is available.

We started with a hybrid structure with long TW velocity bunching section [1, 2]. But in this system, there is a problem about the injection of the driving laser. There were emittance compensation solenoids around the gun, so it was impossible to inject from the side of the cavity. We must inject the laser in front of the gun, This was good in the sense of the emittance. However , the length of the TW section was 3-m long. It would be very difficult to illuminate the cathode through it.

Now we moved the next design where the TW section was separated into two part to make a path to inject the laser (Figure 1). The length of the TW section on the gun was 6 cells. Since a solenoid should be around, the length seemed not to be shorter than it. And shorter gun has advantage in fabrication as well as the laser injection. The basic parameters of the gun is listed in Table 1.

This paper shows the beam dynamics of the separate TW hybrid system, the RF design of three-TW-cell model, and short description of the cold test for the old design.

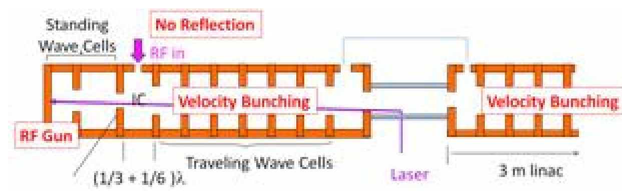


Figure 1: Schematic view of a hybrid photoinjector.

Table 1: Hybrid gun specifications.

Resonant frequency	2856 MHz
SW cavity mode	π mode
TW cavity mode	$2\pi/3$ mode
SW peak field	60 MV/m
TW peak (average) field	18.2 (13.5) MV/m
Number of TW cells	6 cells

BEAM DYNAMICS

The beam dynamics simulations were performed by using PARMELA [3]. There are solenoids around the gun and the following 3-m linac. We can control three paramters: laser injection phase, the gun solenoid, and the linac solenoid. We can also play with the initial bunch distribution and charge, here only 500 pC with the spot size of r=1.2 mm, 5 ps-long “beer can” distribution was performed though.

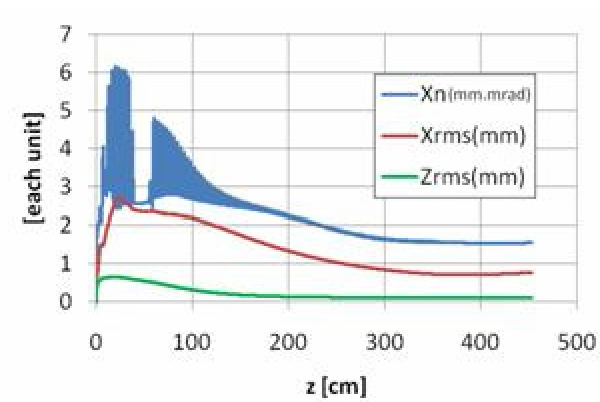


Figure 2: Evolution of the beam; the emitance in mm.mrad (blue), rms beam size in mm (red), and rms bunch length in mm (green).

Figure 2 shows a typical succeeding result. All of the emitance, beam size, and the bunch length were decreasing.

The relation of the injection phase with the bunch length and the emittance are shown in Figure 3 and 4, respectively. When the injection timing becomes earlier, the bunches get compressed stronger. The emittance became worse sharply before the shortest bunch at 42 deg. Since the over-bunching made the emittance worse seriously, it is safe to inject slightly later than the shortest timing.

The distribution of the longitudinal phase space at 44 and 50 deg are shown in Figure 5. As you can see in the 44 deg case, the bunch suffered strong energy modulation. This is because the space charge effect in the longitudinal direction. As the bunch was compressed to very short beam, the space charge became very strong. The head part was pushed forward, and as a result gains energy. The tail part lost energy, vice versa. If you care about the modulation, you should not go to the minimum case. When you compromise the bunch length, you can obtain better emittance and energy spread (Table 2).

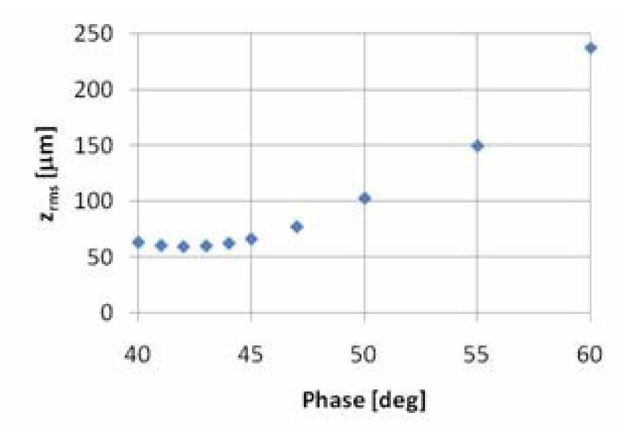


Figure 3: The bunch length with RF phase.

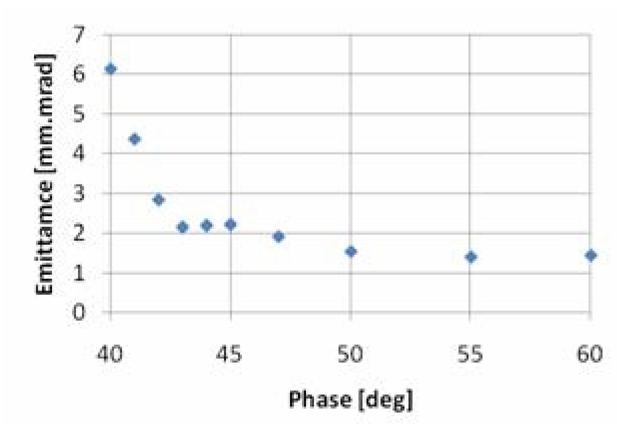


Figure 4: The normalized emittance with RF phase in the gun.

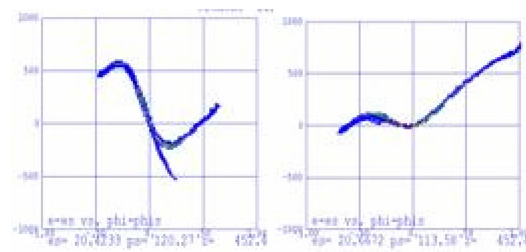


Figure 5: z phase space distribution at the RF phases of 44 deg (left) and 50 deg (right).

Table 2: Beam parameters at 4.5 m.

	44 deg.	**50 deg.**
Energy (energy spread)	20.4 (0.26) MeV	20.4 (0.17) MeV
Normalized emittance	2.2 mm.mrad	1.6 mm.mrad
Rms bunch length	63 µm	103 µm

RF DESIGN

We used HFSS for 3D RF design. Here the hybrid model which has three TW cells is examined. A single side feed type was designed before and now it was updated to dual feed couplers to cancel the quadrupole field in the couplers.

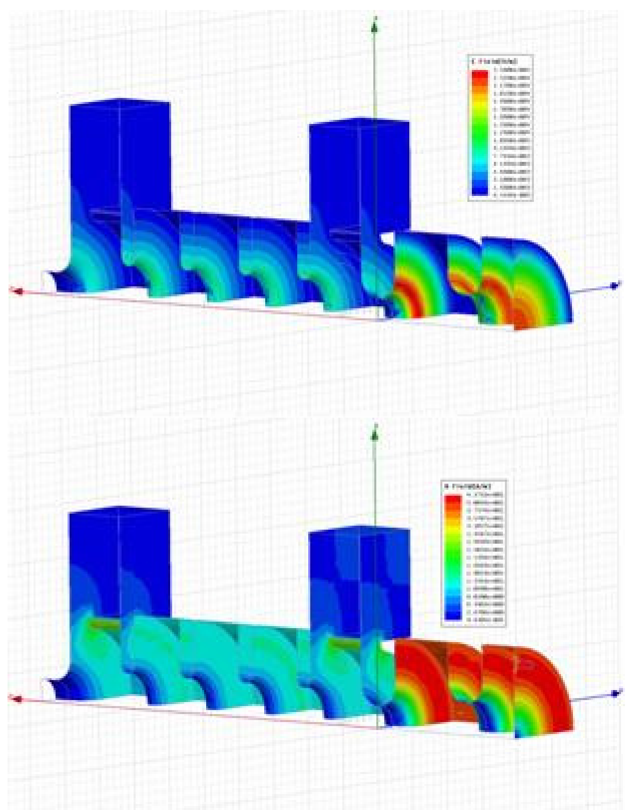


Figure 6: The 3 TW cell model with the surface electric field (top) and magnetic field (bottom).

The cavity shape with the surface fields are shown in Figure 6. The coupler slot shape was z-coupling to mitigate the local heating there.

The field amplitude and phase advance in the cavity are in Figure 7. The amplitude in the SW part was designed to be larger than compared designed gradient of 60 MV/m due to the filling time. Since the coupling of the SW part was very under-coupled (Table 3), the filling time was long compared to the normal case where usually the RF gun has higher than the critical coupling. At 2 μs after the RF injection, the field amplitude in the SW cavity was 88%. So the design amplitude should be 68.1 MV/m, the result here was 73.9 MV/m. This requires father modification.

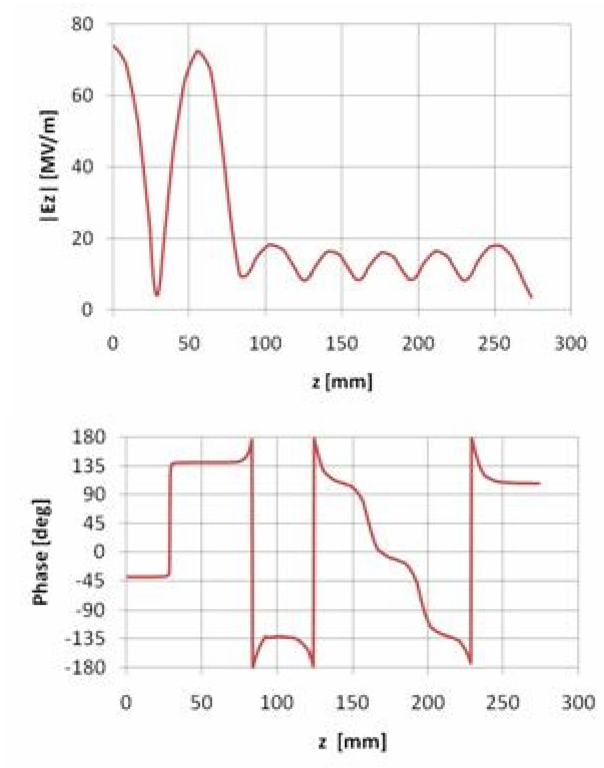


Figure 7: The amplitude of the electric field (top) and the phase (bottom) along the axis.

The S11 of this system is shown in Figure 8. The reflection at the operation frequency was -23 dB. The transmittance was 86 %. This residual power wll be transported to the following linac. The required input power and the output power are also listed in Table 3.

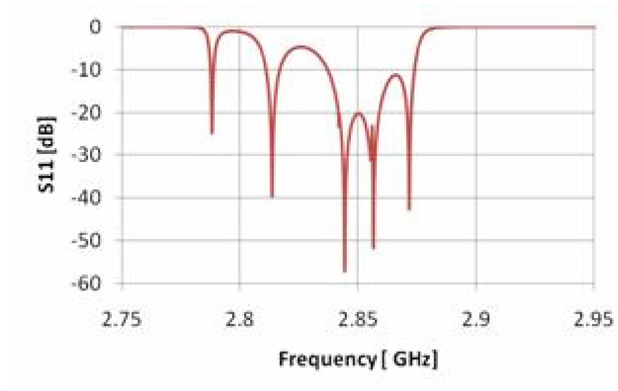


Figure 8: S11 of the hybrid model with tree travelling wave cells.

Table 3: Hybrid gun RF specifications

Input power	29.6 MW
Output power	25.4 MW
Q value	12,000
Coupling β	0.16
Filling time	1.3 μs
TW peak (average) field	18.2 (13.5) MV/m
Fraction of the voltage after 2 μs	88 %

The input coupler had racetrack shape to compensate the quadrupole field. The best distance from the beam axis to the centers of its circles were searched (Figure 9). 10 mm was found to minimize the effect.

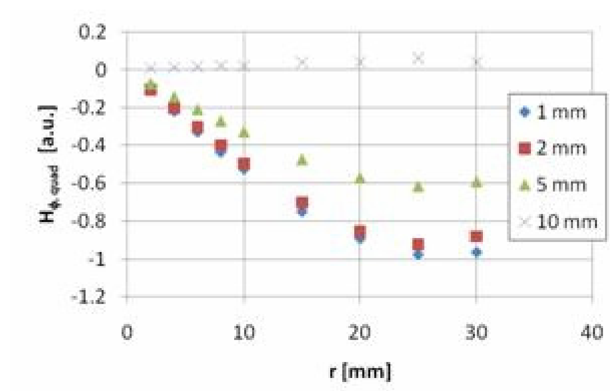
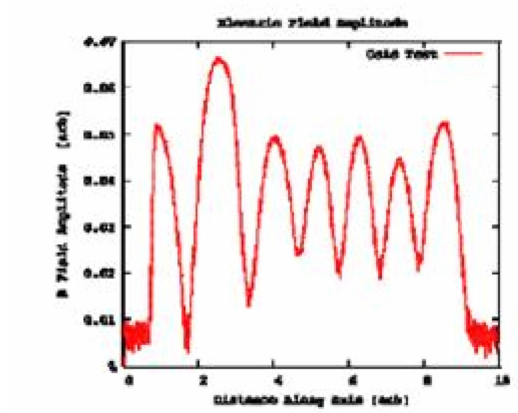


Figure 9: The quadrupole components in the dual feed couplers with changing the distance from the axis to the center of the racetrack circles.

COLD TEST

Cold test for the model with single side coupler were performed at UCLA and INFN. At the UCLA case the field in the SW part was smaller than expected. This is because the RF contact between the cells was not good. The clamping system was not insufficient. The same test was also held at INFN with better clamping system, and it showed better performance (Figure10).



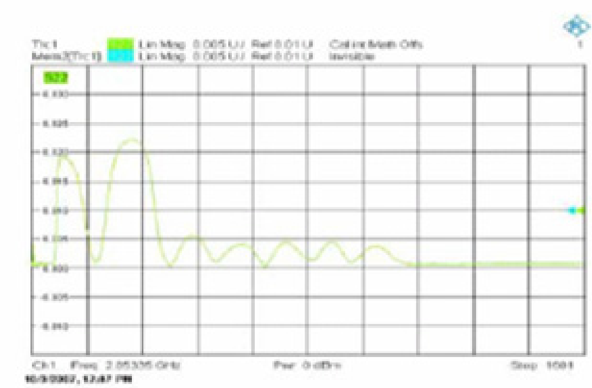


Figure 10: Cold test on the old model at UCLA (top) and INFN (bottom).

SUMMARY

A SW/TW hybrid photoinjector was being developed. Beam dynamics was simulated by using PARMELA. It showed this could produce 1.6 mm.mrad, 103-µm long beam of the charge 500 pC with its energy of 20.4 MeV.

The RF design was made for three TW cell structure with dual feed couplers. The field amplitude was tuned higher than the designed value due to the slow filling. The dual couplers are optimized to compensate the quadrupolecomponents.

The initial cold test was held and the measurement was successful at INFN version. We found the quality factor in SW was important.

REFERENCES

[1] B. D. O'Shea et al., "RF Design of the UCLA/URLS/LNFN Hybrid SW/TW photoinjector", AAC'06, Lake Geneva, WI, July, 2006

[2] A. Fukasawa et al., "Charge and wavelength scalings of the UCLA/URLS/INFN hybrid photoinjector", in the proceedings of PAC'07, (2007) 3609.

[3] B. D. O'Shea et al., "Measurement of the the UCLA/URLS/INFN hybrid gun", in the proceedings of PAC'07 (2007) 2418.