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DESIGN UPGRADES OF THE NEXT SUPERCONDUCTING RF GUN FOR ELBE

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Abstract

At the ELBE user facility a superconducting RF photoinjector has been in operation since several years. The injector is routinely applied for THz radiation production in user beam experiments. For future applications higher bunch charges, shorter pulses and lower transverse emittances are required. Thus it is planned to replace this SRF gun by a next version with an RF cavity reaching a higher acceleration gradient. We also present improvements concerning the photocathode exchange system and report on the status of construction and testing of this SRF gun cryomodule.

INTRODUCTION

Modern electron accelerators for light sources which are operating in continuous wave (CW) mode require adequate electron sources producing high-brightness beam with up to MHz repetition rate in CW. Sources which are suitable for this purpose are photoemission electron injectors either with DC voltage acceleration, with a low-radiofrequency normal-conducting resonators, or with superconducting (SC) radiofrequency resonators (SRF gun). All of these three types of electron injectors have been made considerable progress during the past years. They are in use or planned to be used at a number of new SC accelerators operating in CW. At the user facility ELBE with a SC accelerator based on 1.3 GHz TESLA-type cavities the R&D is focused on the development of SRF guns. Beginning with a half-cell SRF gun the technological basic concept was successfully demonstrated [1]. The ELBE SRF Gun I was put into operation in 2007 [2]. It was the first SRF gun which was installed at an accelerator and was used to deliver beam to ELBE for the production of secondary radiation like infrared light from a FEL [3]. In 2014 the SRF Gun II was commissioned at the ELBE accelerator [4,5]. As the previous gun, it has a 3.5 cell niobium cavity. Additionally a SC solenoid is situated in the gun cryomodule [6].

Although SRF Gun II still did not reach the initially aimed acceleration gradient, the gun is operating very successfully und delivers beam for the ELBE user shifts for the production of coherent THz radiation [7]. Since 2018 the gun has been in regular user operation at the ELBE facility. In 2019 it has been delivered about 20 % of the ELBE beam time, which are about 38 shifts of 12 hours until June 2019 with most of the time for external users. The benefits which creates the SRF gun for ELBE are higher bunch charge of 200 pC, shorter electron bunches, and higher stability. For the THz radiation production based on super-radiant diffraction and undulator radiation, the THz pulse energy and power could be increased by a factor of five to 5 µJ and 0.5 W, respectively. The next step towards higher performance of the THz source, which will be realized with SRF Gun III, is to increase the bunch charge to 500 pC. Thus a higher acceleration gradient of 12 MV/m is aimed.

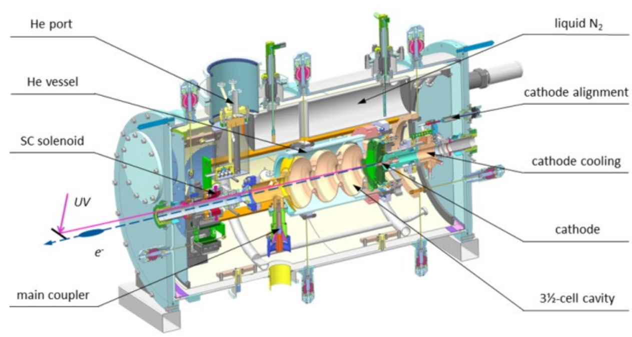

Figure 1: The current ELBE SRF gun design with a 3.5 cell niobium cavity and normal-conducting photcathode.

ELBE SRF GUN III

The technical conception of SRF Gun III is very similar to that of the previous SRF guns at ELBE. The design of the cryomodule is presented in Fig. 1. The main features are: a 3.5 cell elliptical niobium cavity with a fundamental frequency of 1.3 GHz operating at 2.0 K, to the cavity belongs a superconducting RF choke filter; the use of normal-conducting photocathodes, which are cooled by liquid nitrogen, a SC solenoid which is integrated in the cryomodule; an exchange system for photocathodes which is functional in the cold state of the cavity; a remote controlled alignment and positioning system for the photocathode; two cavity frequency tuners, one for the half-cell, and one for the three full cells; two HOM couplers of TESLA cavity type and a pick-up antenna for LLRF control at the downstream end of the cavity; a fundamental power coupler at the downstream end with a liquid nitrogen cooled cold and a warm RF window. The vacuum vessel has a cryogenic shield which is cooled with liquid nitrogen. The coil of the SC solenoid is made of NbTi wire and is cooled with 2 K helium. For align-

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ment the solenoid is situated on a remote-controlled x-y-table with step motors. These motors are also cooled by liquid nitrogen. In addition to the warm mu-metal shield of the cryomodule, the solenoid with motor table has a magnetic shielding.

At present, the SRF Gun II is usually operated at a gradient of 8 MV/m which corresponds to a peak field on axis of 20.5 MV/m. Compared to the other types of CW photoinjectors, this value is quite similar to the acceleration field of the low-frequency RF photo gun at LBNL of 21.5 MV/m [8]. For DC photoinjectors the state-of-the art acceleration field amounts to 5 – 10 MV/m [9-11]. In both cases there are strong technological limits, the cooling of the increasing RF power losses for one type, and the high-voltage break-through limit for the other, which prevents a further significant increase in performance. In contrast, SRF guns have large potential for further improvements. In vertical tests SRF gun cavities could achieve peak fields of up to about 50 MV/m. In the present SRF gun at ELBE the gradient limit is coursed by field emission. The gun cluster network, a collaboration of DESY, HZB, and HZDR within the accelerator research and development program of the Helmholtz Society, has the aim to push the gradient limit for SRF gun cavities. For SRF gun III the existing 3.5 cell cavity produced by RI are being refurbished. A modification of the HPR system at DESY should improve the cleaning, and the very successful DESY handling technology for cavities will be adopted. At the end, the cavity in SRF Gun III should allow for 12 MV/m acceleration gradient. A summarized parameter comparison is given in Table 1.

Table 1: Comparison of Current Parameters of SRF Gun II and Aimed Parameters for SRF Gun III

Parameter	**SRF Gun II**	**SRF Gun III**
Gradient	8 MV/m	12 MV/m
Peak field on axis	20.5 MV/m	30.7 MV/m
Kinetic energy	4 MeV	6 MeV
Bunch charge	300 pC	500 pC
Beam current	30 µA	50 µA,[1)] 500 µA[2)]
Pulse rep. rate	0.1-0.5 MHz,[1)] 13MHz[2)]	0.025-1 MHz,[1)] 13 MHz[2)]
Photocathode	Mg, Cs_2Te	Mg, Cs_2Te
Quantum efficiency	0.2-0.3%,[1)] >1 %[2)]	0.2%,[1)] >1%[2)]
Dark current	35 nA	<50 nA

[1)] Mg cathode, [2)] Cs2Te cathode

The operational experience leads to some design modification for the cryomodule of SRF Gun III. The cavity tuners are driven by warm motors at the outside of the cryomodule. Here an upgrade has been performed in order to make the operation more safe and with less hysteresis. Figure 2 shows the modified design with the new step motor and gear unit.

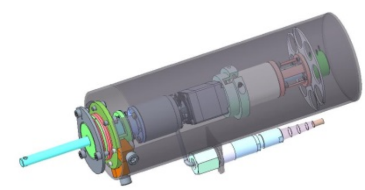

Figure 2: Cavity tuner motor unit for SRF Gun III.

Another improvement is related to the diagnostics in the cryomodule. For the photocathode alignment and positioning system three capacitive distance sensors are installed. They are placed between the cavity connection flange and the liquid nitrogen reservoir as can be seen in Fig. 3. The information of the sensors allows measurements of tilt and position of the photocathode with respect to the gun cavity. In order to improve the temperature measurements at places which are on liquid helium temperature level, Cernox sensors replace the old RhFe sensors. The careful thermal connection of the measuring wires, one example is shown in Fig. 4, and the accurate calibration ensure the needed temperature precision.

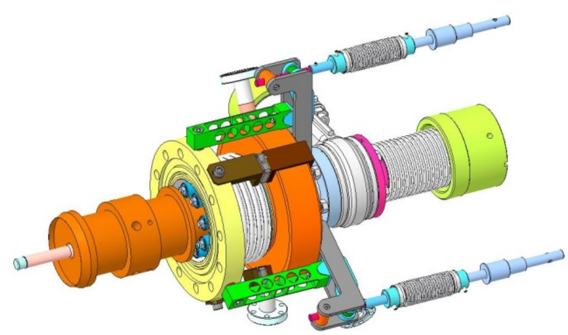

Figure 3: Photocathode cooling assembly with capacitive distance sensors.

It is extremely important to prevent any particle production during the exchange of photocathodes by striking or touching the inner parts of the cooling assembly or even the cavity by the photocathode. Therefore the transfer rod which holds the cathode must be precisely adjusted with respect to the cooling unit and cavity. Unfortunately an initial alignment during assembly and installation is not sufficient. The warm-up and cool-down procedures cause position and angle changes of the cavity in the cryomodule which cannot be measured directly. Therefore an adjustment system has been developed

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which based on two segmented touch sensors installed at the transfer rod (see Fig. 5). The eight signals from the sensors and four actuators at the transfer rod support frame allow a positioning just before the cathode exchange will be performed. A test bench with transfer rod, touch sensor, and actuators was set up and the control software has been developed.

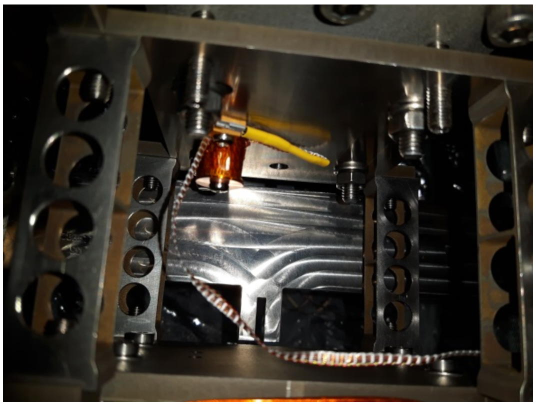

Figure 4: Photograph of one installed Cernox temperature sensors at the gun solenoid.

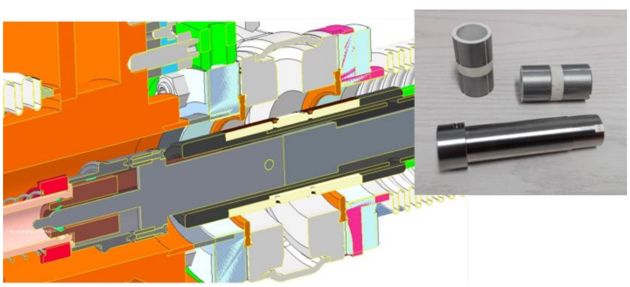

Figure 5: Design drawing of the cathode transfer rod with touch sensors und photograph of the touch sensor parts.

OUTLOOK

The components for the cryomodule of SRF Gun III are nearly complete. At the ELBE facility a new SRF test laboratory is in the commissioning stage. It will allow cryogenic and RF tests of SRF cryomodules before they will be installed at ELBE. In autumn the first use of this lab is scheduled for another test of the cryomodule with the SC solenoid. In the past, it turned out that the solenoid coil was broken. Now the cryomodule and solenoid with replaced coil will be tested. In parallel the gun cavity will be treated at DESY with the aim to reach the specified performance.

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