ISBN: 978-3-95450-192-2 doi:10.18429/JACoW-IBIC2017-MOPWC01

BUILDING THE THIRD SRF GUN AT HZDR

H. Vennekate[1]*, A. Arnold, P. Lu, P. Murcek, J. Teichert, R. Xiang
Helmholtz-Zentrum Dresden-Rossendorf, Germany
[1]also at Technical University Dresden, Germany

Abstract

The multipurpose accelerator ELBE at HZDR which is delivering a large set of secondary beams, is driven by a thermionic DC injector. In order to enhance the beam quality of the machine, the development of superconducting RF injector has been pursued since the early 2000's. The corresponding ELBE SRF Gun I of 2007 and Gun II of 2014 already delivered beam for the operation of several user beamlines, such as the FEL, positron generation, and THz facility. Currently, the next version – Gun III – and its cryomodule are being assembled, characterized, and prepared for the final commissioning throughout late 2017/early 2018. The new module benefits from the experiences gained with regard to emittance compensation and monitoring of operation variables made with the two predecessors.

MOTIVATION

The unique feature of the ELBE accelerator is its ability to run all its modules in continuous wave (CW) mode while delivering electron bunches at a frequency of up to 13 MHz. Hence, a flexible CW source is required for its operation. A superconducting radio frequency (SRF) electron gun represents the ideal solution for this task. Itcombines the advantages of RF injectors and DC guns, which are high field gradients causing enhanced beam parameters and large beam currents due to increased repetition rates, respectively. The ELBE SRF Gun project is an R&D effort to provide such an injector. The two implemented prototypes — Gun I and Gun II — successfully provided beam for several of the beamlines during machine tests as well as for user operation [1]. Due to a degradation of available maximum gradient of the cavity of the currently installed Gun II, the construction of the third version of the photoinjector was initiated. For this purpose, the niobium resonator of Gun I is being refurbished at DESY, Hamburg. In combination with a newly built cryomodule, this cavity is designated to be put in operation as the ELBE SRF Gun III within 2018.

EMITTANCE COMPENSATION

An important aspect of the beam dynamics of an SRF injector is the optimization of the emittance of the electron bunches, which presents more challenges than for a normal conducting gun. In the case of the ELBE SRF gun this is solved by a combination of RF focusing at the photocathode and a superconducting solenoid being integrated into the injector's cryomodule, as shown in the scheme in Figure 1. The use of these two mechanisms has shown a significant

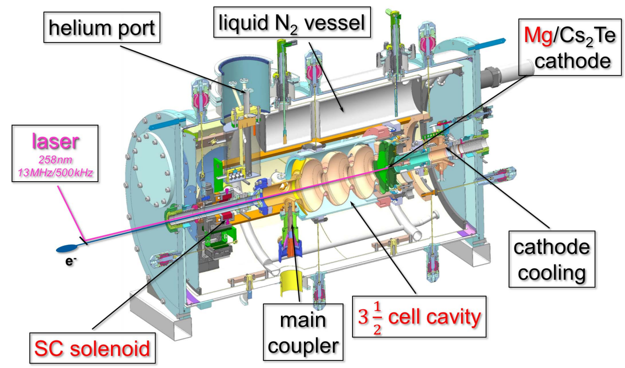

Figure 1: The current ELBE SRF Gun design featuring a 3.5 cell gun cavity and a superconducting solenoid at about 70 cm from the cathode.

reduction of the particle beam's transverse emittance and extent in both, simulation (see Figure 2) as well as in experiment (see Figure 3) [2]. This is of substantial importance for the successful integration into an accelerator's beam dynamics framework.

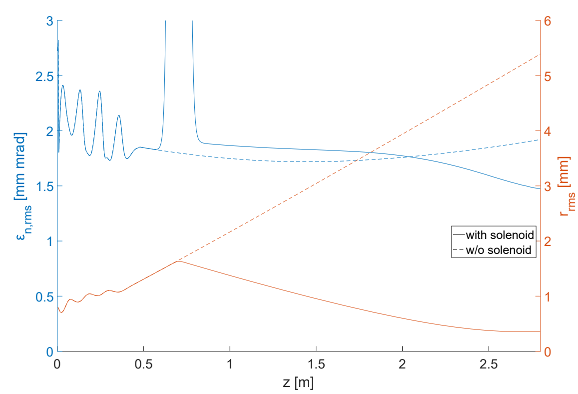

Figure 2: Simulation results of the evolution of a 250 pC bunch in emittance and radius along the first 3 m of beamline [2].

In addition to the characterization of the intentional displacement of the photocathode inside the superconducting cavity to control RF focusing [3], the superconducting magnet requires separate thorough examination and testing prior to its installation inside the module. The corresponding measurements conducted so far are described in the following.

* h.vennekate@hzdr.de

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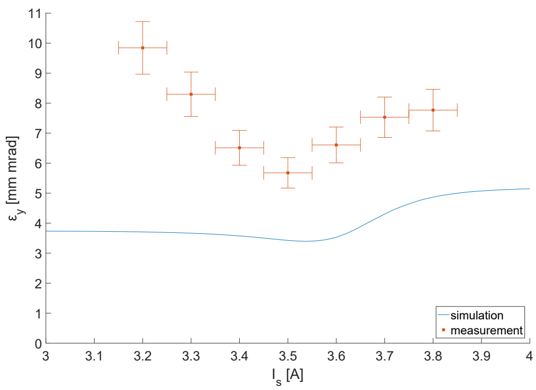

Figure 3: Emittance vs. solenoid current measured with Gun II for a 160 pC electron bunch at about 3 m, [2].

SOLENOID COMMISSIONING

Magnetic Field

In order to determine the field distribution of the magnet[1], a mapping setup, attached to the gun cryostat as shown in Figure 4, was installed. Using currents in the order of few tens of mA, the field in a cuboid shaped volume was recorded in front, inside, and behind the solenoid by a hall probe. The geometrical resolution of this room temperature measurement was 1 mm.

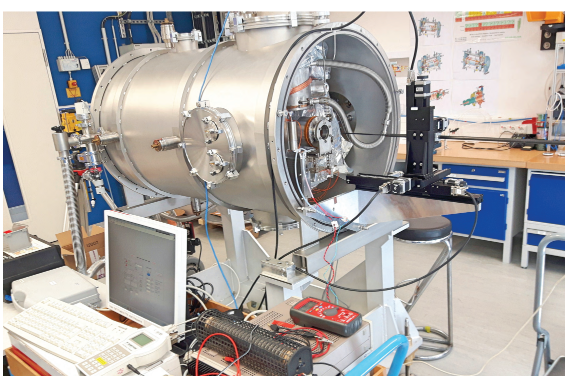

Figure 4: Measurement setup for the room temperature mapping of the solenoid.

For each transverse slice of the measured field the center of the distribution was computed using a two dimensional Gaussian fit. Due to the fact that only the longitudinal field component could be recorded with the available probe[2], the character of this center varies from a maximum in the domain of the fringe fields to a minimum inside the coil. The latter situation being the one depicted in Figure 5.

Using the results for each longitudinal position, a weighted fit for the total beam axis was generated. Here, a deviation from an ideal axis of 1.9 ± 0.7° in one plane

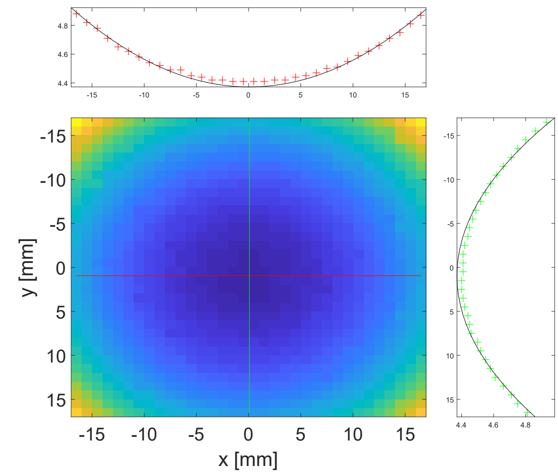

Figure 5: A slice of the longitudinal field inside the magnet's coil.

and 1.3 ± 0.7° in the other was found [4] (see Fig. 6). Such misalignments typically induce steering and other alteration effects on the electron bunch during beam operation. Therefore, two cryogenic steppers are included in the final setup to enable small correction movements of the solenoid in the transverse plane. An error-free alignment of both, the cavity's electrical and the solenoid's magnetic axes is rather difficult prior to cooldown. However, experiences made with Gun II showed that those minor movements of the solenoid are sufficient to compensate for alterations.

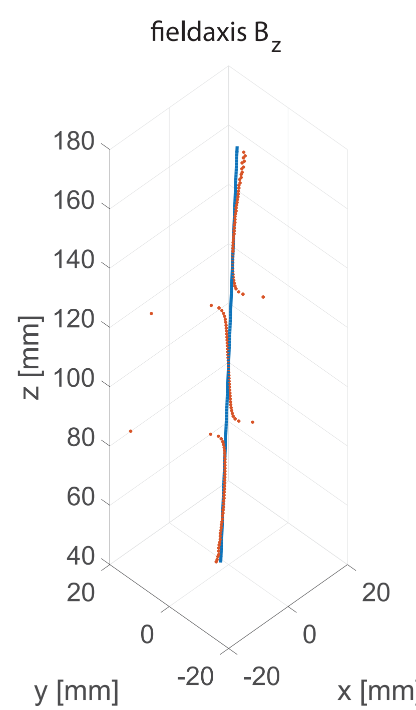

Figure 6: The result of a mapping measurement: the magnetic field axis is reconstructed with respect to the beam axis in 3d [4].

[1] The installed solenoid magnet was manufactured by Niowave Inc. and is on loan from the Helmholtz-Zentrum Berlin.

[2] Recently, a three dimensional hall probe was acquired and is foreseen to be used for future measurements at HZDR.

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Thermal Testing

The entire module of the ELBE SRF Gun features many temperature sensors at relevant locations to monitor the thermal behavior during operation. Depending on the expected temperature range that has to be covered, the type of sensor varies. Taking into account the experiences with Gun II, all RhFe sensores are replaced with Cernox sensors in Gun III. Furthermore, additional copper heat sink bobbins — as shown in Figure 7 — are introduced close to the sensors to absorb the heat introduced by the read-out leads. In first cooling tests with liquid nitrogen and helium this modified setup already showed a significant improvement of the sensor sensitivity [4].

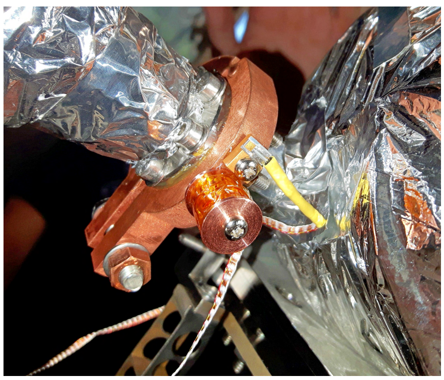

Figure 7: One of the newly installed Cernox temperature sensors at the helium supply line of the solenoid, featuring a heat sink bobbin where the sensor leads are wrapped around the copper body to connect it to the liquid helium system.

CRYOSTAT COMMISSIONING

The new cryomodule of Gun III itself is also undergoing early functional checks at HZDR. These include the obligatory vacuum/leak checks of all components as well as first temperature tests with cryogenic liquids. At its current state, the model does not include its liquid nitrogen or magnetic shield yet. However, the liquid helium reservoir, the superconducting solenoid, and a cavity model were already mounted. Cooling this limited helium system first test measurements could be performed in recent weeks, see Figure 8. These experiments were aimed at a first operation of the solenoid with larger currents, so in its superconducting state, followed by corresponding field measurements, compare [5] for results with Gun II. As the magnet's coil did not cool down sufficiently below its critical temperature, such a test was not possible so far. Nevertheless, the experiment enabled the recording of other valuable data such as the improved temperature signals mentioned above.

OUTLOOK

In the near future, further elements of the new module will be added to the setup and accordingly commissioned. This

Figure 8: The cryomodule of Gun III during cooling with liquid helium.

includes the liquid nitrogen shield, which will be followed by another cooldown of the solenoid. Furthermore, a room temperature magnetic shield has to be installed and will be checked for the magnitude of the remaining stray field at the future position of the niobium resonator. In parallel, the treatment of the gun cavity at DESY is proceeding with a currently pending vertical performance test.

ACKNOWLEDGMENTS

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP7 program (EuCARD-2, contract number 312453), as well as the support of the German Federal Ministry of Education and Research grant 05K12CR1 and the help of all the people of the ELBE shift personnel. In addition, we would like to thank the people of HZB for the loan of their magnet.

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