COMMISSIONING OF AN IMPROVED SUPERCONDUCTING RF PHOTO INJECTOR AT ELBE

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Abstract

In order to produce high-brightness electron beams in a superconducting RF photo injector, the most important point is to reach a high acceleration field in the cavity. For this reason two new 3.5-cell niobium cavities were fabricated, chemically treated and cleaned in collaboration with Jlab. The first of these two cavities was shipped to HZDR and assembled in a new cryomodule. This new gun (SRF Gun II) was installed in the ELBE accelerator hall in May 2014 and replaces the previous SRF Gun I. Beside the new cavity the ELBE SRF gun II differs from the previous gun by the integration of a superconducting solenoid. The paper presents the results of the first test run with a Cu photocathode.

INTRODUCTION

At the superconducting (SC) electron linear accelerator of the ELBE radiation facility [1] a new superconducting electron photo injector (SRF gun) has been installed in May 2014. The new gun (SRF Gun II) replaces the previous one which had been in operation from 2007 until April 2014. For the old SRF gun the handicap was the low acceleration gradient. Due to strong field emission of the cavity the maximum gradient (peak field) was only 17.5 MV/m in CW belonging to a kinetic energy of 3.3 MeV of the emitted electrons. Although SRF gun I could not reach the design specifications, it was successfully operated for R&D purposes and also for some dedicated user experiments at ELBE.

Table 1: Design Parameters of the ELBE SRF Guns at HZDR

Operation mode	FEL mode	High charge mode
Laser rep. rate	13 MHz	100-500 kHz
Laser pulse length	3 ps fwhm	12 ps fwhm
Peak field	50 MV/m	50 MV/m
Bunch charge	77 pC	1 nC
CW beam current	1 mA	≤ 0.5 mA
Kinetic energy	9.5 MeV	9.5 MeV
Transv. emittance	1 µm	2.5 µm

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In a collaboration of HZDR and Jlab two new niobium cavities for the next ELBE SRF gun have been built, treated and tested at JLab. At the same time a new cryomodule has been designed and built at HZDR. One of the two new cavities was shipped to HZDR in November 2013. After arrival the assembly of the cryomodule was completed and the gun was installed in the ELBE accelerator hall in May 2014. The gun has been running since June 2014 for first RF and beam tests

The aim for ELBE SRF gun II is to approach the beam specification as given in Table 1. At ELBE an electron gun with high-brightness beam, high average current, and high bunch charge is needed to fulfill the future user requirements and provide high-flux neutron and positron beams as well as to operate the THz facility and the CBS x-ray source for users.

CAVITY AND CRYOSTAT DESIGN

The design of the new cryomodule for SRF gun II is shown in Fig. 1. The 1.3 GHz Nb cavity consists of three TESLA cells and a specially designed half-cell. Another superconducting cell, called choke filter, prevents the leakage of the RF field towards the cathode support system. The normal conducting (NC) photocathode is installed in this system, which is isolated from the cavity by a vacuum gap and cooled with liquid nitrogen. This design allows the application of NC photocathodes with high quantum efficiency (QE) like Cs_2Te.

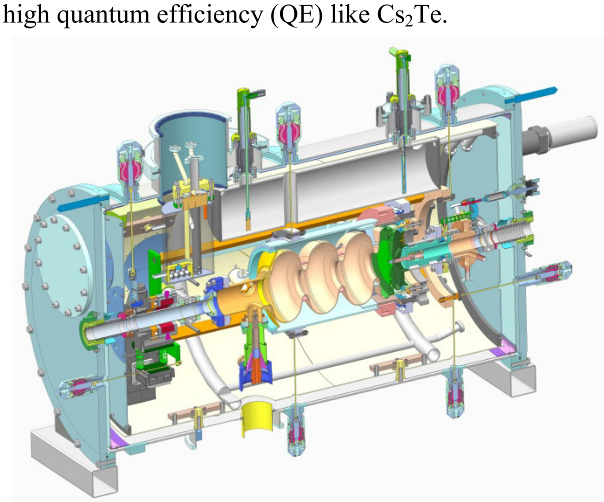

Figure 1: CAD view of the SRF Gun II cryomodule.

Similar to cavity and cathode support system, most of the cryomodule components, the cavity tuners, and the fundamental power coupler are identical in the design

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with that of the previous SRF gun I [2]. The new cavity differs in the improved half-cell stiffening and some other minor modification [3].

New is the integration of a SC solenoid in the cryomodule for emittance preservation purposes. Compared to the NC solenoid of SRF gun I which was placed downstream the gun, the new design is much more compact and the distance to the cavity is smaller. The SC solenoid is placed on a remote-controlled x-y table to align its center to the electron beam axis. The cryogenic design of the assembly is sophisticated: The solenoid is cooled with 2 K He by means of a bypass from the cavity. The in-vacuum step motors and translation tables are on 77 K to reduce the heat load to the liquid He bath. Additional μ-metal shields hold the solenoid remanence field and the step motors fields on a 1 μT level near the cavity. Details of the SC solenoid design and testing are published in ref. [4].

GUN COMMISSIONING

Installation

The installation of SRF Gun II is organized in two phases. The first step was the replacement of the gun cryomodules in the ELBE hall during the spring shutdown in May 2014. At once the cathode transfer system of SRF Gun I was dismounted for revision and cleaning. The commissioning started with a copper photocathode mounted in SRF Gun II during the clean-room assembly. The second step is the installation of the refurbished cathode transfer system. This work is scheduled for the ELBE autumn shutdown in October 2014. In the following run, the SRF Gun II can be operated with Cs_2Te photo cathodes.

RF Measurements

At first the cavity was undertaken a testing and conditioning program with pulsed RF. After that the cavity was tested and measured in CW. The preliminary results of the cavity performance (intrinsic quality factor versus acceleration gradient) are presented in Fig. 2. For comparison, the figure shows also the results of the final vertical test at Jlab (blue), as well as the best (after a high power processing), and the latest results for the old SRF gun I cavity. The acceleration gradient of about 10 MV/m, obtained up to now as the maximum, belongs to a peak field of 27 MV/m in the TESLA cells of the cavity. In the final vertical test this cavity reached 38 MV/m peak field. Remarkable for the new gun is, that the high quality factor of $>10^{10}$ could be retained after assembly and installation.

Superconducting Solenoid

The SC solenoid was already tested and its field distribution measured before (see Ref. [5]). In the gun the proper operation of the x-y table, the magnetic shielding, and the cryogenic behavior has been checked. The maximum design value for the current of 10 A could be reached without quenching. Moving the solenoid an increased microphonics level is visible in the RF control system. But it is small enough that it does not cause an RF trip. The solenoid position has been arranged by beam based alignment. There is evidence for a small horizontal tilt of the solenoid axis. The fluxgate magnetometer in the cryomodule allows to monitor the fringe field value near the cavity. A degaussing procedure will be developed and implemented in the computer control system.

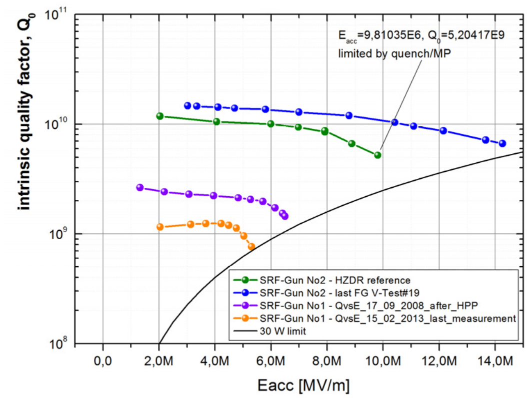

Figure 2: Comparison of cavity performance for the ELBE SRF guns.

Beam Parameter Measurements

In the following we present preliminary results of beam parameter measurements together with ASTRA [6] results. The measurements should confirm that all subsystems, like RF control, drive laser, timing and synchronization work well.

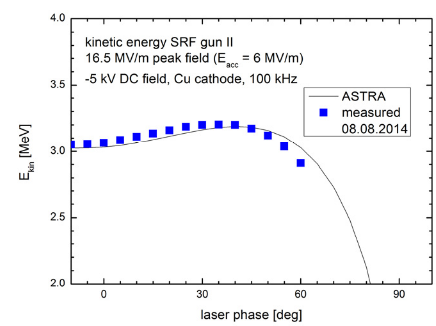

Figure 3: Measured kinetic energy versus laser phase.

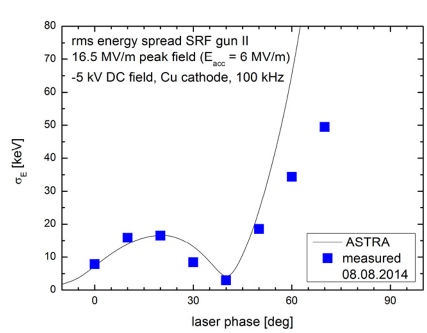

Figure 4: Measured rms energy spread versus laser phase.

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The beam characterization was performed in CW with an acceleration gradient of 6 MV/m (16.5 MV/m peak field). At this gradient the cavity RF losses are about 3 W. The dark current measured in the Faraday cup, which is about 1 m downstream of the gun, was less than 1 nA. The low QE of the Cu photo cathode of less than 10^{-4} allows typical CW beam currents of 10-20 nA with the 258 nm UV drive laser operated with a repetition rate of 100 kHz. Due to the very low bunch charge the beam parameters are RF field dominated. An exception is the transverse emittance which is determined by the thermal emittance of the photo cathode of about 0.5 µm per mm laser spot.

Before each measurement the laser arrival phase was calibrated with a laser phase scan (0° corresponds to the zero-crossing of the RF field.) and the laser spot was centered on the photo cathode by means of beam based alignment.

The energy and energy spread of the beam was measured with the 180° dipole magnet in the diagnostics beamline [7] and are presented in Fig. 3 and 4. The kinetic energy has a maximum at a phase of 40° which leads to a change in the sign of correlation, and a minimum in the energy spread at this phase.

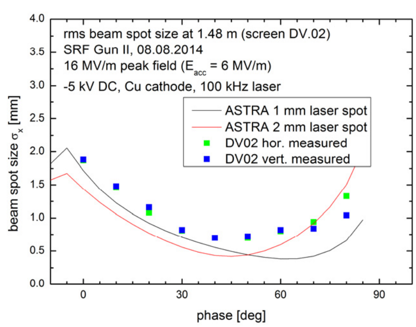

Figure 5: Measured rms beam spot size.

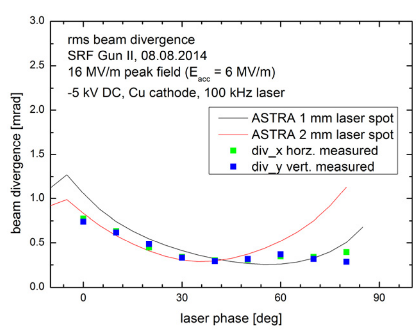

Figure 6: Measured rms beam divergence.

The absence of space charge effects leads to a nearly collimated beam which needs no further focusing. The spot size measured on a screen with 1.42 m distance to the cathode is shown in Fig. 5. Performing beam size measurements on two consecutive screens delivers the divergence of the beam coming out of the gun (Fig. 6).

Transverse emittance measurements were carried out using the moving slit scan technique. Results are shown in Fig. 7. A first determination of the bunch length was obtained from the phase scan method (Fig. 8). Thereto the beam was guided into the ELBE accelerator and then through the first linac module. For one of the accelerator cavities the phase was varied and a following dipole magnet was used to measure the energy spread as function of this phase.

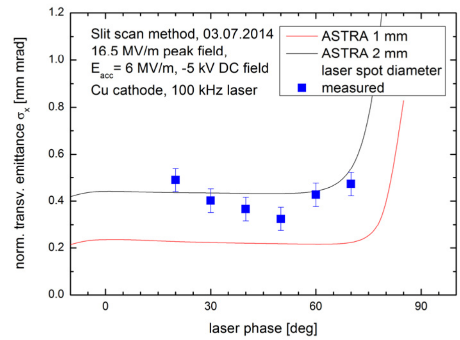

Figure 7: Measured normalized transverse rms emittance.

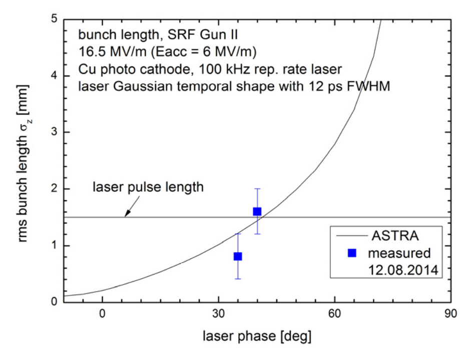

Figure 8: Measured rms bunch length.

CONCLUSION

The results of the first commissioning period of SRF Gun II are very promising. The RF performance measurements show that the intrinsic quality factor is still at 10^{10} after gun assembly and the cavity does not suffer under field emission. Compared to SRF Gun I an improvement of about a factor two in the maximum gradient could be achieved. First beam parameter measurements with the Cu cathode show good agreement with simulations and confirm the proper operation of all subsystems.

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