ISBN: 978-3-95450-190-8 doi:10.18429/JACoW-ERL2017-MOPSPP006

SPOCK - A TRIODE DC ELECTRON GUN WITH VARIABLE EXTRACTION GRADIENT

L.M.Hein[†],V.Bechthold, M.A.Dehn, S.Friederich, C.Matejcek, K.Aulenbacher

Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, Mainz, Germany

Abstract

The electron source concept SPOCK (**S**hort **P**ulse **S**ource at **K**PH) is a 100kV DC source design with variable extraction gradient. Due to its triode inspired design the extraction gradient can be reduced for e.g. investigations of cathode physics, but also enhanced to mitigate space charge effects. In the framework of the MESA-Project (**M**ainz **E**nergy-Recovering **S**uperconducting **A**ccelerator) [1] its design has been further optimized to cope with space charge dominated electron beams. Although it injects its electron beams directly into the LEBT (**L**ow **E**nergy **B**eam **T**ransport) matching section, which excludes any adjustments of the electron spin, the source SPOCK will allow higher bunch charges than the MESA standard source.

CONCEPT

The concept of the horizontal DC electron gun SPOCK [2] is based on the design of triodes developed beginning 20th century. By means of an additional control plate in-between anode and cathode the extraction voltage can be altered, see Fig. 1.

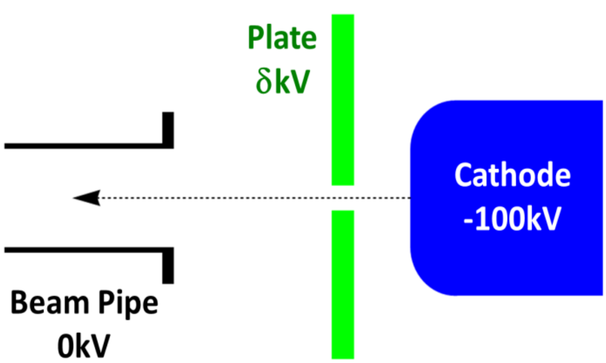

Figure 1: Concept of SPOCK

The basic design idea has been developed [3] in order to clarify the contribution of photocathode energy spread to the time response [4] of photocathodes. Due to variations of the extraction field gradient its contribution can be isolated from other effects and separately investigated. Further details to this subject will be recapitulated in e.g. [4]. Simultaneously, this layout possesses a potential for high brilliance electron beams. A major challenge is the preservation of the transverse emittance in presence of space charge. By setting the control plate at a high potential the extraction field at the cathode surface is significantly amplified. Hence the electron acceleration is considerably enhanced mitigating the space charge impacts on the beam qualities such as the transverse emittance and the energy spread.

Design and Dimensions

The design of the source is based on the design of the JLAB source [5]. It features electrode supporting insulators extending into the interior of the grounded vacuum vessel. This is known as an "inverted" source. An overview of the specific features and technical advantages of such a design is given in [5]. The main components of the source are the cathode, the anode and the control plate. By means of two ceramic isolators the cathode and plate are electrically separated. Anode and beam pipe are grounded. As in case of high intensity beam operations an early transverse focusing is beneficial, a plug-in vacuum vessel is designed containing space for a double-solenoid. This double solenoid will be placed approximately s=220mm downstream the cathode. In order to ensure the vacuum condition of $p \approx 10^{-11}$mbar ten NEG (Non Evaporable Getter) modules grouped in two half circles are surrounding this plug-in vessel. Two additional IGP (ion getter pumps) will be attached to the main chamber. A scheme of the source design is given in Fig 2.

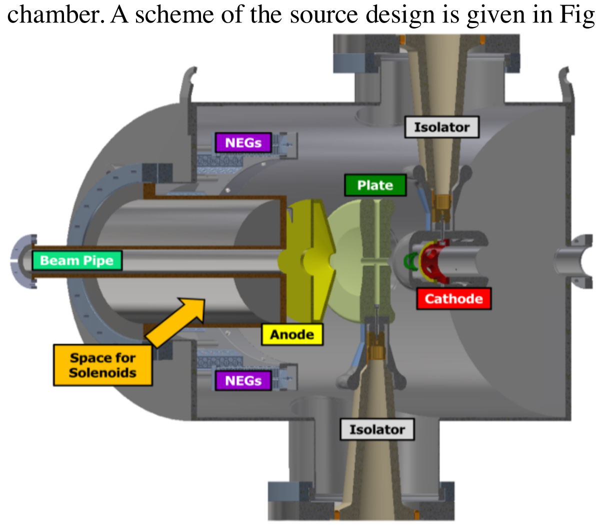

Figure 2: Design SPOCK

The dimensions of the main source vessel are length L=620mm and diameter D=410mm. A CF200 flange connects the main source chamber with the plug-in vessel. In the design phase the diameter of the plug-in vessel is set to d=170mm. Apart from hosting the double solenoid and the CF40 beam pipe the plug-in vessel also serves as a support for the extraction anode, whose shape is adapted from the source STEAM (**S**mall **T**hermalized **E**lectron Source **A**t **M**ainz) [6]. The isolators are type R30 isolators with a height of h≈240mm. Numerous minor variations in the design of the control plate and the cathode were required to mitigate potential field emissions and to allow a

59th ICFA Advanced Beam Dynamics Workshop on Energy Recovery Linacs ERL2017, Geneva, Switzerland JACoW Publishing
ISBN: 978-3-95450-190-8 doi:10.18429/JACoW-ERL2017-MOPSPP006

straightforward assembly of the components. The design of the control plate is currently in the final stage.

Field Maps

A major challenge of DC particle sources is the control of field emission. In order to avoid field emission during operation the design field gradients at the source SPOCK and STEAM were limited to E<10MV/m. At the source SPOCK the highest field gradients are located at the front plane of the cathode, at the rounding of the voltage shoes of the cathode and control plate as well as at the back plane of the control plate. In case of a grounded control plate the field gradients do not exceed 6MV/m. The peak fields are at the rounding of the cathode front plane, the upper part of the plate and at the cathode voltage shoe, see Fig. 3.

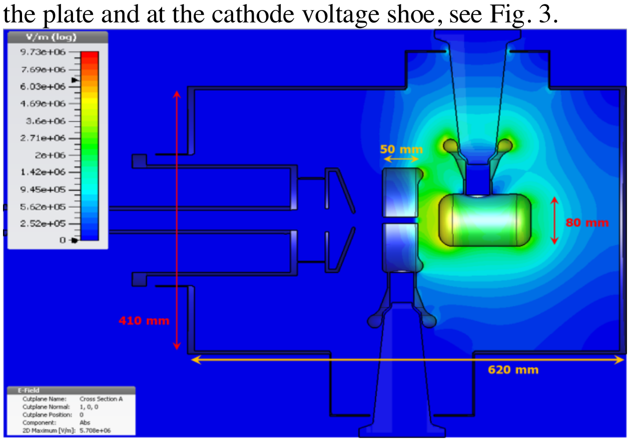

Figure 3: Field Map – U_{plate}=±0kV

By setting the plate potential to U_{plate}=+80kV the field gradients are close to the limitation of E_{max}=10MV/m. They are concentrated at the rounding of the cathode front plane and the upper part of the plate, see Fig. 4.

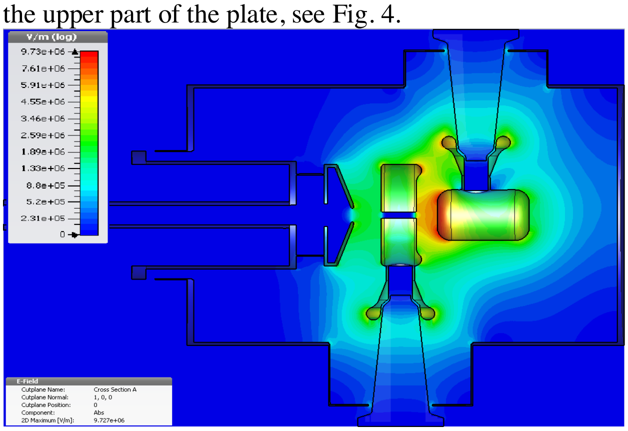

Figure 4: Field Maps – U_{plate}=+80kV

The field calculations were conducted using the code Computer Simulation Technology (CST) [7].

SIMULATION PARAMETERS

The simulations of the electron bunch generation were conducted using the code CST as well. Due to the unique properties of the source the generation of two mainly different types of electron beams is contemplated. For investigations of the cathode physics mostly low intensity, short bunches will be generated. The investigation of this scenario is work in progress, in the following the focus is on bunches characterised by larger bunch charges and bunch lengths. For this scenario the rms bunch length is defined to σ=50ps. This leads to a total bunch length of ΔT=200ps to ΔT=300ps. In both scenarios the longitudinal density distribution is defined by Gaussian profiles, which are truncated at L=±3σ_t. The transverse laser profile at the cathode surface is also characterised by Gaussian functions. Most simulations were conducted assuming a laser spot size of R_{laser}=0.3mm. Studies with R_{laser}=0.5mm are in preparation. Further initial beam parameters are E_{kin}=0.2eV, E_{spread}/E_{kin} =95% and angular spread Δϑ=89.9deg. The simulations were conducted using the CST Particle in Cell (PIC) solver with at least 150.000 particles for the high bunch charge studies.

SOURCE BEAM DYNAMICS

The beam dynamics of the DC source SPOCK is mainly determined by the potential setup of the cathode and the control plate as well as the settings of the laser. Major parameters of the laser such as its pulse length and its transverse cross section are maintained constant during the parameter sweeps. Hence, the electron bunch length within the first 200mm downstream the cathode is defined by the particle acceleration respectively deceleration. At high bunch charge operations higher extraction field gradients are beneficial, since the superior acceleration near the cathode extends the initial bunch length, i.e. the distance from the first emitted particles of the bunch to the last emitted particles leaving the cathode, and so it leads to a lower charge density during the electron extraction. A grounded control plate, i.e. U_{plate}=0kV, specifies an average extraction field gradient of approximately 3.3MV/m. It results in a total, initial bunch length of L=35 mm. A control plate potential of U_{plate}=+80kV extends the bunch length to approximately L=55mm. Its impact on the normalised transverse emittance of a bunch with charge of q=1pC is illustrated in Fig. 5.

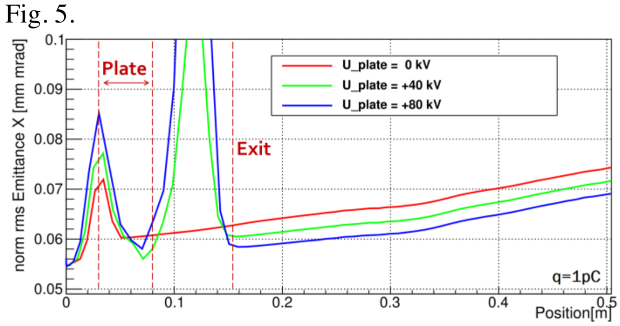

Figure 5: Emittance Development along the Source

Position s=0m indicates the position of the cathode surface. The control plate covers the distance from s=0.03m to 0.08m. At position s=0.16m the beam enters completely the extraction cathode and at approximately s=0.2m the solenoid edge field. Upstream the extraction anode the transverse normalised emittance varies significantly. Since the bunch length is comparable with the drift lengths between cathode and control plate respectively between control plate and anode, the particle energy varies significantly

ISBN: 978-3-95450-190-8 doi:10.18429/JACoW-ERL2017-MOPSPP006

along the bunch. During the passage through the control plate major fractions of the electric field induced energy spread are cancelled, which leads to the drop of the emittance at position s= 0.07m. As the initial bunch length of the setting U_{plate}=+80kV exceeds the length of the control plate of L=50mm, its electric field induced energy spread is not completely compensated.

At position s=0.16m the beam enters the extraction anode, its average kinetic energy is set to E_{kin}=100keV and the correlated energy spread induced by the acceleration/deceleration field is cancelled. The deceleration or acceleration downstream the control plate to the final energy also adjusts the initial bunch length. Due to the enhanced acceleration at settings with a positively charged control plate space charge effects near the cathode are mitigated, which leads to superior transverse emittance preservations. Moreover, the higher extraction field gradients also lead to lower energy spread values and lower longitudinal emittances. A brief quantitative recapitulation of the beam parameters at the source exit, i.e. at position s=0.2m, is given in the next paragraph. Fig. 6 shows exemplarily a phase space plot of two particle distributions at position s=0.2m, i.e. inside the extraction anode.

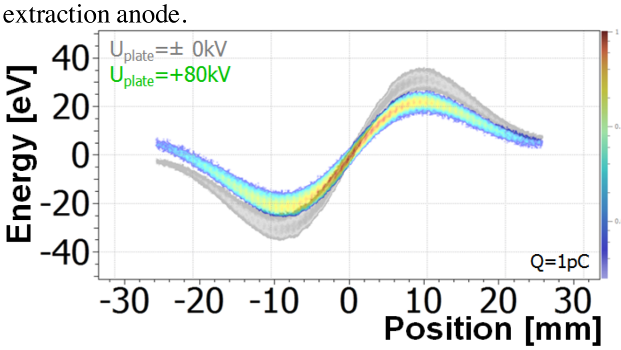

Figure 6: Longitudinal Phase Space Plot [8]

The non-linear space charge effects are causing a characteristic dependency between the particle energy and its position within the bunch [9].

PARAMETER SWEEPS

A non-finalised design parameter is the shape of the control plate. Its modelling can be used to further enhance the extraction field gradient as well as to apply additional beam focussing. A summary is given in [2]. Additional parameters are the bunch charge, the potential of the control plate, the radius of the laser spot at the cathode and its time pattern. In the framework of the MESA Project the source STEAM is foreseen as primary source to generate polarised electron beams. Since this source is designed as a high brilliance electron source, its parameters are used to benchmark the transverse emittance values of the SPOCK source. Therefore, the beam parameters are recorded at the source exit at position s=0.2m. The extraction gradient of STEAM [6] at $U_{cathode}$=100kV is comparable with the SPOCK field gradient with grounded control plate. Hence, comparable transverse emittance values are expected. A sweep of the total bunch charge indicates the similar dependency as well as the benefit of the extraction field enhancement, Fig 7.

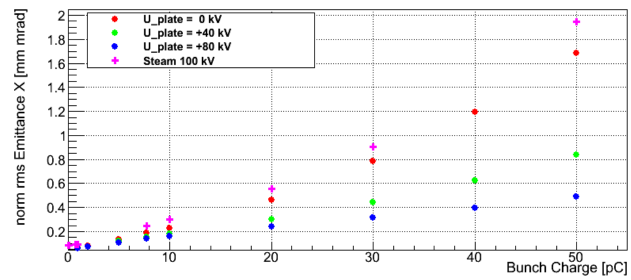

Figure 7: Transverse Emittance

Especially at high bunch charges q≥10pC the field enhancements of 40% and above lead to superior preservations of the transverse emittance. As a result of the transverse emittance growth at high bunch charges the growth of the longitudinal emittance is mitigated, Fig. 8.

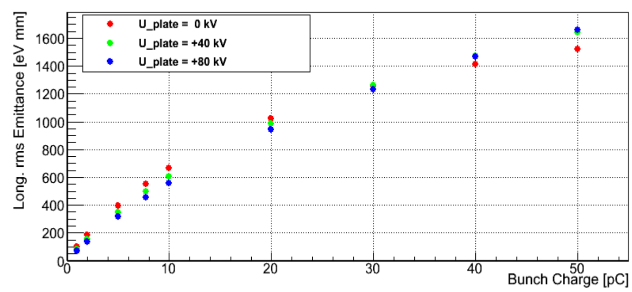

Figure 8: Longitudinal Emittance

However, at bunch charges below q=20pC lower transverse and longitudinal emittances are feasible by means of amplified initial acceleration. The impact of the acceleration gradient and the bunch charge on the rms energy spread is plotted in Fig. 9.

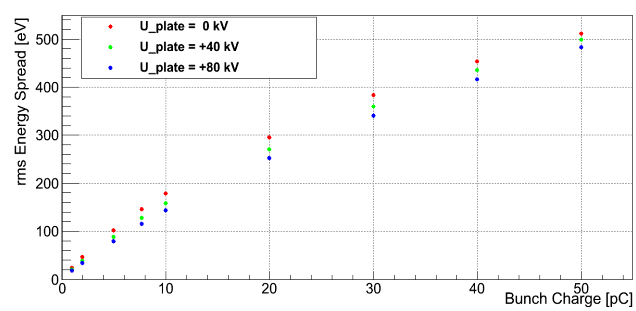

Figure 9: rms Energy Spread

REDUCED MELBA

The length of the entire MELBA (**ME**SA **L**ow Energy **B**eam **A**pparatus) section accounts to approximately 10m. Its first half is dedicated to the source diagnostics, vacuum separation and the manipulation of the electron spin. The second half (MELBA-2) is used to match the beam to the downstream accelerator [10]. Since the SPOCK electron beams will be injected directly into the matching section, the significant length reduction of the low energy transfer section will be beneficial to preserve the beam quality in presence of space charge effects. The layout of the SPOCK MELBA is illustrated in Fig. 10.

The remaining 4.7m long section between the cathode and the MAMBO accelerator (**Mil**li**am**pere **Bo**oster) [11] con-

ISBN: 978-3-95450-190-8 doi:10.18429/JACoW-ERL2017-MOPSPP006

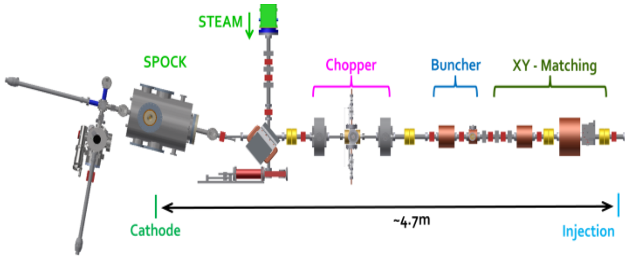

Figure 10: Scheme LEBT

tains the chopper, the buncher and the transverse matching elements, i.e. quadrupole magnets and solenoids. In order to minimise the length of the MELBA-2 section in favour of emittance preservation and the integration into the MESA facility an alternative design of the differential pumping stage is under investigation. In between the source and the MELBA injection a dipole section with a 12 deg deflection angle and a reduced aperture from CF40 down to CF16 will be inserted. The aperture reduction in combination with the bending section will reduce the residual gas load from the MELBA and in particular from the chopper collimator. Moreover, the 12 deg deflection also allows a head-on laser injection into the source. Further details to the laser injection and laser adjustments are recapitulated in [2]. However, due to this dipole section the transverse symmetry is broken. The dispersion causes an increase of the horizontal emittance and an additional focusing in the horizontal plane. Its impact on the development of the transverse beam sizes for a q=1pC bunch is shown in Fig. 11.

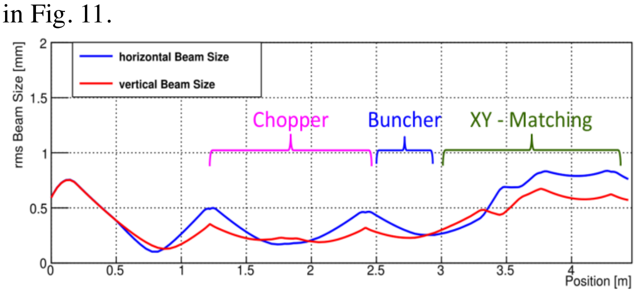

Figure 11: rms Beam Size along the LEBT

An enhancement of the optics distortion is given at higher bunch charges as well as settings of the source solenoid, which are leading to a larger horizontal beam size at the dipole entrance. Another critical part of the MELBA section is the chopper, which consists of adjustable collimator embedded into a double solenoid with a focal length of f≈0.17m. In order to mitigate its impact on the transverse beam size two double solenoids surrounding the chopper are foreseen to minimise the transverse beta function around the collimator. The optimised settings of the chopper are not defined so far and require further detailed studies of the downstream accelerator. In the presented simulation the beam is not collimated. In terms of emittance preservation the XY-matching section downstream the buncher is especially crucial. By means of the buncher [12] a correlated energy spread is imprinted. Along the XY-matching section the bunch length decreases, which leads to an increase of the charge density and an amplification of the space charge forces. Hence, any strong and rapid variations of the transverse beam sizes have to be avoided while matching the transverse Twiss parameters.

CONCLUSION AND OUTLOOK

Compared to the standard source for MESA it has been demonstrated that with the new source SPOCK significant advantages can be achieved. Moreover the shortening of the injection beam line by about a factor 2 will also help to increase the bunch charge for MESA even if no increase of the source energy is envisaged. Shortly the shape of the electrodes will be finalized. The potential for higher bunch charges injected into the second half of the MESA-LEBT will soon be fully explored and a decision if SPOCK will be integrated in MESA will be taken.

ACKNOWLEDGEMENT

The authors like to thank J.Rosche for his assistance at the design of the source and it components, the fruitful discussions and the continuous support. This work is supported by the German Federal Ministry of Education and Research (BMBF project HOPE-II FKZ 05K16UMA) and the Cluster of Excellence "PRISMA".

REFERENCES

[1] K.Aulenbacher et al., “Elementary Design Report for the Mainz Energy Recovering Superconducting Accelerator MESA”, Institut für Kernphysik, Mainz, Germany, Oct. 2014.

[2] L.M.Hein, “SPOCK - Short Pulse Source at KPH, Technical Design Report”, Institut für Kernphysik, Mainz, Germany, to be published.

[3] M.A.Dehn, “"Bau einer Elektronenquelle mit variablem Extraktionsgradienten zur Femtosekunden-Elektronenemissionsspektroskopie”, Dissertation Thesis, Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, Mainz, Germany, in preparation.

[4] V.Bechthold et al., “Time Resonse Investigations of K2CsSb Photocathodes” presented at ERL17, CERN, Switzerland, MOPSPP004, this workshop.

[5] M.Poelker et al., “Load-locked dc high voltage GaAs photogun with an inverted-geometry ceramic insulator” Phys. Rev. ST Accel. Beams 13, 2010.

[6] S.Friederich et al., “The Small Thermalized Electron Source at Mainz (STEAM)” presented at ERL17, CERN, Switzerland, MOPSPP005, this workshop.

[7] Computer Simulation Technology, Darmstadt, Germany.

[8] *PlotWin (V4)*, D.Uriot, CEA Saclay, France, April 2017 http://irfu.cea.fr/en/Phocea/Page/index.php?id=263

[9] K.Schindl, “Space Charge”, in Proc. CERN Acclerator School, DESY, Zeuthen, Germany, Sept. 2003, pp. 305-320.

[10] C. Matejcek et al., “Low Energy Beam Transport System for MESA” presented at ERL17, CERN, Switzerland, MOPSPP008, this workshop.

[11] R.Heine et al., “Current Status of the Milliampere Booster for the Mainz Energy-Recovery Superconducting Accelerator”, in Proc. *7th Int. Particle Accelerator Conf. (IPAC'16)*, Busan, Korea, May 2016, paper TUPOW002, pp. 1741-1743.

[12] P.Heil, “Longitudinale Emittanzanpassung durch Geschwindigkeitsmodulation im Injektionssystem am MESA”, Master Thesis, Johannes Gutenberg-Universität Mainz, Mainz, Germany, 2015.