COMPACT ELECTRON RF TRAVELLING WAVE GUN PHOTO INJECTOR

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Abstract

This paper reports on studies of a travelling wave photo gun as multipurpose device. The gun would be a cost effective and compact alternative to thermionic guns with a bunching system or a standing wave photo injector gun. It allows in addition much larger beam energies at the gun output. It can provide a beam with energy of up to 50 MeV and several hundred pC charge with low emittance and short bunch length. We envisioned a compact and industrial grade photocathode drive laser having high MTBF and low maintenance cost. The gun design is based on the two-meter long accelerating structures installed in SwissFEL, It is powered by a C-band (5.712 GHz) modulator-klystron system, identical to those of SwissFEL. The input coupler is a simple double feed coupler and it has been designed to increase the electric field enhancement at the cathode surface to improve the emittance. The first three accelerating cells have been readjusted in length in order to get the proper phase advance and synchronism with the beam. The remaining 110 accelerating cells and the output coupler follows the original design of the accelerating cavities for SwissFEL.

INTRODUCTION

Injectors for electron synchrotron machines normally make use of pulsed triode grid configuration thermoionic guns combined with a buncher section and an accelerating linac. An alternative injection scheme is based on the use of a photo-gun followed by travelling wave accelerating structures that boost the electron beam up to the required injection energy. The novel idea, proposed in this paper, consists in integrating the photo-cathode together with a traveling wave constant gradient accelerator structure in the same radiofrequency (RF) cavity. This solution allows to replace the complex and large injector with a single two-meter structure in many compact electron synchrotrons. The design of the gun is mainly based on the two meter C-band constant gradient travelling wave structures developed and built for the SwissFEL project [1]. In total 104 of these structures are installed in the SwissFEL. PSI has the complete know-how in machining and brazing C-band structures, this is one of the main advantages in developing a two meter C-band travelling wave gun. This approach can ensure compactness and cost reduction together with the relatively low emittance of the beam.

GUN DESIGN

The gun is composed by 113 accelerating cells, it is a travelling wave structure, and the input power comes from the cathode side. The RF power propagates along the structure and reaches a matched load mounted at the output. The input coupler is a simple double feed coupler to remove dipole components and it has been designed to increase the electric field at the cathode surface to improve the emittance. The field pattern is in Figure 1.

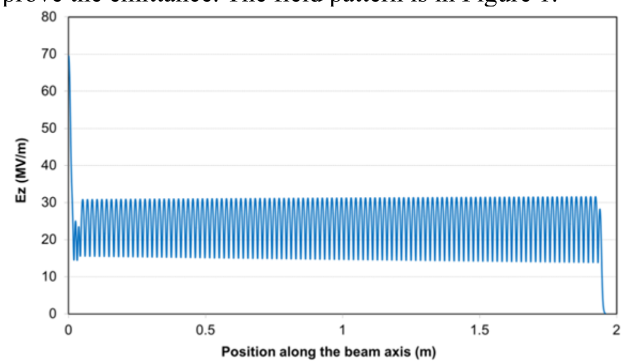

Figure 1: Electric field pattern computed with HFSS along the gun axis.

The cathode design is based on the CERN CTF gun [2]. The only modification concerns the input coupler and the first three accelerating cells in order to get the best phase advance and synchronism with the beam. Mechanically the input coupler is very compact to allow the installation of the solenoid that can be introduced or removed from the cathode side. Eventually a load-lock system can be added to allow quick cathode exchange under vacuum .A global view of the gun is shown in picture 2 and a detailed view of the cathode in Figure 3.

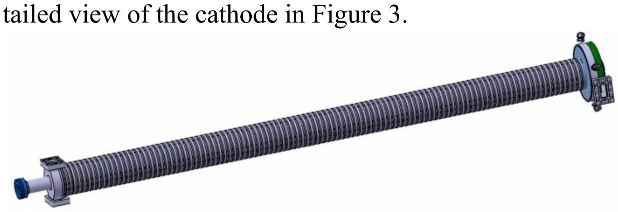

Figure 2: Full two-meter long gun, the cathode and the power input are on the left side.

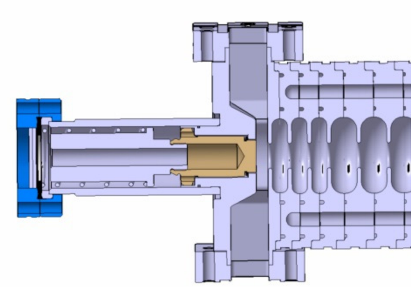

Figure 3: Input coupler of the gun. The removable cathode is in brown. The length of the first three cells has been reduced.

The gun has two solenoids, the main one 460 mm long mounted over the structure and a second small one, the bucking coil, mounted on the back of the structure to reduce to zero the magnetic field at the cathode. The two solenoids are shown in Figure 4 and the resulting magnetic field for a current of 120 A in the main solenoid is in Figure 5.

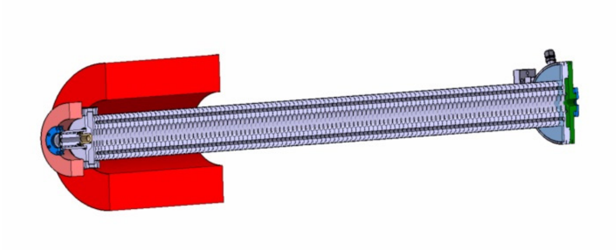

Figure 4: Gun with the main solenoid and bucking-coil.

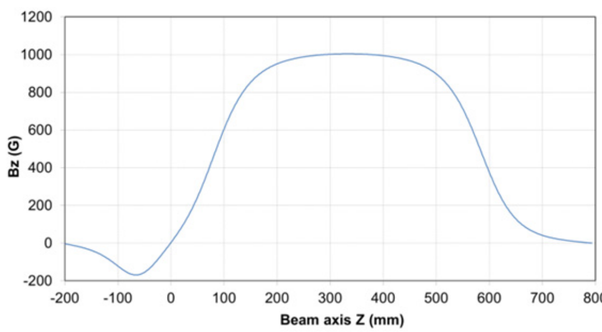

Figure 5: Longitudinal component of the magnetic field along the beam axis. The cathode is at z=0.

The gun is equipped of eight internal cooling channels which are capable to dissipate a power of 1.8 kW with only one degree of input to output water temperature variation for a water flow of 25l/m. The power dissipation is very homogenous along the gun and for an input peak power limited to 20 MW and a pulse length equivalent to the filling time of only 330 ns, the repetition rate of the gun could reach 400 Hz. This value is much larger of the required repetition rate of conventional electron synchrotrons and opens the possibility to use the gun also for other application where a higher repetition rate is required. The power supply system is composed by a klystron and a pulsed modulator. A good candidate for the klystron is a TOSHIBA E37210 model, [3]. This klystron has been developed for the SACLA project [4] and successively upgraded for the SwissFEL project. This klystron can provide 50 MW 3 microseconds peak power at 100 Hz repetition rate. In SwissFEL the required pulsed cathode voltage and current are provided by solid state modulators provided by two different companies, Scandinova Systems AB [5] and Ampegon [6], both could be used for the gun. The klystron output can be directly connected to the travelling wave gun input via waveguide under vacuum without any circulator.

The main parameters of the gun are listed in Table 1.

Table 1: Cavity Parameters

Length (m)	2.108
Number of accelerating cells	113
Phase advance/cell (°)	120
Frequency (GHz)	5.712
Repetition rate (Hz)	≤400
Attenuation (dB)	-5
Filling time (ns)	330
Gradient (MV/m)	20
Max. field at cathode (MV/m)	70
Output beam energy (MeV)	40-50
Input power (MW)	20
Water flow required (l/min.)	25 (400 Hz)

PHOTOCATHODE LASER

As photocathode laser, we envision to use a compact, industrial grade and turnkey laser amplifier. A good candidate is an Ytterbium based laser system delivering sub-picosecond FWHM laser pulses at a central wavelength of 1030 nm. This amplifier seeds a frequency conversion stage in order to produce sub-picosecond laser pulses at 257.5 nm that will be used to generate the photo-electron on the gun cathode. Since the amplifier uses a CW pump diode, very high pulse energy stability can be reached, (typically <2% rms long term) which is crucial for the charge stability. The system is compact (footprint smaller than 1.5*1.5m), turn-key and directed diode pumped (MTBF >20000 hours) which turns in low maintenance costs compared to other laser technologies. The system could eventually be placed outside the accelerator bunker for both better accessibility and radiation protection. In this configuration the laser beam will be transported toward the cathode via a vacuum optical transfer line. Imaging can be used to passively stabilize the laser position on the cathode. The basic parameters of the laser are summarised in Table 2.

Table 2: Laser Parameters

Central wavelength (nm)	257.5±5
Pulse duration “Pt” (fs-rms)	150<Pt<1300
Pulse energy (μJ)	<100
Repetition rate (Hz)	1-100
Long term energy stability (% ptp)	<3
Long term energy stability (% rms)	<2
Oscillator phase noise (fs rms)	<250

BEAM DYNAMICS

The simulation method was adapted from the high brightness traveling wave gun [7] to include constant gradient structures and the effect of phase advance tuning. The space charge multi particle tracking code ASTRA, together with a MATLAB based optimizer was used to

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get the parameters of the gun phase, solenoid field, laser spot size and length of the first three cells. A charge of 150 pC was assumed in the first simulation. Figure 6 shows the evolution of the normalized transverse emittance which is below 3 π mm mrad at the output of the gun with an rms energy spread below 70 keV, as indicated in Figure 7. The beam parameters are summarized in Table 3.

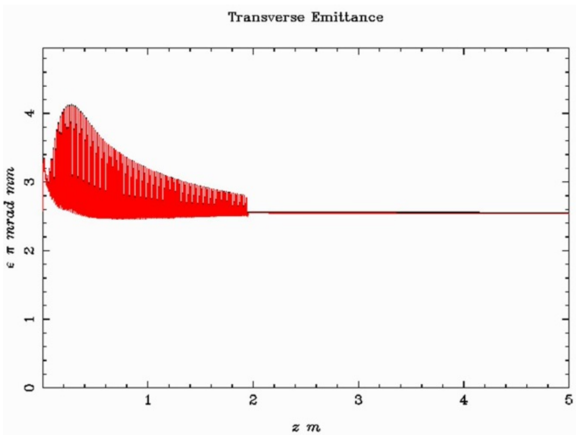

Figure 6: Transverse emittances symmetric in the two planes versus position.

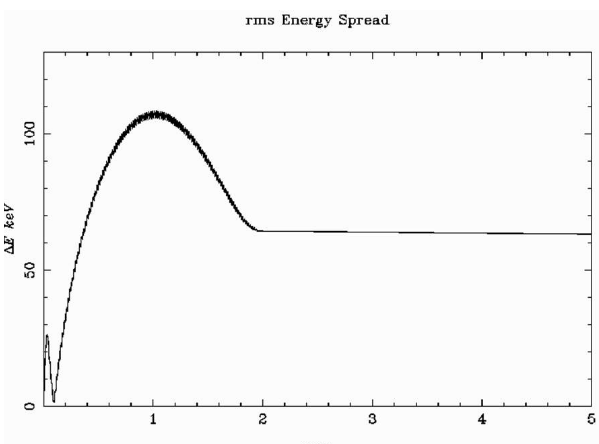

Figure 7: Energy spread versus position.

One of the advantage of a travelling wave gun is the possibility to modulate the phase and eventually also the amplitude along the pulse in order to provide different acceleration schemes including ballistic compression. The possibility to produce ultra-short bunches is under study and preliminary results with a 0.1 pC charge are summarized in Table 4. These results have been obtained by introducing a linear phase variation of 0.5°/mm in the first four centimetres of the structure followed by a constant phase in the rest of the cavity and by adding a second solenoid identical to the main one at the gun output to focus the beam. The linear phase variation introduces a bunching effect on the beam before it becomes relativistic. The second solenoid allows to keep the beam size below 10 microns rms in the beam waste at 1.8 m from the gun output. The transverse emittance is relatively large for only 0.1 pC bunch charge but could be reduced by further optimising the laser and solenoid parameters.

Table 3: Beam Parameters

Bunch charge (pC)	150	0.1
Laser Pulse rms (fs)	650	200
Laser spot size rms (mm)	0.4	0.25
Bunch length rms (fs)	1300	20
Emittance (π mm mrad)	2.5	0.3
Beam energy (MeV)	45.2	42.3
Energy spread (dE) rms (keV)	63	15
Correlated dE (keV)	-12	-14.9

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CONCLUSION

The proposed gun has several interesting features. It allows a very high beam energy up to 50 MeV, with a conservative gradient, potentially can work at 400 Hz end is extremely flexible in terms of beam dynamics since the RF pulse can be modulated both in phase and in amplitude. This RF gun can be a compact and cost effective injector for a small electron ring. The design of this novel gun is strongly based on the existing travelling wave structures in SwissFEL and does not require strong effort in the engineering development.

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