CRYOMODULE AND TUNING SYSTEM OF THE SUPERCONDUCTING RF PHOTO-INJECTOR*

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Abstract

The designs and a report on the progress in construction and testing of the cryomodule and the tuning system for the SRF gun are presented. The SRF gun project, a collaboration of BESSY, DESY, MBI and FZR, aims at the installation of a CW photo injector at the ELBE linac. The cryostat consists of a stainless steel vacuum vessel, a warm magnetic shield, a liquid N cooled thermal shield, and a He tank with two-phase supply tube. A heater pot in the He input port will be used for He level control. The 10 kW power coupler is adopted from the ELBE module. A cooling and support system for the NC photo cathode has been developed and tested. It allows the adjustment of the cathode with respect to the cavity from outside. The cryomodule will be connected with the 220 W He refrigerator of ELBE and will operate at 1.8 to 2 K. The static thermal loss is expected to be less than 20 W.

Two tuners will be installed for separate tuning of the three TESLA cells and the half-cell. The tuners are dual spindle-lever systems with step motors and low-vibration gears outside the cryostat. Functionality, tuning range and accuracy have been tested in cryogenic environment.

INTRODUCTION

Superconducting radio frequency (SRF) acceleration technology is well established for electron linacs with considerable progress in acceleration gradient during the last years [1]. The adequate SRF photo-injector was already proposed in 1988 [2], but up to now such an injector has not been operated at an accelerator. As electron sources for SRF electron linacs, DC photo-injectors or thermionic injectors are in use for CW operation or normal-conducting RF photoinjectors in pulsed mode. The RF photo-injectors deliver electron beams of highest quality (short bunch length and low transverse emittance at high bunch charge). Its combination with a superconducting cavity would further allow CW operation. After a successful proof-of-principle experiment with a half-cell cavity [3] a project for a SRF photo injector has been launched in 2004. The goal of this project, carried out in a collaboration of BESSY, DESY, MBI and FZR, is to build a fully functioning SRF photo-injector for the ELBE accelerator. Beside the significant beam quality improvement, the operation at ELBE will allow long term studies of important issues of SRF injectors like low-temperature operation and lifetime of photo cathodes, or cavity quality degradation.

The design parameters of the SRF gun are presented in Table 1. The gun will be operated in three modes: the standard ELBE FEL mode with 77 pC and 13 MHz pulse repetition, the high charge mode for neutron physics at ELBE and ERL studies (1 nC, 1 MHz), and the BESSY FEL mode (2.5 nC, 1 kHz). A UV driver laser system for these three operation modes is under development [4]. Beam parameter studies will be performed with a new diagnostic beam line [5]. The ELBE mode is determined by the two existing far infrared FELs which need 13 MHz bunch repetition rate, as well as the maximum average current of the ELBE accelerator. The high charge mode is essential for neutron physics experiments planned at ELBE where time-of-flight measurements require 1 µs pulse spacing without average current reduction. At the same time, 1 nC is a typical bunch charge for new FEL projects and state-of-the-art normal conducting RF photo injectors (e.g. FLASH at DESY) where the beam parameter should be measured and compared. It is planned to study and optimize different emittance compensation methods proposed for SRF guns, like a downstream magnetic solenoid, RF focusing with a backtracked and properly shaped photocathode, and RF focusing with an additional TE mode [6] in a future upgrade. For the soft x-ray BESSY FEL project [7] a bunch charge of 2.5 nC is envisaged and the SRF gun will be evaluated with respect to future application.

CRYOMODULE

The basic design for the SRF gun cryomodule was adopted from the ELBE cryomodule [8] which contains two 1.3 GHz TESLA cavities and is developed for CW operation with 10 MeV per cavity at a beam current up to 1 mA. ELBE modules are in routine operation since 2001 at FZ Rossendorf and wide experience has gained for these modules. The SRF gun cryomodule contains one 3½ cell cavity which consists of a half-cell with the normal-conducting cathode in it and three acceleration cells with TESLA shape [9]. The envisaged acceleration gradient of this cavity is 18.8 MV/m which corresponds to a

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maximum axial peak field of 50 MV/m in the TESLA cells. The geometry constant is 240 Ω and R/Q is 165 Ω. For $Q_0 = 1x10^{10}$ and the gradient mentioned above a RF power dissipation of 26 W is expected.

Table 1: Gun design parameters and expected beam values for the planned operation modes

	ELBE mode	high charge mode	BESSY-FEL
RF frequency	1.3 GHz		
beam energy	9.5 MeV		
Operation	CW		
drive laser	262 nm		
Photocathode	Cs_2Te		
quantum efficiency	>1 %		>2.5 %
average current	1 mA		2.5 µA
pulse length	5 ps	20 ps	50 ps
Repetition rate	13 MHz	[1MHz	1 kHz
bunch charge	77 pC	1 nC	2.5 nC
transverse emittance	1.5 µm	2.5 µm	3.0 µm

Fig. 1 shows a section view of the SRF gun cryomodule. The stainless steel vacuum vessel has a cylindrical shape with 1.3 m length and 0.75 m diameter. The vessel has flat plates on both sides and is designed as short as possible in order to get a minimum length of the transfer rod for cathode exchange, and on the beam line side it is planned to install a solenoid magnet for emittance compensation as close as possible. The He port and the N_2 port are on top on the right hand side. The refrigerator delivers 4.5 K helium to the valve box, about 5 m before the cryomodule. There is the Joule-Thompson valve for expansion. From the port the He flows through a heater pot and the two-phase supply tube into the chimney of the He tank. For the cooling of the thermal shield, liquid nitrogen is used. The 70 K shield consists of a cylindrical Al sheet welded to two circular tubes filled with N_2. The liquid N_2 tank in the upper part of the module must be refilled after about 5 h from an outside dewar. The liquid N_2 is also used for the cooling of the photo cathode stem. The photo emission layer, which is Cs_2Te, and the Cu cathode stem are normal conducting. The heat load from the RF field into these parts, estimated to be between 10 and 20 W, burdens the liquid N_2 bath.

The cavity is passively protected against ambient magnetic fields by means of a µ-metal shield, placed between the 80 K shield and the vacuum vessel. The shield is fabricated and its suppression of the earth magnetic field was measured. The results are shown in Fig. 2. In the region where the Nb cavitiy will be placed, the residual magnetic field is below 1 µT which is the limit during the cool-down [9].

The He tank is made of titanium. Three stainless steel bellows are integrated for the two tuning systems and for the manually tuned choke filter cell. The ten thin titanium spokes support the He tank and allow the adjustment of the cavity position. The spokes end in micrometer drives and vibration dampers attached to the vacuum vessel. The main power coupler is the 10 kW CW coupler of the ELBE module. It contains a conical cold ceramic window at 70 K in its coaxial part. The warm REXOLITE window is in the waveguide.

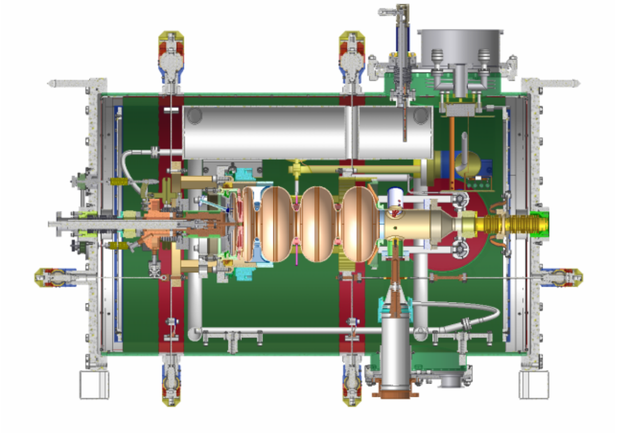

Figure 1: Cut drawing of the SRF gun cryostat.

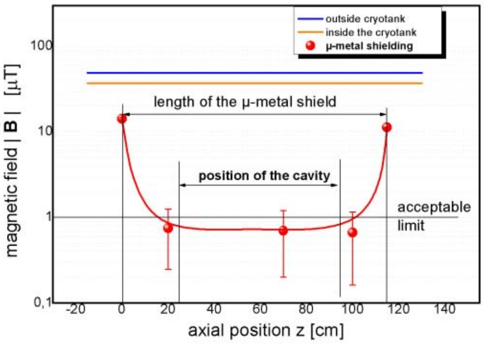

Figure 2: Measurement of the earth magnet field suppression by the µ-metal shield.

From outside it is also possible to move the cathode support and cooling system which allows the adjustment of the photo cathode with respect to the cavity. For that reason, three rotation feed-throughs exist in the backside plate of the vacuum vessel. Fig. 3 shows the design of that system.

The main sources for the static heat leak are the coaxial tube of the power coupler, the beamline vacuum tube and the vacuum tube for the cathode exchange system (both DN40), and the rotational drives of the two tuners. For all these subsystems the design is similar to the ELBE cryostat. Thus nearly the same static heat leak of less than 20 W can be expected.

The SRF gun will be installed in parallel to the existing thermionic injector of the ELBE accelerator. The cryostat will be connected with the existing 220 W He refrigerator. A new helium transfer line with valve box was assembled and tested in January 2006. Its design allows the connection of the SRF gun cryostat without warming up the other two ELBE cryomodules. The cryostat can be operated down to 1.8 K but the standard operation temperature at ELBE is 2 K (31 mbar). In the ELBE helium cooling system, the pressure stabilization is performed with cold compressors located in the cool box of the helium refrigerator. It will be performed for all three cryostats together based on a pressure value in one module. During operation of the two ELBE modules, it turned out that the common pressure stabilization worked well for constant liquid helium flux to the modules. In order to realize that, the total heat power from the electrical heater in the module and the RF power dissipation was hold constant by means of a feed-forward control.

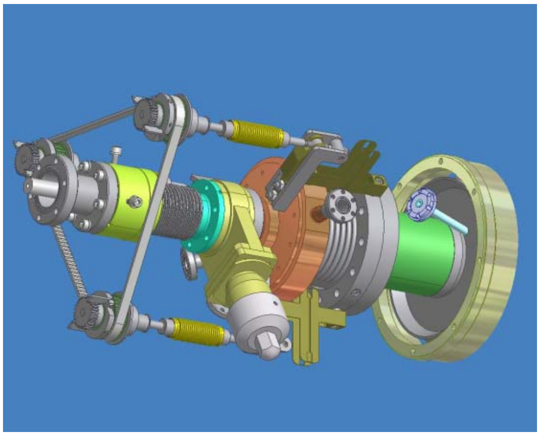

Figure 3: The cathode alignment system.

TUNING SYSTEMS

For the SRF gun cavity a frequency tuning is needed for the choke filter, the half-cell and the three TESLA cells. The bandwidth of choke filter is comparably large. Therefore a tuning during assembling in the warm stage is sufficient. For the accelerating cells tuning is required during operation. The half-cell on one hand and the three TESLA cells on the other essentially differ in their mechanical properties, especially in their stiffness. Therefore it was decided to use two separate tuning systems, one for the half-cell and one for the three TESLA cells in common.

The tuner design is adopted from the ELBE cryomodule dual spindle-lever tuning system [8]. Main objectives are a sufficiently large tuning range, high resolution, a hysteresis-free and linear operation, long life time and low cryogenic loss. But the requirements are less restrictive than for tuners in high-energy SRF linacs: Due to CW operation a fast tuning for the compensation of Lorentz force detuning (LFD) with piezoelectric actuators is not needed. This applies to active microphonics compensation too, since for a bandwidth of about 100 Hz and a moderate acceleration gradient up to about 20 MV/m, passive methods for microphonics reduction are sufficient. Costs per unit and compactness are less important too. On the other hand, the two tuners for the SRF gun cavity have required a sophisticated mechanical design due to many mechanical and cryogenic constraints and the insufficient clearance at cathode side of the cavity and the He tank. At the end, the ELBE tuner design was modified essentially.

The tuner mechanism consists of a spindle with partly left-hand thread and right-hand thread and two levers. Via the threads and the lever system the rotational motion is transformed into a longitudinal motion performing the length variation of the half-cell and the TESLA cells, respectively. The use of two levers ensures that no axial force is present on the spindle. The bearing point of the leverage system has no rotational parts. It consists of two flexible links as it is shown in Fig. 4. The advantage is the lack of any hysteresis due to friction effects and bearing clearance. The third flexible link is connected with a moving bolt which transfers the force to the parts of the He tank joint to the end plates of the half-cell or the TESLA cells. To allow the movement the He tank has two bellows.

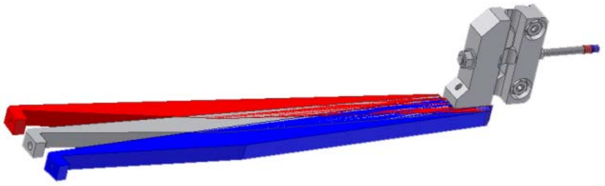

Figure 4: Lever and flexible link of the tuner.

The step motor driving the tuner spindle is outside the vacuum vessel. The fixed point is between the half-cell and the first full cell where the star-like arranged plates of the cavity are welded with the He tank. The motor motion is transmitted by rotation feed-throughs and a two-stage bellows coupling (the 70 K point is in between) to the spindle of the tuning system. The bellows compensate the shrinking offset and reduce the heat conduction. Both tuning systems have the same design. They differ in the lever lengths only.

The frequency constants Δf/dL of the SRF gun cavity were measured with the help of the warm tuning machine developed at FZR [10]. The measurement results are 254 kHz/mm for the half-cell and 449 kHz/mm for the three TESLA cells. These values belong to the change of the π mode frequency of the whole cavity, where the three TESLA cells were unchanged in the first case, and the half-cell in the second. Simple numerical estimations with SUPERFISH assuming a smoothly and homogeneous change of the surface contour give 674 kHz/mm for the half-cell and 625 kHz/mm for the TESLA cell tuning. The large difference for the half-cell seems to be an effect of the low stiffness of the end disk or of other weak areas having low influence on the frequency.

For operating tests and parameter measurements a test bench for the designed tuning system was built up. This test bench consists of the liquid nitrogen dewar, the leverage of the tuner, a spring packet to simulate the cavity, and the equipment to produce the tuning force, to perform force and length measurements. The spring packet was variable in order to simulate the half-cell and the three TESLA cells, as well as to measure with preload. For the three TESLA cells a spring constant of 9 kN/mm was taken [11]. The spring constant for the half-cell was assumed to be about three times higher. The preloads were varied between zero and 9 kN. In comparison to the final tuning systems the levers were made of aluminium instead of titanium and the tests were carried out with one lever only.

The results of the tuner test bench are summarized in Table 2. As expected, the tuning range became smaller with 5 kN preload due do the elastic behaviour of the flexible link of the tuner. The hysteresis measured is caused by the test bench mechanics itself. Fatigue effects were not found.

Table 2: Measurements of the tuning ranges in the tuner test bench

tuning range for 2° Lever range	half-cell tuner	TESLA cell tuner
without preload D = 0 N/mm	436 µm 416 kHz	450 µm 247 kHz
with 5000 N preload D = 9000 N/mm	218 µm 208 kHz	223 µm 122 kHz

Table 3 presents the properties of the two tuners for the SRF gun including the test bench results. The limit in the tuning range is given by the maximum bending of the flexible links of ± 1.5°. The expected tuning ranges are sufficient. By comparison, the tuning range in the ELBE modules is 230 kHz [8]. The overall tuner resolution given in the table are estimations taken from the ELBE system. A complete 3D view of the SRF gun tuners with parts of the He tank and the cavity is given in Fig. 5.

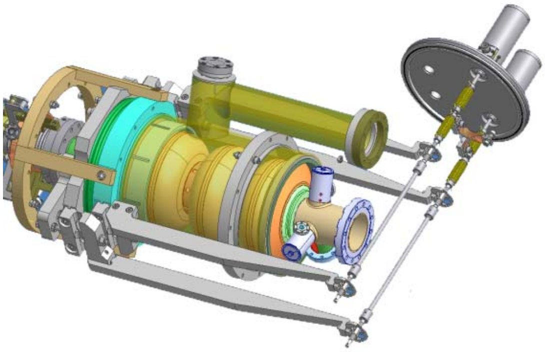

Fig. 5: The two tuners of the SRF gun.

SUMMARY AND OUTLOOK

In the paper the design and the parameters of the cryostat and the cavity tuning systems for the 3½ cell SRF gun are presented. Tests and parameter measurements of the tuners were carried out in a cryogenic test bench with sufficient results. At present, the different subsystems of the cryostat are being assembled und checked. In autumn, first vacuum and cryogenic test are planned. In parallel the treatment and measurement of the niobium cavity is carried out, following by the He tank welding. The commissioning is envisaged with the cool-down and RF tests beginning of 2007.

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Table 3: Parameters of the SRF gun tuners

	half-cell tuner	TESLA cell tuner
lever length	630.6 mm	570.2 mm
leverage	50.4	44.2
lever range	33 mm 3.0°	30 mm 3.0°
tuning range	0.7 mm 204 kHz	0.7 mm 404 kHz
cavity frequency constants Δf/dL	178 kHz/mm	283 kHz/mm
mechanical drive step	0.70 nm/step	0.62 nm/step
frequency drive step	0.23 Hz/step	0.28 Hz/step
mechanical resolution	3 nm	
frequency resolution	1 Hz	
position of step-motors	warm, outside	

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