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TRANSVERSE EMITTANCE COMPENSATION FOR THE ROSSENDORF SRF GUN II

H. Vennekate*, P.Lu, HZDR, TU Dresden, Dresden, Germany
A. Arnold, P. Murcek, J. Teichert, R. Xiang HZDR, Dresden, Germany
P. Kneisel, JLab, Newport News, VA, USA
T. Kamps, HZB, Berlin, Germany

Abstract

Superconducting RF particle sources combine the advantages of normal conducting RF sources and high duty cycle non-RF sources. The Rossendorf SRF gun was the first to demonstrate this injecting electrons into the ELBE accelerator at 13 MHz. Recently, a new 3-1/2-gun cavity has been prepared at Jefferson Lab for its use in an updated injector which is expected to increase the electron energy from 2.4 to 7.5 MeV. Along with this new cavity, a new gun cryostat has been introduced. It combines several minor updates to the setup with the installation of a superconducting solenoid right at the exit of the gun, compensating the emittance growth of the electron bunch at an early stage. Hereby, the results of the commissioning of the new cryostat including the solenoid are concluded and compared to the prior concept of using a normal conducting solenoid outside the cryostat. As it is of great importance to this subject, studies of the magnetic shielding are going to be presented as well.

MOTIVATION

The main goal of a superconducting radio frequency (SRF) electron injector is to operate at high repetition rates, therefore delivering high beam currents, while maintaining a good beam quality i.e. high beam brightness. In order to show the capabilities of such a concept for electron machines using the 1.3 GHz TESLA (or similar) accelerator technology, a first test setup, based on a half-cell niobium cavity, has been created at the HZDR. This prove of principle injector—referred to as “Drossel”—lead to a first-beam experiment in 2002 [1]. It was followed by the design and construction of a 3-1/2-cell niobium gun cavity, inserted into a complete new cryostat, the Rossendorf SRF Gun I. By 2010 [2] this injector had been integrated into the ELBE (Electron Linac for beams with high Brilliance and low Emittance) accelerator facility at HZDR and delivered its first all superconducting beam. Besides other aspects, this has also been the start of the development of the next gun based on a new 3-1/2-cell resonator—the Rossendorf SRF Gun II—including an improved cavity design and new features to the cryomodule, caused by the experience gained so far. Still during the production and processing of the new niobium resonator at JLab, the first operation of a free electron laser with an SRF injector was achieved with the existing Gun I at the ELBE center in 2013 [3].

* h.vennekate@hzdr.de

EMITTANCE COMPENSATION

Solenoid

All of the Rossendorf SRF guns are photoinjectors. An external UV laser, operating at a wavelength of 262 nm, is used via a system of mirrors to extract electrons out of the surface of a coated, exchangeable (photo)cathode. This can be done at different repetition rates of up to 13 MHz. The later one being referred to as continuous wave mode. By the geometrical attributes of the space in where the cathode enters the resonator, its accelerating field can be used to generate the so called effect of “RF focusing”—a first stage of emittance compensation described in more detail in [4]. Although this RF lens is located at the smallest possible distance to the actual bunch generation, it is also limited by the accelerating gradient. Another more independent method has been realized for the SRF Gun I by mounting a huge solenoid around the beam pipe just next to the injectors cryostat, see figure 1. This electromagnetic coil with a diameter of 70 cm of its iron yoke, generated a magnetic field with peak values of 440 mT over a track of 12 cm, working as a focusing lens for the electron bunches leaving the gun. Mostly dominated by the dimensions of the gun cryostat, the front of this setup has been set at a distance of roughly 110 cm from the photocathode’s surface.

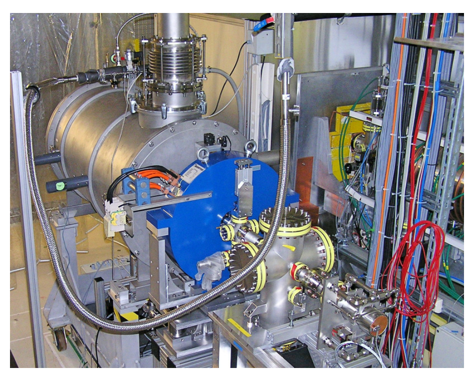

Figure 1: Picture of the Rossendorf SRF Gun I beam line including the cryostat in the back and the normal conducting solenoid (blue) at the injectors exit. The beam direction is to the lower right.

Superconducting Solenoid

In order to get the focusing forces closer to the cathode and so to the initial generation of the electron bunch, the

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design of the new crystoat for the SRF Gun II includes a superconducting solenoid next to the cavity, surrounded by an additional magnetic shield. This solenoid has been manufactured by Niowave using NbTi-wires and is integrated into the same liquid helium supply system as the helium vessel of the niobium resonator itself.

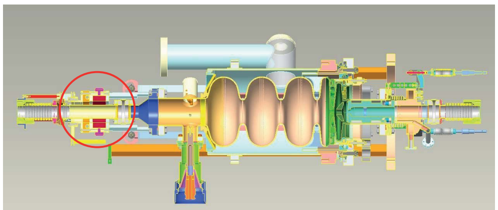

Figure 2: Drawing of the cavity string of the 3-1/2-cell resonator with highlighted position of the superconducting solenoid which is located about 70 cm from the cathode in the first half-cell.

The cooling of the SC wire is done via an U shaped tube filled with liquid helium inside a solid copper ring, which is again thermally connected to the solenoid yoke via an indium disc as shown in figure 3.

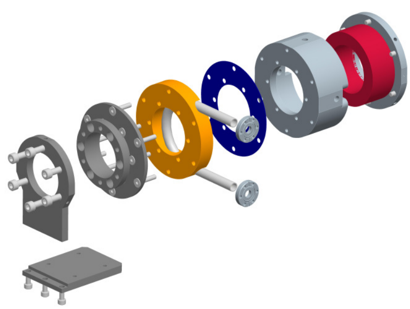

Figure 3: Exploded view of the superconducting solenoid, from left to right: Front plate with base plate, connector, copper cooler with helium pipe, indium disc, solenoid yoke, coil, yoke back plate.

The whole structure rests upon two stepper motors, that are able to move the magnet around the beam pipe in the plane perpendicular to the beam axis in order to compensate for possible errors in its field distribution. The superconducting solenoid has a diameter of 14 cm and reaches a peak magnetic on-axis field of about $B_{z,max} \approx 450\,\text{mT}$. With its length of approximately 6 cm it generates a refractivity of $\int_{z'} B_z^2\,\text{dz} \approx 0.009\,\text{T}^2\text{m}$ at a distance of about 70 cm to the cathode's surface [5]. Besides it being much smaller and less power consuming, the superconducting solenoid is hence hoped to contribute to enhanced beam quality for the whole injector section. Results of a recent measurement of the emittance of the SRF Gun I can be found in [6].

MAGNETIC SHIELDING

Cryomodule

As soon as a magnetic field is present in the area occupied by the superconducting material during the cool down phase, the magnetic field lines are "frozen" in the superconductor, consequently limiting the critical field it is able to withstand before quenching. In order to shield the SRF gun cavity from the earth's magnetic field, the cryostat of the Rossendorf SRF Gun II contains a large μ-metal cylinder, set between its liquid nitrogen shield and the outer vacuum vessel. The chosen limit to reach large values of the quality factor of the resonator has been set to 2.5 μT. The cryostat's "warm" μ-metal shield has first been formed—i.e. bent—and welded, before undergoing the typical high temperature annealing process. After its installation in the gun's cryomodule, the magnetic absorption, so the remaining field in the inside has been determined using several probes and setups. The results of the most precise measurement, using a 3-d fluxgate magnetometer by Förster with a resolution of less than 0.2 μT, are presented in figure 4.

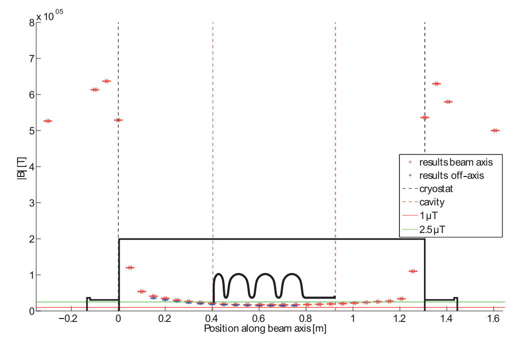

Figure 4: Combined results of measurements of the absolute magnetic field inside the cryostat. The red tics represent two measurements done at different orientations of the cryostat, both measured along the beam axis. The blue marks show a measurement of the field on an axis through an off-axis hole in the shield, this is roughly at the position of the resonator's equator.

Degaussing

Because of the lack of an additional cold magnetic shield around the niobium resonator inside the cryomodule, the introduction of any magnetized parts within that shield, has to be avoided. During the assembly of the Rossendorf SRF Gun I a lot of experience considering that matter has been gained. Therefore, severe checks on all parts of the new cavity string have been performed prior to its installation. Especially the vacuum parts, including two hand valves, demanded further treatment. Parts like these can be demagnetized or "degaussed" by applying an altering field using simple coils around their magnetic hot spots. Figure 5 shows the degaussing of a valve at the rear end of the cavity string. The applied fields have to meet certain requirements regarding the coercivity of the material and the decrement of the field amplitudes during their oscillations [7]. Other smaller parts, like screws or nuts, have been demagnetized using a simple plate degausser by Maurer Magnetic.

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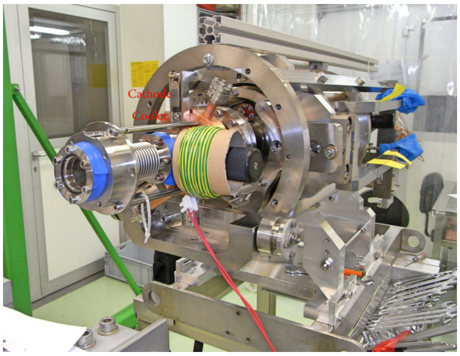

Figure 5: A coil made of copper wire, wrapped around one of the critical hand valves at the rear of the cavity string. The coil is operated by two power supplies, generating a altering, decreasing current.

Solenoid and Steppers

The coil of the superconducting solenoid can be used to degauss its own yoke. Additionally, a cold, cylindrical magnetic shield is put around the entire solenoid itself to offer a passive level of shielding. However, the steppers used to adjust the solenoid's position around the beam pipe, contain permanent magnets which are essential for their operation. Thus, both of the steppers had to be shielded individually to maintain the targeted remaining field value of less than 2.5 μT in the area of the niobium resonator. The final setup is depicted in figure 6.

After all the measures mentioned above were applied, the magnetic field inside the cryostat, with the entire cavity string installed, has been measured again at several critical spots. The absolute fields here were all below the value of 2 μT within the precision of the measurement. Furthermore, a fluxgate magnetometer has been installed between the solenoid and the resonator to monitor the magnetic field during cool down and operation within the closed module.

SUMMARY

The HZDR has a very successful recent history of building superconducting injectors, which—in combination with CW accelerator—provides a unique situation in the field of electron machines. Most currently the new Rossendorf SRF Gun II has been designed to be another milestone on this path. A new approach towards better emittance compensation has been taken. Since the method of using an SC solenoid is also done at other laboratories, the results from Dresden may have an increased impact on the technology. At the moment, the SRF Gun II has passed the assembly and entered the commissioning phase. The cryostat has recently been installed in the ELBE hall and was cooled down with liquid helium, resulting in measured resistance of the solenoid close to zero. The magnetic field determined by the integrated fluxgate magnetometer along the beam axis is in the range of 1 μT, while first RF tests are being conducted. The first beam with the new injector has successfully been generated on June 10th.

Figure 6: Front view of the SRF Gun II cryostat with both steppers—holding the SC solenoid—installed and fully equipped with their thermal anchors and magnetic shielding. (The magnetic shielding of the solenoid itself is not yet installed in this picture.)

ACKNOWLEDGMENT

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