Poster

ACTIVITIES AT NCBJ TOWARDS DEVELOPMENT OF THE FUTURE, FULLY-SUPERCONDUCTING, XFEL-TYPE, RF ELECTRON GUN

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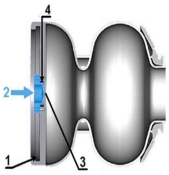
Background

R&D program on low and medium current, fully-superconducting, RF electron photo-injector is a part of the task of performance improvement of E-XFEL and similar facilities. The concept of a SRF, electron injector for linear superconducting accelerators was proposed and developed within long-time collaboration of many research centres, which includes the use of a fully superconducting photocathode with a photoemitting component in the form of a Pb film applied to a niobium „plug" mounted to the back wall of a 1.6-cell, TESLA-type, 1.3 GHz SRF cavity (see the figure below).



1 – cavity backplane
2 – niobium plug
3 – Pb film on the plug tip
4 – vacuum seal of In

The work on optimization of the electron gun destined for Polish Free Electron Laser (PolFEL) is focused on three areas:

1. Improvement of e- beam focusing and reduction of it transverse dimensions, based on beam dynamics computations.
2. Development of an optimal technique of applying a Pb layer on the photocathode plug as a step in Nb-Pb photocathode preparation.
3. Development and implementation of a laser and optical system for photocurrent excitation from the cathode surface.

Beam dynamics and improvement of e- focusing inside SRF gun

The main challenge in designing superconducting RF guns is to counteract the space charge forces, particularly in the non-relativistic, low energy e- beam region immediately downstream of the cathode. In case of sc accelerating structures the beam focusing cannot be acomplished with magnetic field from external solenoid. Therefore, it was decided to focus the near-cathode electrons by generating a radial component of electric field that comes from retraction of the photocathode tip back into the cavity wall. This issue was studied by computing the dynamics of electron bunches in typical operation conditions.

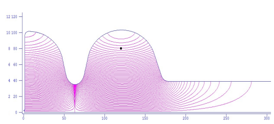


Fig. 1. Electric field lines in a 1.6-cel gun cavity.

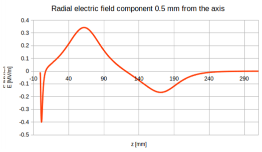
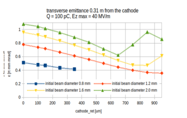


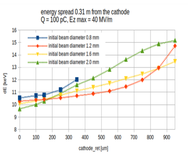
Fig. 2. Radial electric field component 0.5 mm off the axis. A few mm wide spike of focusing field is present close to the cathode surface.

Beam dynamics computation - conclusions

Electric field geometry for accelerating gradient Eacc=40 MV/m has been computed using Poisson Superfish code. The radial field component distribution 0.5 mm off the cavity axis is depicted in Figure 2. A short focusing field spike is visible next to the cathode surface. The spike amplitude grows with the distance from the axis. To simulate electron bunch dynamics Astra code was used taking into account space charge fields as well as mirror charges at the cathode. (Similar computations were done at DESY). Calculations were performed for different positions of the cathode in relation to the back cavity wall. The reduction of transverse emittance at the gun cavity end, of a 100 pC e- bunch as a function of the cathode retraction distance (top-right figure) is accompanied with bunch elongation and tnergy spread (bottom-right figure). Choosing the right position of the cathode takes finding a compromise between focusing and keeping the energy spread within acceptable limits. A large numer of simulations for bunches with charges 20 to 250 pC (depending on diameters (0.8 - 2.8 mm) and laser pulse lengths (4 - 24 ps)), indicated that cathode retraction by 0.45 mm is favorable for the discussed e- beam parameters.



Normalised transverse emittance (on the top) and bunch energy spread for 100pC bunch, 31 cm from the cathode for different initial beam sizes at the cathode and positions of the emission surfaces in relation to the back wall cavity.



Preparation of a Nb-Pb, hybrid, sc photocathode

Three promising procedures have been proposed and implemented within last years at NCBJ for preparation of Nb-Pb hybrid, sc photocathode:

Procedure 1

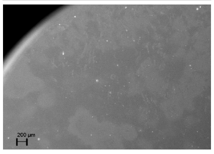
based on using a cathodic arc coating system equipped with a 30° bent magnetic Pb droplets filter between the arc cathode and the substrate to reduce droplets stream from the arc plasma.

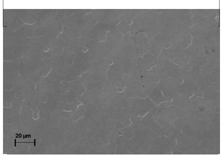
Procedure 2

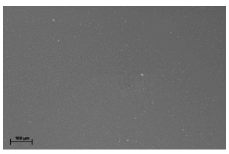
based on using a cathodic arc coating system without droplets filter, followed by ex-situ Pb layer treatment in argon pulsed plasma stream in a rod plasma injector.

The novel procedure no. 3

based on using a cathodic arc coating system combined with Pb deposition by lateral extraction of Pb ions (normally to arc plasma stream) to eliminate Pb droplets from the layer.







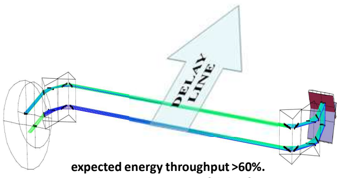
SEM images of lead film surface

List of arc parameters for Pb coating on niobium and the resulting morphology features, quantum efficiency (QE) at 260 nm, accelerating field Eacc in SRF gun cavity at a quality factor of 10^{10} and dark current (DK) at 60 MV/m from 1 cm² area

Coating method	Arc volt. (V)	Arc curr. (A)	Deposition rate (µm/min.)	Film thick. (µm)	Target bias (V)	Film surface morphology	QE	Eacc MV/m	DK (nA)
Arc with 30° bent filter	≈22	25	0.2	1-5	-70	Planar film with few semispherical protrusions of high aspect ratio, sized up to 30 µm (the sources of dark current).	3.5 e-4	28	200
Arc coating + pulsed plasma treatment	≈22	25	3.0	15-20	-70	Complete, planar film with round, elongated surface forms (up to 2 µm high) of low aspect ratio.	2.2 e-4	26 (31 at Q_o = 4.3e-9)	40
Arc deposition with lateral ion extraction	≈17	≈18	0.07	0.6	-20	Smooth film with a small number of rounded protrusions of low aspect ratio	To be checked	To be checked	To be checked

Future laser system for exciting photoemission in PolFEL SRF gun

Photocathode laser system will base on commercially available Pharos laser (Lithuanian company Light Conversion, UAB). The laser fundamental parameters after regenerative amplifier are: repetition rate of 50 kHz, Gaussian pulse duration FWHM ≈ 300 fs, wavelength of 1026 nm at a pulse energy of 400 µJ and ca. 3 mm beam diameter. A fourth harmonic generation module attached to this laser system will give a radiation pulse 256 nm in wavelength and of energy above 40 µJ. It takes 4–30 ps FWHM pulse duration (flat top both, in space and time) to excite and extract from the photocathode a perfect "cylindrical" e- bunch.

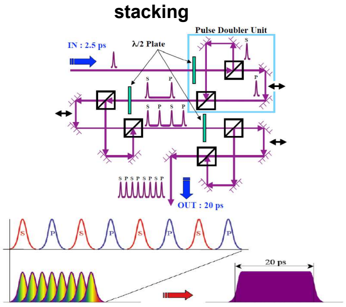


expected energy throughput>60%. ~0.3-4ps pulse stretch per 1m of delay for 257nm wavelength

Courtesy of Hauri, Christoph & Ganter, Romain. (2009). Gun Laser systems for the SwissFel project. Proc. 27th FEL Conference.

Converting Gaussian pulse shape in time requires two additional optical setups. The first one is needed to stretch the Gaussian pulses from 300 fs to 4 ps pulse duration at the most, by using double prism pulse stretcher. It will add negative Group Delay Dispersion.

Temporal beam shaping – pulse stacking



Courtesy Yuelin Li, Accelerator Systems Division, Argonne National Laboratory & SP8 - Japan

The second optical setup – pulse stacker – will divide the pulse and stack them together on polarizing beam cube splitter. As a final output of these conversions a flat top beam shape will be reached in time domain with FWHM pulse duration from 2.4 ps to 30 ps.

Spatial beam shaping

To convert the Gaussian spatial profile after passing the pulse stretcher and stacker, a commercially available pi-shaper module is to be applied, preceded by a telescope. The latter will convert the original 3 mm beam diameter to 6 mm or 12 mm (1/e²) required by the pi-shaper. A pinhole is to be added into the telescope to reach a perfectly Gaussian spatial pulse profile at the entrance to the pi-shaper.

After the above described conversion of Gaussian pulses to "cylindrical" ones, a special "travelling" lens system will deliver UV beam to the photocathode with possible varying of its diameter on the cathode from 50 µm to 3 mm. It will give flexibility of choice between hundreds of pC electron bunches (at a large beam diameter) and "skinny", low emittance bunches (for beam diam. 50 – 250 µm), required for different types of PolFEL's undulators: VUV, IR or Terahertz.

Acknowledgment

The authors thank the KEK team: Taro Kononomi, Eiji Kako and Kensei Umemori for providing the data on reaching E_{acc} = 54 MV/m in a 1.6-cell gun cavity after its multiple electro-polishing. Thanks are also due to D. Basil of DESY for his computation results which predict essential beam emittance reduction after rising E_{acc} from 40 up to 50 MV/m.