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RUNNING STATUS OF SRF GUN-II AT ELBE CENTER*

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Abstract

As a new electron source with higher brilliance, the second version of the superconducting RF photoinjector (SRF Gun-II) has been successfully commissioned at the ELBE Center for high power radiation sources since 2014. SRF Gun-II features an improved 3.5-cell niobium cavity as well as a superconducting solenoid in the same cryomodule. With Mg photocathode SRF Gun-II can provide high current beam with bunch charge up to 300 pC at 100 kHz repetition rate. For user operation the SRF Gun-II successfully generated stable beam with 200 pC in CW mode and sub-ps bunch length. In this presentation the gun's status and beam parameters will be presented.

INTRODUCTION

The unique feature of the ELBE accelerator is its ability to operate in continuous wave (CW) mode for high average power output. Hence, a flexible CW electron source is required. An rf photoinjector based on superconducting technology represents the ideal solution for this task. It produces high field gradients causing enhanced beam parameters and large beam currents due to increased repetition rates.

The ELBE SRF Gun project is the R&D effort to provide such an injector. Commissioning with further improvements and optimization of components as well as our operational experience has increased the performance and reliability so that the SRF Gun-II is now applied for user operation.

SRF GUN-II

SRF Gun-II has been installed in the accelerator hall since May 2014 [1]. The main design is based on the first SRF Gun [2] with a modified 1.3 GHz Nb cavity and a superconducting solenoid at about 70 cm from the cathode [3]. The combination of 258nm laser and Mg cathode allows to provide beam with bunch charge up to 300 pC, which is limited by the space charge effect in the gun with an acceleration gradient of 8 MV/m (20.5 MV/m peak field on axis).

SRF Cavity and RF Performance

The 1.3 GHz Nb cavity was built, treated and tested at JLab [4]. It consists of three TESLA like cells, a specially designed half-cell and a choke filter. This filter is surrounding the cathode, preventing RF leakage into the cathode support system (see Fig. 1).

The performance of cavity has been measured regularly in the gun cryomodule without or with cathodes. Compared to the last vertical test at Jlab the cavity lost about 30% of its performance. A serious contamination was caused by particles sputtered from cathode surface onto the first iris of the cavity. Nevertheless, the remaining gradient is still higher than that of SRF gun-I. The safe gradient for the routine operation is 7 MV/m, with field on cathode 10.7 MV/m, and the main drawback is the field emission under higher field.

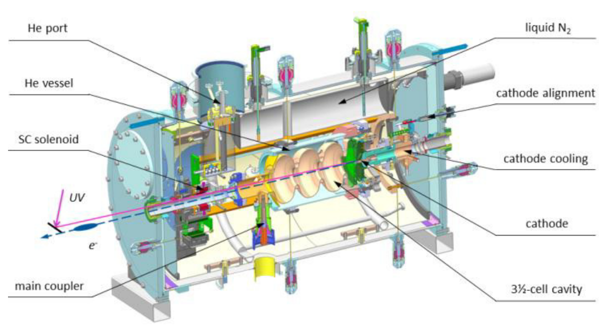

Figure 1: Cross section of the ELBE SRF gun II cryomodule, holding a 3.5 cell gun cavity and a superconducting solenoid at about 70 cm from the cathode.

Photocathode and Laser

In the first SRF gun at ELBE operating until 2014, the main problem caused by Cs_2Te photocathodes was multipacting in the gap of cathode hole, but the lifetime was not a problem [5]. In SRF Gun-II, the life time of Cs_2Te photocathodes was only two weeks. The possible reason of its degradation is the overheating of the cathode plugs during the operation. Further detailed studies and technical modifications are going on.

Mg cathodes made of bulk magnesium and cleaned with focused UV laser beam are working for the regular ELBE user operation with the SRF gun. Magnesium has a low work function of 3.6 eV. Illuminating with UV laser light at 258 nm, the expected quantum efficiency (QE) of Mg can be as good as 0.6 %, which is the best QE ever reported in rf guns. The UV drive laser can deliver pulses with up to 3 μJ at 100 kHz repetition rate, which is enough to produce bunches up to 300 pC with a Mg photocathode. The laser spot size on photocathode is about ϕ 4 mm. The temporal profile is Gaussian with an rms pulse length of about 2 ps.

Figure 2 shows the measured Faraday cup current (and bunch charge) versus drive laser phase for different laser power. The laser phase of the SRF gun in operation is indicated by the vertical zone between 40° to 60°. One

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can observe a strong space charge effect at the low rf phase and Schottky effect at the rf phase higher than 50°.

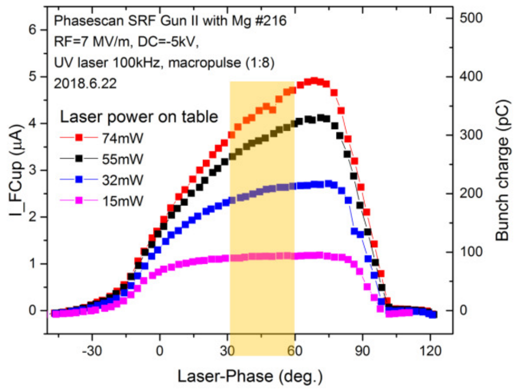

Figure 2: Measured Faraday cup current (and bunch charge) vs. drive laser phase. The working laser phase of the SRF gun is indicated by the vertical zone (40° to 60°).

Diagnostics Beamline

A separate diagnostics beamline lies directly behind the SRF gun at ELBE. An insertable Faraday cup after the solenoid is to measure the total current. Three quadrupoles focus the beam for further transport, followed by five screen-stations for beam observation, plus moving slit for transverse phase space distribution and emittance measurement. The rms transverse emittance is showed in Fig. 3 with an error less than 15% [6].

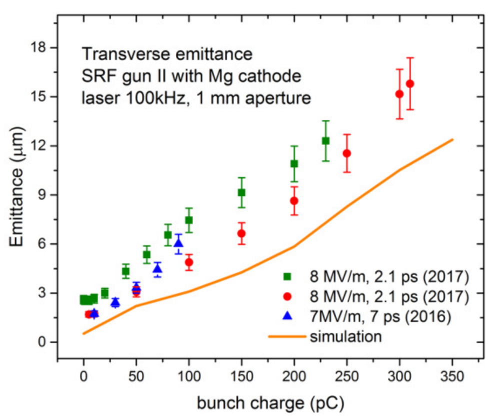

Figure 3: Measured transverse emittance vs. bunch charge, compared with the ASTRA simulation result.

A 180° horizontal dipole (C-bend) is for energy and energy spread measurement. Figure 4 presents the energy and energy spread versus the laser phase, with gradient of 8 MV/m. In the gun operation, laser phase is set as 40° to 60°, and the energy spread is 5 - 25 keV.

To do the measurement of the longitudinal distribution and bunch length, ELBE Linac is used by applying the zero phase chirping method [6].

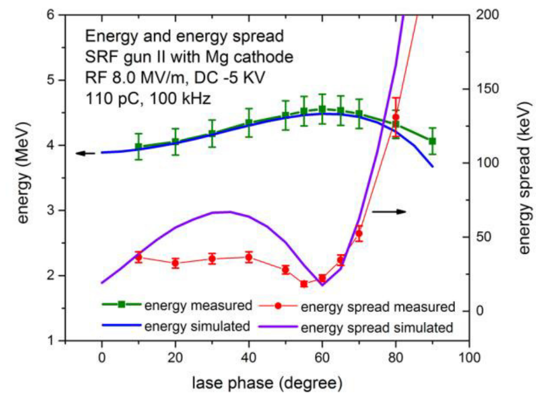

Figure 4: Energy and energy spread versus the laser phase, here with gradient 8 MV/m. The working phase for SRF Gun II is between 40° to 60°.

BEAM PARAMETERS

Table 1 lists the main beam parameters of SRF gun-II with Mg cathode. For the injector of a user facility, the stability is one of the most important characters. Figure 5 shows the beam current measured from cathode and collected by the Faraday cup. The difference between the two curves came from about 5% beam loss and also due to some calibration issue. The small fluctuation on cathode current in the first houses was induced by the treating effect of a DC gun nearby. In more than 24 hours of continuous operation the current kept high stability of 1%.

Table 1: Main beam parameters of SRF gun with Mg cathode (with gun gradient 8 MV/m).

Parameter	Measured
energy	4.5 MeV
bunch charge	0 – 300 pC
transverse emittance	2 – 15 µm
energy spread	5 – 25 keV
micro pulse rate	100 – 500 kHz
beam current (CW)	30 µA
dark current	50 nA

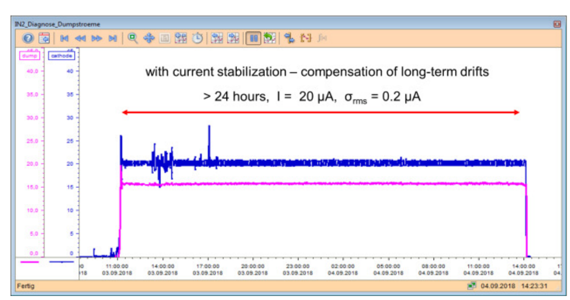

Figure 5: Beam current measured from cathode and collected by the Faraday cup. The beam loss from cathode to FC is 5%. The rest difference in between is due to some calibration issue. A high stability of 1% is kept in 24 hours of continuous operation.

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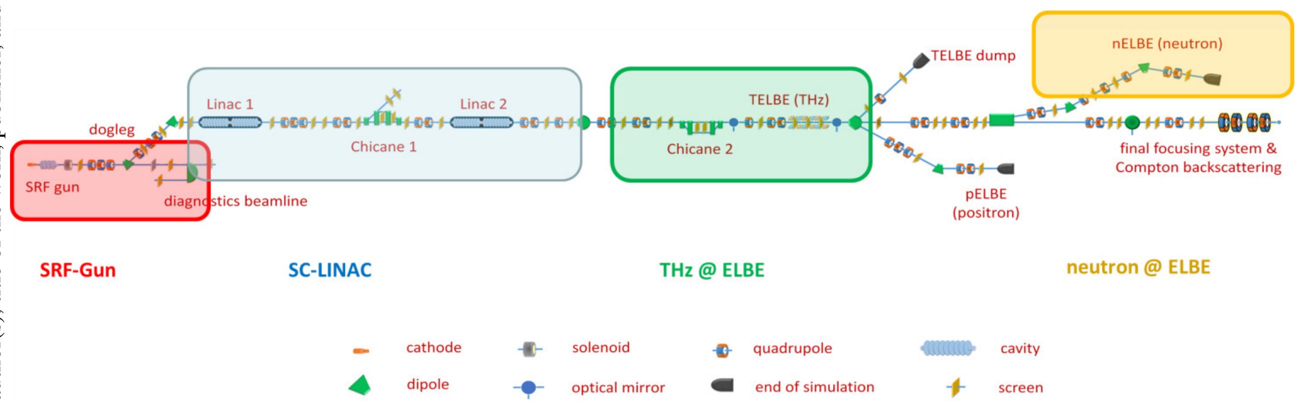

Figure 6: Layout of the SRF gun and SRF linac followed by THz beam line (TELBE) and neutron beam line (nELBE).

USER APPLICATION

Figure 6 shows the beamline layout at ELBE hall for the THz radiation production with the SRF gun injection into ELBE SRF Linac. The beam leaves the SRF gun, passes through a matching quadrupole triplet and the achromatic dogleg structure and enters into the ELBE Linac beam line. There the relativistic beam is further accelerated on-crest in the SRF Linac 1 and off-crest in the Linac2 in order to produce the required energy chirp for bunch compression. The final beam energy is 26.5 MeV in the latest experiment. In the magnetic bunch compressor (chicane 2) the bunch is compressed to sub-ps length. The electron beam passes through the undulator U300. In this electromagnetic undulator with 8 periods and a period length of 300 mm the super-radiant undulator radiation is produced with a designated range between 0.1 and 3 THz [7].

The SRF gun operated stably for a number of subsequent shifts without any shutoffs. Applying the SRF gun with a bunch charge of 200 pC, convincing results for THz production has been obtained. The output power was four times higher compared to that with the thermionic injector (80 pC/bunch), reaching more than 300 mW at 1 THz. Consequently, higher THz power together with better stability could be delivered to user experiments.

CONCLUSION AND OUTLOOK

Although SRF Gun-II doesn't reach the designed parameters due to cavity pollution, it has successfully provided electron beams for ELBE user operation. The SRF gun operated stably for a number of subsequent shifts without any shutoffs in 2018. Applying the beam with high bunch charge of 200 pC and sub-ps pulses with the bunching concept in ELBE, the convincing results for THz production has been obtained.

A new gun lab consisting of an SRF gun and a diagnostics beamline has been planned at ELBE centre to support the research and development of SRF gun since 2018. It will be separated from the ELBE accelerator hall in order to offer more time for the gun experiments.

ACKNOWLEDGEMENTS

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