INTRODUCING GUNLAB - A COMPACT TEST FACILITY FOR SRF PHOTOINJECTORS*

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Abstract

Superconducting radio-frequency photoelectron injectors (SRF photoinjectors) are promising electron sources for high brightness accelerators with high average current and short pulse duration like FELs and ERLs. For the upcoming ERL project bERLinPro we want to test and commission different SRF photoinjectors, optimize the beam performance and examine photocathode materials in an independent test facility. Therefore we designed GunLab to characterize beam parameters from the SRF photoinjectors in a compact diagnostics beamline. The main challenge of GunLab is to characterize the full six dimensional phase space as a function of drive laser and RF parameters. Here we present design and estimated performance of GunLab.

Motivation

bERLinPro [1, 2] will be an ERL demonstrator which combines high average beam current with small emittance which is determined by the electron injector. In a step-by-step approach the photoinjector concepts will be developed and commissioned towards the final bERLinPro-gun. In the last two years Gun 0.1 [3] and Gun 0.2 [4] comprising of hybrid Nb/Pb SRF gun cavities were tested successfully. Both tests were done at HoBiCaT [5] extended by a test beamline. Based on the gained experiences we designed GunLab as an independent and optimized beamline to characterize the next SRF guns for bERLinPro and to investigate different phase space measurement systems for the extracted electron bunches. With GunLab the complete six dimensional phase space of electron bunches in the energy range of up to 3.5 MeV can be investigated. The realization of GunLab is one of the important milestones of the bERLinPro project on the way to optimize the performance of SRF photoelectron injectors for the upcoming future accelerators. Here we will present the estimated beam and SRF gun parameters and how they will be investigated in GunLab.

Parameters of Gun and Drive Laser

The two central parts of the electron generation in GunLab are the gun module [6] and the drive laser [6]. The gun module consists mainly of the RF and HOM couplers, a superconducting solenoid, the SRF gun cavity [7] with the normal conducting photo cathode [8, 9] and the cathode transfer system. Additional steerer and corrector magnets are installed inside the gun module (see Fig. 1). The parameter settings of these elements define the beam parameter of the accelerated electron bunches. Tab 1 shows the typical parameters for SRF gun (GUN 1.1) and drive laser.

Table 1: Parameter ranges of cathode, SRF gun, drive laser and solenoid

Parameter	Symbol	Value
Cathode material		CsK_2Sb
Drive laser wavelength	λ	515, 258 nm
Drive laser pulse length	τ	3...16 ps (FWHM)
Transversal laser shape	σ_r	FlatTop
Spot size on cathode	σ_0	0.5 mm (rms)
Drive laser repetition rate	f_{Laser}	1.3 GHz
Macro pulse repetition rate	f_{rep}	10 Hz
Duty cycle	single pulse ... 50%	
SRF gun frequency	f_{RF}	1.3 GHz
Electric peak field	E_0	30 MV/m
Launch phase	ϕ_{launch}	0 ... 80 degL
Integrated solenoid strength	$\int B^2 dz = B^2_{max} * L_{eff}$	1 T^2mm

Beam parameters

With the dimensions of the cold section and the field models of SRF gun [10] and solenoid we calculated the range of the electron bunch parameters. These simulations were done with ASTRA [11] for different SRF gun (peak field, launch phases, cathode positions) and drive laser parameters (intensity, pulse length). The drive laser parameters were implemented as bunch charges and temporal emission length of the electron distribution at the cathode. Each setting has a transversal flat top distribution with a diameter of 2 mm and an initial emittance of 0.265 mmmrad. To compare the beam parameters along the beam line for different SRF gun and laser setups the solenoid value was optimized for ideal emittance compensation at one reference point. This reference point is 2.2 m downstream the cathode and is approximately the position of the first Booster Cavity of bERLinPro. Therefore it defines the initial point for phase space investigation of the electron bunches. For each SRF gun and laser setup we calculated the beam parameters and analyzed their spread along different positions of the beamline. Tab 2 shows the range of relevant bunch parameters for GunLab.

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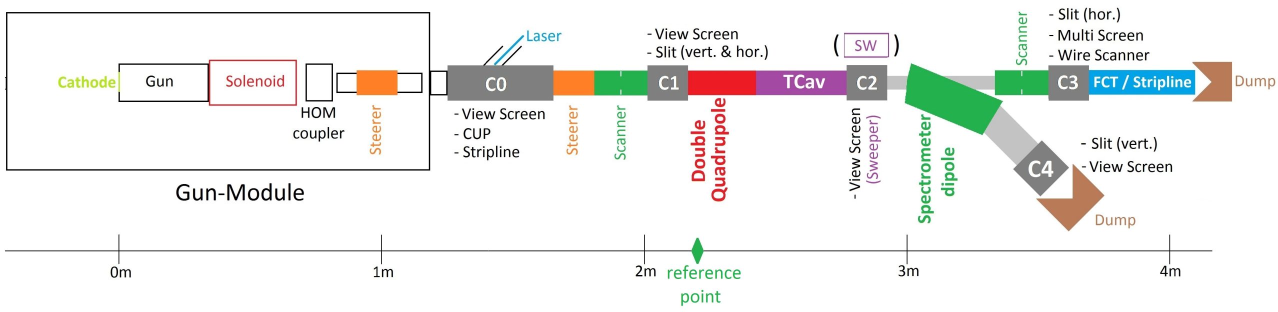

Figure 1: Schematic view of GunLab

Table 2: Estimated parameter ranges of the electron beam

Parameter	Value	Unit
Bunch exit energy	$1\ldots3.5$	MeV
rel. energy spread (@3.0m)	$0.2\ldots5$	%
Bunch charge	$0\ldots100$	pC
Bunch length (@2.5m)	$2\ldots10$	ps (rms)
max. Average current	4	μA
Normalized emittance (@2.2m)	$0.4\ldots10$	mm mrad

Layout of GunLab

GunLab is separated in a cold (gun module) and a warm section (beamline). The gun module and the first part of the beamline are identical with the later setup for bERLinPro. It contains the duct for the drive laser, the cathode view port, a faraday cup, the first viewscreen and a stripline BPM.

At the reference point we install a pepper pot (slit-station) to investigate the projected transverse phase space of the electron bunches. In front of this station two steerer coils will move the beam parallel to the beam axis through the slit (see below). Behind the pepper pot two quadrupoles are placed, used for quadrupole scans (transversal emittance) and together with a transverse deflecting cavity (TCAV) [12] also for slice emittance measurements. The TCAV will be a normal conducting one cell cavity which deflects with a TM110 mode in horizontal or vertical direction. It will operate at a frequency of 1.3 GHz, but with only 10 Hz repetition rate and a duty cycle of below 1%. A spectrometer dipole [13] was designed to investigate energy distribution of electron bunches at kinetic energies below 10 MeV. The magnet is placed 3.0 m behind the cathode and separates the following beamline in a dispersive and a straight section. In the straight section a multi-view-screen station is incorporated. It allows us to investigate the performance of different materials and thicknesses of three independent view screens. A wire scanner will be included to compare optical and electrical transverse beam size measurement methods.

Measurements at GunLab

Bunch length measurement: In a BMBF funded collaboration with TU Dortmund a transversal deflecting cavity (TCAV) was designed to streak an electron beam with an energy of 2.5 MeV and bunch lengths of sub-ps up to tens of ps. The streaked beam will be investigated at the screen station behind the spectrometer dipole.

Slice emittance measurement: The TCAV can also be used for slice emittance measurement in horizontal and vertical direction. The beam will be focused in one direction on the screen station by the double quadrupole and then streaked by the TCAV. In a second step a so called double-quadrupole-scan will be used to investigate the transverse emittance of each slice. Therefore both quadrupole strengths will be manipulated in a way, that the beam width in streaked direction stays constant on the screen. The resulting beam width of each slice in the perpendicular direction as a function of the quadrupole values will be used to reconstruct the phase space distribution at the reference point.

Energy and energy spread measurements: In a second BMBF funded collaboration with Moscow State University, Institute of Nuclear Physics (MSU) we designed a spectrometer dipole [13] (energy range of 1 to 10 MeV) to measure the energy distribution of the electron bunches. The target values for the accuracy are 1% for the absolute energy and $\frac{\Delta p}{p} \approx 10^{-4}$. The parameters of the spectrometer dipole (bending radius and angle, angle of pole face rotation) were chosen such that the horizontal and vertical distributions on the screen in the dispersive section are not influenced by the emittance at the reference point. Furthermore we will use a vertical slit at the reference point to suppress the small influence of the horizontal beam width on the measurements.

Projected transversal phase space measurements with pepper pot and scanner: GunLab combines different techniques to investigate the projected transversal phase space, e.g. quadrupole-scans and tomography. But only with a pepper pot methode the transverse phase space can be observed directly. Therefore we designed next to the reference point different slits (vertical and horizontal with different slit widths). A slit scan can be implemented by moving the slit through the stable electron beam or moving the beam over the slit. The second one is the faster method, because only the current in two steerer coils has to be changed. But one has to be sure, that the beam is moved correctly and the phase space is not distorted by nonlinear effects - especially at large deflections. In addition, the magnets have to be coil

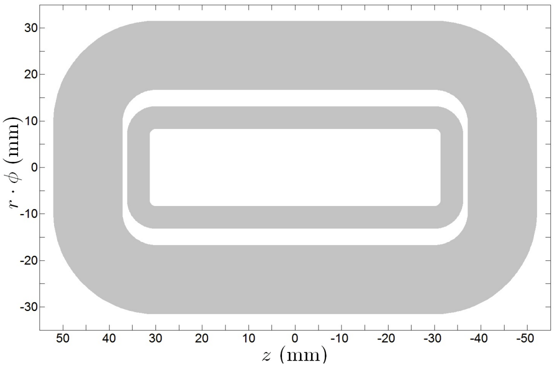

Figure 2: An example of a flat wire distribution for a half $\cos\theta$-coil which suppress the first 14 magnetic multi-poles.

dominated to work without iron yokes and residual magnetic fields. The adopted solution is a kind of $\cos\theta$-coils [14]. Fig. 2 shows an unfolded wire distribution of a structure which produce a dipole field and suppress other magnetic multi-poles up to the 14^{th} order. A complete scanner consists of two coils with opposite field directions. Our design will allow to shift the beam up to 10mm of axis with a uncertainty of distortion and deflection in the range of 1%. The final design is work in progress.

Beam halo: Beam halo are electrons with a transversal or longitudinal displacement to the main electron bunch. These displacements are often correlated with different electron momenta and optical functions. Beam halo is generated due to drive laser effects - light scattering, reflection, or background light emission between two laser pulses - or by electron scattering in bunches with high bunch charges. In general the integrated current of the beam halo is unknown, but for the SRF cavities and for the ERL-mode it is important that the halo current is more than 6 magnitudes smaller than the main beam current. Investigations of the beam halo can

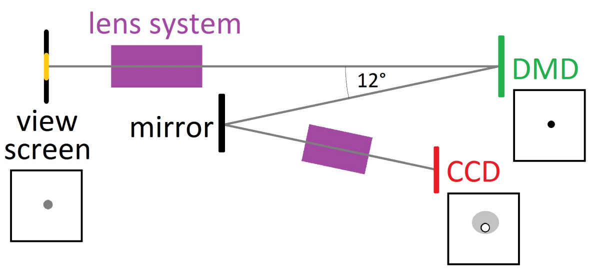

Figure 3: Schematic view of the image system with the DMD and an illustration of imaging. The bright part of the viewscreen image is blocked by the DMD (blocking mask on the DMD) so that the background luminescence will be visible for the CCD.

be done only simultaneous to the main beam. Therefore we have to use a technique which blocks the dominant parts of the beam to examine only the outer parts (transversal and longitudinal). To solve this problem we want to use a digital micromirror device (DMD) [15] between view-screen and CCD chip. A DMD consist of many small mirrors ($\approx$ 10x10μm) which can be individually switched between two angle positions. Thereby two different CCDs can observe different parts of the same picture (see Fig. 3). The camera with the blocked main beam can operate with higher gain and longer exposure time values without saturation. Thereby the background luminescence of the view screen will be visible. With this technique it should be possible to investigate more than 5 orders of magnitudes of the beam distribution [16].

SUMMARY AND OUTLOOK

GunLab will be the new SRF Gun test facility at the HZB to characterize precisely and optimize Photoinjectors for future accelerator concepts like bERLinPro. Different techniques are realized to investigate the complete phase space of the extracted electron bunches over a wide range of beam energies, bunch lengths and transversal emittances. The design of TCAV and spectrometer dipole is almost fixed and the tendering phase has been started. Currently we starts with the optimization of the optical systems and the final calculations and testing of the scanner and steerer magnets. First beam in GunLab is planned for spring 2015.

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