STATUS OF THE SUPERCONDUCTING RF PHOTO-INJECTOR DEVELOPMENT*

J. Teichert#, A. Arnold, H. Buettig, D. Janssen, M. Justus, U. Lehnert, P. Michel, K. Moeller, P. Murcek, Ch. Schneider, R. Schurig, F. Staufenbiel, R. Xiang, FZD, Dresden, Germany,
J. Stephan, IKS, Dresden, Germany, W.-D. Lehmann, SGE, Dresden, Germany,
T. Kamps, BESSY, Berlin Germany, G. Klemz, I. Will, MBI, Berlin, Germany,
D. Lipka, A. Matheisen, B. v. d. Horst, DESY, Hamburg, Germany
P. vom Stein, ACCEL Instruments, Bergisch Gladbach, Germany
V. Volkov, BINP, Novosibirsk, Russia

Abstract

A status report of the superconducting RF photo electron injector development at Forschungszentrum Dresden-Rossendorf (FZD) is given. The SRF gun project is a collaboration of BESSY, DESY, MBI and FZD and aims at the installation of a high average current CW photo injector at the ELBE superconducting electron linac. Main design parameters of the SRF gun are an electron energy of 9.5 MeV, a maximum average current of 1 mA, transverse normalized emittances (rms) of 1 mm mrad at 77 pC and 2.5 mm mrad at 1 nC bunch charge. The 1.3 GHz niobium cavity consists of three full cells with TESLA geometry, a specially designed half-cell in which the photo cathode is placed, and a choke filter in order to prevent rf losses at the cathode side of the cavity.

Presently, the helium tank welding and cavity treatment have been finished. The cavity is now in the FZD and the cryomodule assembly has been started. Various subsystems like cathode cooler, cavity tuners, cryostat components, and the niobium cavity are still being tested and measured. A photo cathode preparation system was developed and installed. The equipment is now in operation and the first series of Cs_2Te photo cathodes has been produced. The development of the 262 nm driver laser system for the high charge mode (500 kHz, 1 nC) is finished. A diagnostic beamline, which is especially designed for the SRF gun parameter measurement, is being build up.

INTRODUCTION

Since the beginning of the year 2004, a superconducting radiofrequency photoelectron injector has been designed and constructed at FZD. This SRF gun will be installed at the ELBE superconducting linear accelerator. As is well known, superconducting accelerating structures obey quality factors greater than 10^{10}. The corresponding RF power losses in the range of some ten watts per cavity allow operation in continuous wave (CW) mode. The SRF gun comprising a superconducting rf accelerating cavity will also have this advantage together with the high performance of an RF photoelectron injector.

At ELBE the new SRF gun will reduce the pulse length and the transverse emittance for the standard FEL operation mode with 77 pC bunch charge and 13 MHz pulse repetition rate compared to the existing thermionic electron injector. With the SRF gun a second operation mode is now planned at ELBE with a bunch charge of 1 nC and a repetition rate of 500 kHz. Furthermore, it is envisaged to characterize the gun and to study different emittance compensation methods at high bunch charges up to 2.5 nC which is important for future application of the SRF gun in the BESSY FEL [1]. An overview of the gun parameters and planned operation modes is given in Table 1.

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 wave length	262 nm		
Photocathode	Cs_2Te		
quantum efficiency	>1 %		>2.5 %
average current	1 mA	0.5 mA	2.5 µA
pulse length	5 ps	15 ps	40 ps
Repetition rate	13 MHz	500 kHz	1 kHz
bunch charge	77 pC	1 nC	2.5 nC
transverse emittance	1 µm	2.5 µm	3 µm+)

+) flat top laser

An overview of the ELBE accelerator facility is shown in Fig. 1. The heart of the radiation source is a superconducting linac with a thermionic injector and two cryomodules each containing two TESLA-type RF cavities. The accelerator operates in CW, the maximum electron energy is 40 MeV, and the average current is 1 mA. The

* We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number RII3-CT-2003-506395) and the support of the German Federal Ministry of Education and Research grant 05 ES4BR1/8.
#j.teichert@fz-rossendorf.de

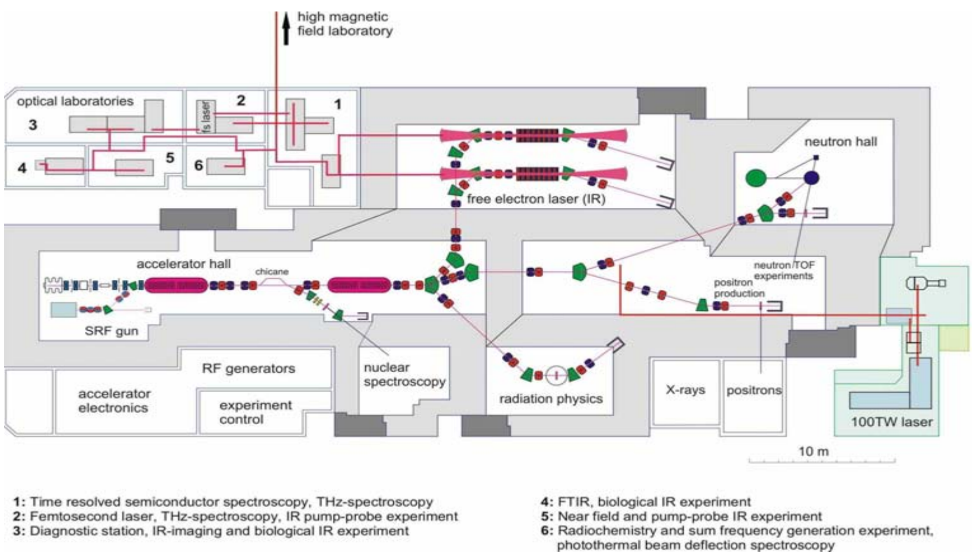

Fig. 1: Layout of the Radiation Source.

electron beam is used in two FELs for the generation of infrared radiation. To conduct nuclear physics and radiation physics experiments beams of γ-radiation and x-rays are produced. Two further beamlines are under construction for neutron physics experiments and for the generation of positrons applied in material research.

The new SRF photo injector will be installed in parallel to the existing injector in the accelerator hall. It will be connected to an about 4 m long diagnostics beam line. During the first operation period, the SRF gun will be operated separately from the ELBE accelerator and the diagnostics will be used for characterization and optimization of the SRF gun. The diagnostics beamline designed by BESSY [2] comprises all the devices needed such as several screen stations, a slit mask emittance measurement system, an c-bend magnet for energy and energy spread measurements, and devices for bunch length measurement with a streak camera and by electro-optical sampling. Later in 2008, a short beamline with two dipole magnets will be installed which will connect the gun to the accelerator.

Despite its advantages the development of an SRF photo electron injector is still a great challenge. The main difficulties caused by the presence of a photocathode inside a superconducting cavity are:

i) The special geometrical shape required for the gun cell differs from an optimum gun cell shape with respect to superconductivity requirements. Thus it is still an open question whether the designed gradient value can be obtained in a SRF gun cavity.
ii) The quality factor of the superconducting cavity may be deteriorated by impurities from the cathode.
iii) There is little experience on photocathode operation at cryogenic temperatures and long-term stability.
iv) The necessary focusing and emittance reduction by a solenoid cannot be performed close to the cathode where it is most efficient.

The first SRF gun project was launched at the University of Wuppertal in 1988 [3,4]. The photocathode was a Cs_3Sb layer on a superconducting Nb stem [5]. At Rossendorf the first electron beam from a SRF gun was produced in 2002 in a proof-of-principle experiment [6]. Later in 2005, at the Peking University an electron beam with DC-SRF gun was generated. In this gun the photocathode is outside of the cavity and the first acceleration step is performed with a DC field [7]. Currently, seven SRF gun projects are proposed with four projects actually running [7-14]. But up to now, none of these electron sources were developed to the point of being operational accelerator injectors. To take this step forward is the aim of the project presented here.

PHOTOCATHODES

In normal-conducting RF photoinjectors the semiconductor cesium telluride is the preferred photo cathode material. Cs_2Te has a high quantum efficiency for UV light, a long lifetime and requires a moderate vacuum of about 10^{-10} mbar [15]. An extremely good vacuum (10^{-11} mbar) is needed for GaAs photocathodes [16]. Thus they can only be applied in DC photo guns. Their advantages are the high quantum efficiency and the illumination with green light. In comparison to semiconductors, metallic photocathodes have orders of magnitude lower quantum efficiency.

Due to the good experience in normal-conducting RF photoinjectors, Cs_2Te seems to be the preferred material for SRF photoinjectors too. For CW electron current of 1 mA and a typical quantum efficiency of about 1 %, the UV laser power must be about 1 W. Suitable driver laser systems with such power have been developed [17].

The use of a Cs_2Te cathode in the SRF photoinjector means that a normal-conducting part is inside the superconducting cavity. In order to prevent this additional heat load burdening the liquid He cooling system the cathode is isolated from the cavity and separately cooled with liquid nitrogen. This concept was developed for the first Rossendorf prototype SRF gun [18] and later successfully proved [6]. There are three parts in the heat load of the photocathode: the absorbed laser energy, the ohmic surface current losses due to the magnetic RF field, and the dielectric losses due to the electric RF field in the semiconducting photo layer. For the present SRF gun these contributions are about 1 W, 5 W, and 15 W, respectively. The surface current losses can be easily calculated by a code like SUPERFISH [19] and are determined by the cathode stem material (Molybdenum) since the skin depth is about 1 µm. For the 10 to 50 nm thick Cs_2Te photo layer the dielectric properties are unknown. Thus we used the estimation for the dielectric losses given in Ref. [20] which yields roughly 15 W in the present case. The design of the photocathode is shown in Fig. 2. It has a bayonet fixing and it is pressed by a spring into the cone of the cooling unit. Fig. 3 presents the design of the whole cooling system.

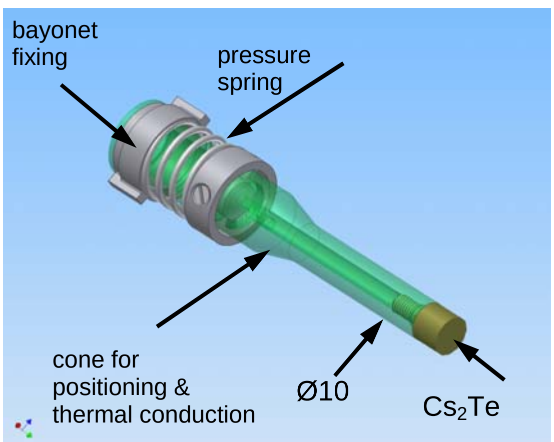

Fig. 2: Design of the photo cathodes.

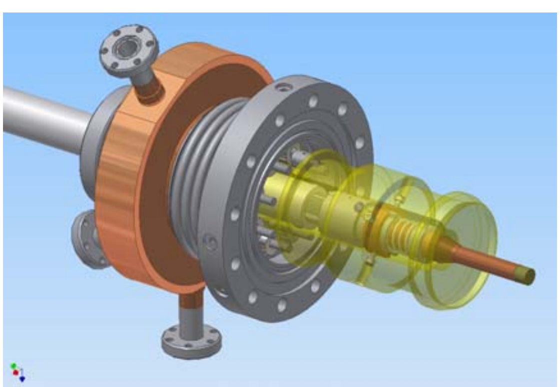

Fig. 3: Design of the cathode cooling system.

The proper operation of the photocathode cooling system was previously proven in an extra test bench. For a heat load of 20 W a cathode temperature increase of 40 degrees was found [21]. This corresponds to ~ 20 mW heat radiation to the niobium cavity via the vacuum gap.

A serious problem for SRF guns could be cavity degradation by particles produced at the photo cathode surface. The damaging of the photo layer by arc discharges and ion back-bombardment is well-known in normal conducting RF photo injectors. The much better vacuum in SRF guns can prevent these effects. The only measurement which exists [6] did not see any degradation effect.

Alternatively, superconducting photocathodes like Nb or Pb can be applied [8,12]. For these metallic photocathodes the lower quantum efficiency is unfavourable. Recently, acceptable values up to 0.1% have been obtained for Pb by means of laser beam cleaning and illumination with shorter wavelength UV light [22]. In the DC-SRF gun the normal-conducting Cs_2Te cathode is placed outside the Nb cavity and a DC voltage accelerates the electrons before they enter the RF cavity [7]. For the production of very high electron currents (≥ 100 mA) a diamond amplifier cathode is currently being developed at BNL [23].

A photocathode preparation system for the deposition of the Cs_2Te layers has been designed and constructed (see Fig. 4). The equipment is installed in a clean room in order to ensure low particle contamination of the cathodes. Main components are the vacuum chamber for the Cs_2Te deposition, a UV laser system (4 mW @ 262 nm) for online measurements of the quantum efficiency, the exchange and storage system for the photocathodes, and the electronics units for process control. The deposition equipment allows standard deposition technology (Te and Cs in succession) as well as the simultaneous evaporation proposed at CERN [15]. Two quartz monitors measure the deposition rates of Te and Cs separately, and the process computer controls the heating power of the evaporators in order to adjust the stoichiometric ratio of 1:2 between Te and Cs. Although the improvement and optimization is still ongoing, a number of cathodes with quantum efficiencies >4 % have been prepared.

The photo cathode transfer systems were developed for the transport of the cathodes between the SRF gun and the preparation lab. Two of these systems are needed. The design of the systems is presented in Fig. 5. Each of the systems consists of an exchange chamber, a docking station, and a transportation chamber. By means of the exchange chambers the cathodes are moved in and out of the SRF gun or preparation chamber. The docking stations serve for the change of the transportation chambers without breaking the vacuum. In the transportation chambers up to six cathodes can be stored and moved between the preparation system and the SRF gun. The first of the two transfer systems is in operation in the preparation lab, where as the second is constructed and is waiting for cleaning. For the system which will be connected to the SRF gun, remote control of the photocathode exchange is envisaged.

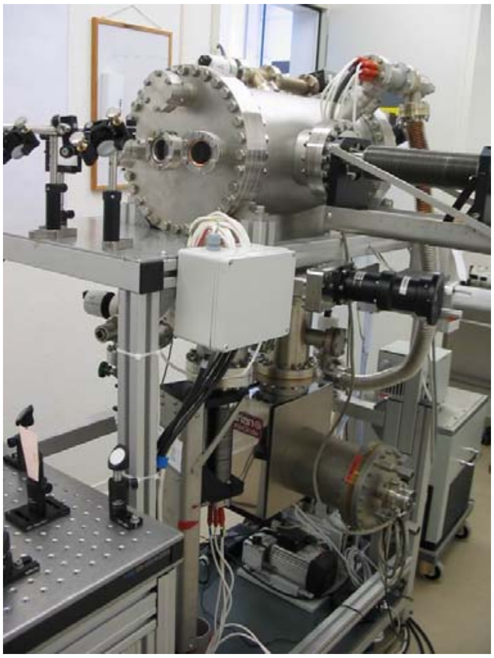

Fig. 4: The photocathode preparation chamber.

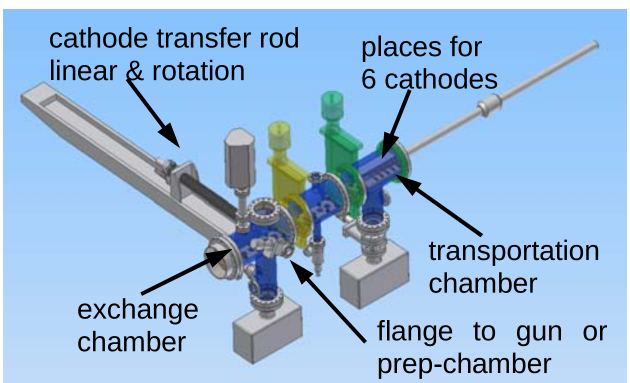

Fig. 5: Design of the photocathode transfer system.

NIOBIUM CAVITY

The 1.3 GHz SRF gun resonator is a 3 ½ cell niobium cavity. The three full cells have TESLA-cell shape except for the first cell which is slightly modified. The shape of the half-cell in which the photocathode is located is the result of a numerical optimization procedure. The coaxial gap formed by the opening in the back plane of the half-cell and the cathode stem forms an RF transmission line. Therefore a choke filter cell is placed behind which prevents RF power flow through this line. Further parts of the cavity are two higher order mode filters, a flange for the main power coupler, and a pick-up antenna at the beamline tube, as well as a second pick-up antenna in the choke filter. A detailed description of the cavity design and its RF parameters can be found in Ref. [24]. A 3D drawing of the cavity is shown in Fig. 6.

Two cavities, one of Nb grade RRR 300 and one of grade RRR 40 were fabricated by the company ACCEL Instruments. The RRR 300 cavity is for the SRF gun, whereas the cheaper RRR 40 is a model for technological tests and RF measurements. After delivery and a first mechanical inspection, the warm tuning of the cavities was carried out at Rossendorf. For that reason a bead pull device for field profile measurements and a tuning machine were built. Details are published elsewhere [25]. The following preparation of the cavities, 100 µm BCP etching inside, 20 µm etching outside, and 800 °C baking in the UHV oven were carried out at DESY. After these treatments the RF measurements were repeated and second warm tuning was performed.

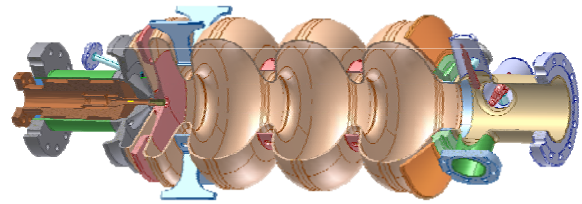

Fig. 6: 3D model of the SRF gun cavity.

Following the tuning, the cavity was moved to DESY for low temperature RF tests. For these measurements the cavity was prepared by buffered chemical polishing (40µm BCP) and high pressure rinsing (HPR). Afterwards the cavity was tested in a vertical cold test. During the cool down from 4.4 K to 1.6 K the unloaded quality factor was measured at low rf power and the residual surface resistance was determined to be R_{res}=3.4 nΩ.

The results of the Q versus E measurements at 1.8 K from the first vertical test are shown in Fig. 7. For comparison, the values are plotted as function of the peak field in the TESLA cells. As shown in the figure, field emission started early and the quality factor decreases. Further increase of rf power results in strong field emission and two Q-switches, which are probably caused by thermal breakdown at activated field emitters. After the second Q-switch the field was limited by quench. The behaviour of the Q-switches is most likely due to defects in the bulk niobium or to surface pollution. This might be induced by the hardly cleanable choke filter. Because of the narrow cathode feed through between choke filter and gun cell, direct cleaning of the filter cell was not feasible.

Based on the experience of the first vertical test bench, an improved cleaning was realized by the company ACCEL Instruments. A special high pressure rinsing lance was built to enable an additional cleaning of the choke filter beside the established preparation of the cavity cells. Due to technical problems during the cleaning the achieved results of the followed 2nd and 3rd tests are unsatisfactory (Fig 9).

Due to shortage of time the 4th preparation and the vertical test had to be the base for further assembly. As shown in Fig. 8 the first measurement started very promising. Unfortunately a Q-switch at 27 MV/m paired with the beginning of field emission decreased the quality factor and the maximum peak field. The last measurement of the π-mode after several tests resulted in the red Q_0 vs. E_{peak} curve. In comparison to the first curve we found no

Q-switch but the field emission started much earlier so the quality factor decreased. This is probably caused by a field emitter that was activated during the first measurement at the Q-switch. This assumption is supported by a small scratch that we found inside the cavity at the back plane of the half cell. The damage results from a collision between the cavity and the high pressure rinsing lance during the cleaning. We are confident that the field emission was caused by the scratch so its removal will result in better performance. Unfortunately there is no time for a 5th vertical test so we have to wait for further tests until the cryostat is completely assembled.

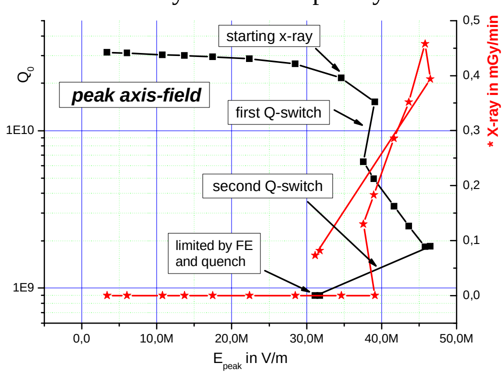

Fig. 7: Q versus E measurement and field emission of the first vertical test.

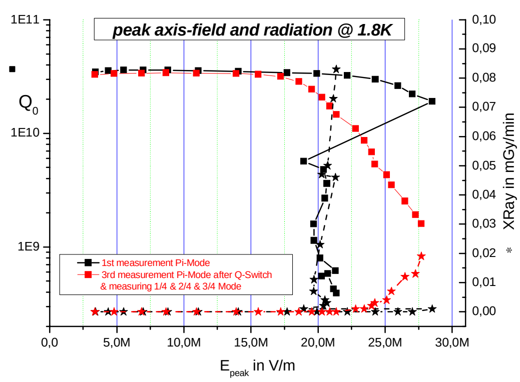

Fig. 8: Q versus E measurement and field emission of the fourth vertical test.

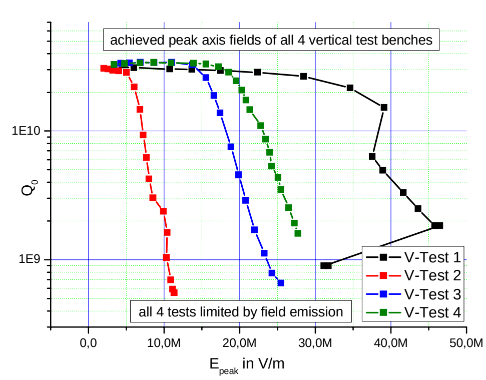

Fig. 9: A comparison of the four vertical test measurements of the SRF gun cavity.

A further indication that the field emission problem limiting the gradient of the cavity is caused by the half-cell comes from a comparison of the measurements for the four pass band modes performed in the 4th vertical test. The field distributions of the four modes are shown in Fig. 10. As can be seen, the π/4 mode especially is mainly located in the half-cell. In the results for the four modes in Fig. 11, where Q_0 is now plotted versus the peak field in the half-cell, the drop-down of the curves happens at the same field value in the half-cell.

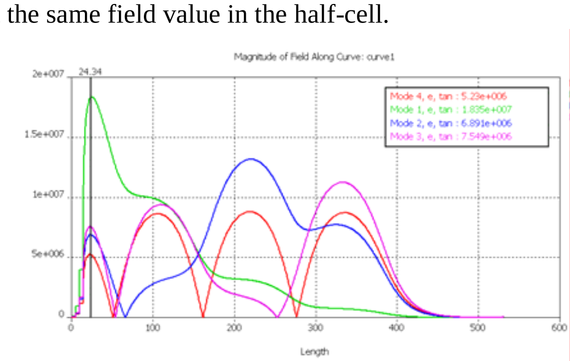

Fig. 10: Field distributions of the four pass band modes.

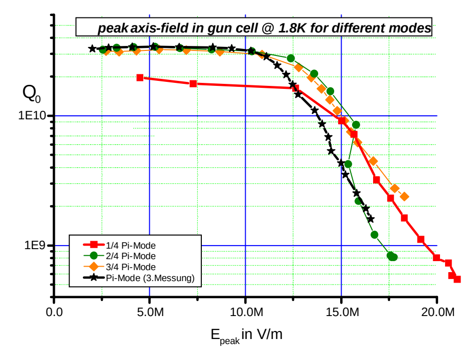

Fig. 11: Measured curves for the four pass band modes. In the graph Q_0 is plotted versus the peak field in the half-cell.

At ACCEL Instruments the helium vessel was welded around the cavity following vacuum leak checks and RF field profile measurements in Spring 2007. Then the etching of the cavity was carried out (20 µm BCP, clean water rinsing, drying in class 10 clean room), pick-up and HOM feed-throughs were attached in the clean room, and the cavity was finally cleaned (high pressure rinsing, drying in class 10 clean room, valve assembly, vacuum leak check, filled with clean N_2 gas). A photograph of the cavity after welding into the He tank is shown in Fig. 12.

In parallel the RF conditioning of the main power coupler was carried out and the clean room at FZD was equipped with the auxiliary devices for the further assembly. In the class 10 clean room of the FZD further assembly work was carried out: mounting of cavity tuner parts, assembly of the main power coupler antenna and of the pick-up antenna in the choke filter, temporary insertion of an RF antenna for HOM coupler tuning and adjustment of the choke filter frequency. Finally the beam line parts were mounted at the down-stream side and the complete cathode cooling and support system at the up-stream side of the cavity. Therewith the clean room work was finished and the cavity can now be inserted into the cryostat.

Fig. 12: Photograph of the He tank and cavity.

CRYOMODULE

The basic design for the SRF gun cryomodule was adopted from the ELBE cryomodule [26] 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 FZD and wide experience has been gained for these modules. The design of the SRF gun cryostat is presented in Fig. 13. The stainless steel vacuum vessel has a cylindrical shape with 1.3 m length and 0.75 m diameter. The He port and the N_2 port are on top on the right hand side.

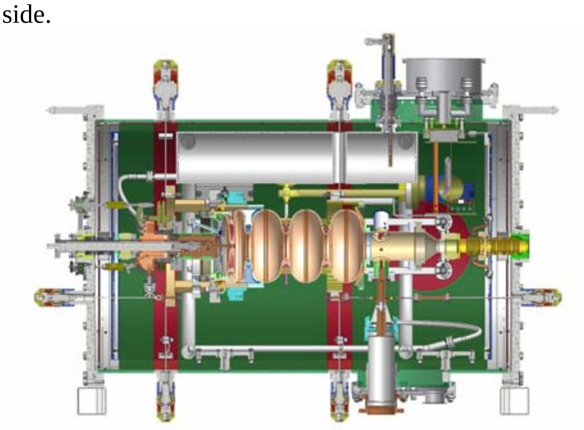

Fig. 13: Design of the SRF gun cryomodule.

The refrigerator delivers 4.5 K helium to the valve box, about 5 m before the cryomodule. There 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 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.

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 the choke filter is comparably large. Therefore tuning during assembly 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, 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 adopted from the ELBE cryomodule is a dual spindle-lever tuning system [26]. 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 with the advantage that there is no hysteresis due to friction effects and bearing clearance. The tuners were tested and characterized by means of a special test bench in cryogenic environment. The tuning ranges measured are 70 kHz (0.28 mm) for the half-cell tuner and 150 kHz (0.34 mm) for the TESLA-cells tuner with tuning resolutions of 1 Hz and 1.5 Hz respectively.

The cathode is geometrically adjusted by the cathode cooling system mentioned. This system is connected via a bellows to the cavity and can be moved by means of three rotational feed-throughs from outside the cryostat as shown in Fig. 14. This allows to center the cathode in the cathode channel as well as to shift the cathode in the longitudinal direction over a range of a few millimeters.

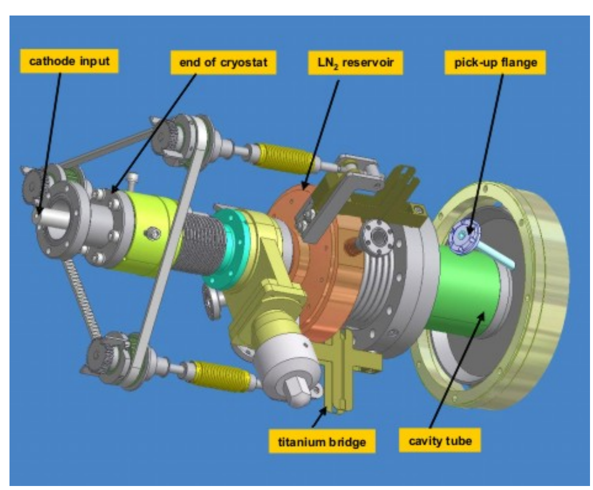

Fig. 14: The photocathode alignment system.

In November 2006 the cryostat was completely assembled with the exception of the He tank and the cavity. The cryostat was pumped, vacuum-leak checked and cooled-down with liquid nitrogen. The Figures 15–17 show pictures taken at that time with the still open He port, the main coupler with the warm window, and the whole cryomodule.

Fig. 15: Photograph of the He port.

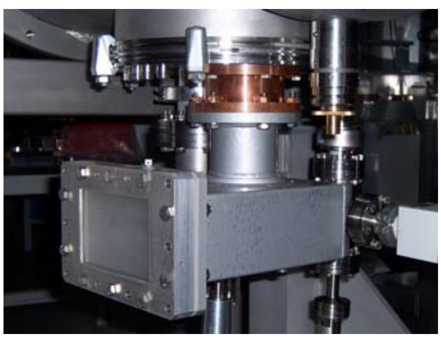

Fig. 16: Photograph of the 10 kW CW main power coupler with the warm window.

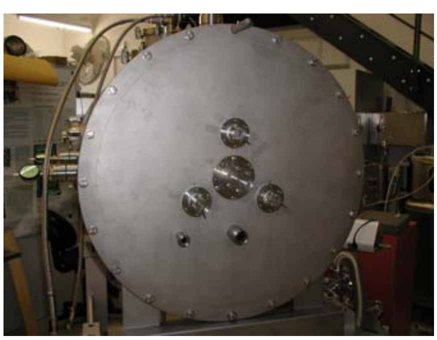

Fig. 17: Backplane of the cryostat vessel with flange for the cathode exchange in the centre and three rotational feed-throughs for the cathode alignment.

EMITTANCE COMPENSATION

An essential step in improving the beam quality of normal conducting RF photo injectors was the implementation of a solenoid field for transverse emittance improvement. Unfortunately, this concept cannot be simply adopted to SRF guns due to physical and technical reasons. Besides the proposed installation of a superconducting solenoid inside the SRF gun cryostat [10,20] further methods for emittance improvement are discussed in the literature:

i) solenoid down-stream, ouside the cryomodule [11],
ii) RF focusing by a retracted photo cathode [27],
iii) improvement by a shaped cathode surface [28], and
iv) exploitation of the RF magnetic field of a suitable TE mode additionally excited in the cavity [29].

In the present SRF gun the RF focusing with a retracted cathode will be applied. Besides the axial alignment, the cathode adjustment system allows for remote controlled positioning of the cathode. Thus this effect can be studied in detail and optimized. Later on, photo cathodes with modified shapes can be inserted. Beam dynamical simulation showed that an optimized cathode shape can further reduce the transverse emittance at high bunch charges [28]. Furthermore a suitable solenoid was designed and constructed. It will be installed downstream of the SRF gun cryostat in the diagnostics beamline.

LASER AND LASER BEAMLINE

The UV driver laser needs a CW power of about 0.5 W at the cathode. It turned out that the different parameters of the operation modes of the gun required nearly two completely different laser systems. These lasers are under development at MBI Berlin [30]. The first laser system which will be installed is the system for the high bunch charge mode with 500 kHz pulse repetition frequency, a pulse length of about 12–15 ps FWHM and a pulse energy of about 1 µJ at 262 nm wave length. The laser has a 13 MHz oscillator and a regenerative amplifier. The laser material is Nd:YLF pumped with fiber-coupled pump diodes. The conversion into ultraviolet is performed with LBO-BBO crystals.

The laser beamline, which should transport the laser pulses onto the photo cathode, needs seven mirrors. Due to radiation safety reasons the path from the laser room into the accelerator hall must go through the baseplate. Two telescopes with four lenses image the laser spot first onto a beam shaping aperture and later onto the photo cathode. Near the gun a virtual cathode will be installed. A small part of the laser light will be deflected by a beam splitter allowing an inspection of the laser spot by means of a video camera as well as position and laser power measurement with a detector.

DIAGNOSTICS BEAMLINE

After commissioning the SRF gun will be characterized using the diagnostic beamline. The main components of this beamline are designed and manufactured by BESSY. A detailed scheme is presented in Fig 18. Besides optical components for focusing and steering, the following diagnostics will be available:

- current: Faraday cups and ICTs,
- beam position: beam position monitors,

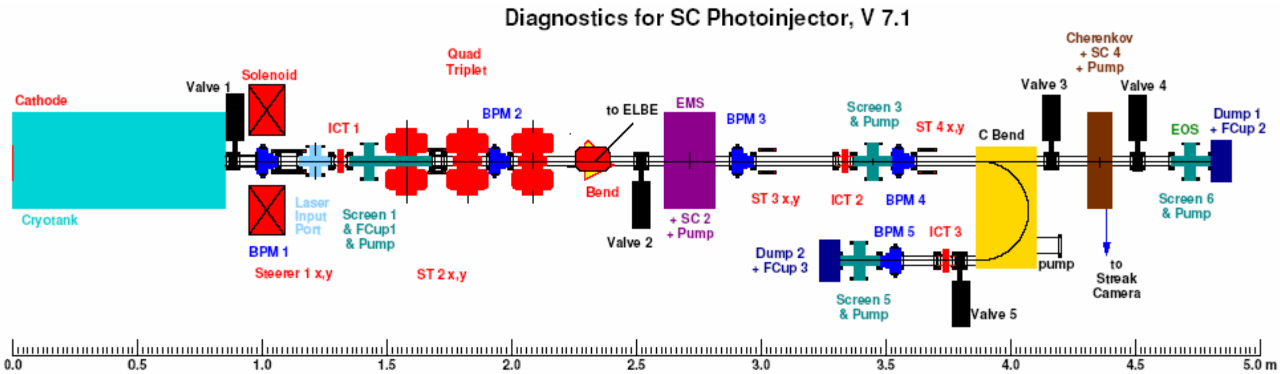

Fig. 18: Layout of the diagnostics beamline (EMS:transverse emittance measurement station; Cherenkov: bunch length measurement with Cherenkov radiation and streak camera; EOS: bunch length measurement by means of electro-optics sampling).

- energy and energy spread: C bend magnet,
- transverse emittance: slit mask,
- bunch length: Cerenkov radiator + streak camera with electro-optical sampling.

At present, the beamline is completed and tested on the roof of the ELBE accelerator shielding (see Fig. 19). The beamline also comprises the emittance compensation solenoid, shown in Fig. 20.

Fig. 19: Photograph of the diagnostics beamline.

Fig. 20: Photograph of the Solenoid.

SUMMARY AND OUTLOOK

A SRF photoinjector will be installed at the ELBE linac in Summer 2007 for 1 mA cw operation. The next steps on this path are the assembly of the cryomodule, the cleaning and “white” assembly of the cathode transfer system, the delivery of the 500 kHz driver laser and the installation of the SRF gun.

In the future the SRF gun will improve the beam quality for ELBE users (higher bunch charge, lower transverse emittance). In parallel it will be a test bench for SRF injector studies. Therefore a sophisticated diagnostics beamline has been constructed. Different emittance compensation schemes suitable for SRF guns will be investigated.

In a future SRF gun cavity design, cleaning and clean room handling should be better considered.

REFERENCES

[1] “The BESSY Soft X-ray Free Electron Laser”, TDR BESSY March 2004, eds.: D.Krämer, E. Jaeschke, W. Eberhardt, ISBN 3-9809534-0-8, Berlin (2004).

[2] T. Kamps, et al.,”Diagnostics Beamline for the SRF Gun Project”, Proc. of FEL´05, Stanford, USA, 2005, p. 530.

[3] H. Piel et al., 10th FEL Conference, Jerusalem, 1988.

[4] O. H. Chaloupka, et al., “A proposed superconducting photoemission source of high brightness”, Nucl. Instr. and Meth. A **285**, 327 (1989).

[5] A. Michalke, *PhD Thesis, University of Wuppertal, Germany, 1992.*

[6] D. Janssen, et al., “First operation of a Superconducting RF-Gun”, Nucl. Instr. and Meth. A **507,** 314 (2003).

[7] G.M. Wang, et al., “Experimental Progress of the DC-SC Photoinjector at Peking University”, Proc. of FEL´05, Stanford, USA, 2005, p. 161.

[8] I. Ben-Zvi, *Proceedings of the International Workshop on Energy Recovery Linacs, Erlangen, Germany, 2002, p. 89.*

[9] J. Teichert, et al., „A Superconducting Photoinjector with a 3½-Cell Cavity for the ELBE Linac”, Proc. of EPAC´04, Lucerne, Switzerland, 2004, p. 333.

[10] M. Ferrario, et al., “An Ultra-high Brightness, High Duty Factor, Superconducting RF Photoinjector”, Proc. of EPAC, Lucerne, Switzerland, 2004, p. 402.

[11] F. Marhauser, “Photoinjector Studies for the BESSY Soft X-ray FEL”, Proc. of EPAC´04, Lucerne, Switzerland, 2004, p. 315.
[12] J. Smedley, et al., “Progress on Lead Photocathodes for Superconducting Injectors”, Proc. of PAC´05, Knoxville, USA, 2005, p. 2598
[13] A. Todd, et al.,”State-of-the-art electron guns and injector designs forenergy recovery linacs (ERL)”, Nucl. Instr. and Meth. A557, 36 (2006).
[14] J. Smedley, et al., these proceedings.
[15]G. Suberlucq, “Technological Challenges for High Brightness Photo-injectors”, Proc. of EPAC´04, Lucerne, Switzerland, 2004, p. 64
[16] C.K. Sinclair, et al., “Development of a high average current polarized electron source with long cathode operational lifetime”, Phys. Rev. Special Topics AB 10, 023501 (2007)
[17] I. Will, et al., these proceedings
[18] D. Janssen, et al., “The Development of a Superconducting RF Gun: Status of the Drossel Collaboration”, Proc. of PAC´97, Vancouver, Canada, 1997, p. 2838
[19] J.H. Billen and L.M. Young, Poisson Superfish, LANL, Report LA-UR-96-1834, revised April 2000
[20] P. vom Stein, *Hochfrequenz Elektroneninjektoren für cw-Beschleuniger*, PhD thesis, Dresden University of Technology , 1998, Report FZR-227.
[21] F. Staufenbiel, et al., “Test of the photocathode cooling system of the 31/2 cell SRF gun“, Physica C 441, 216 (2006).
[22] J. Smedley, et al., “Photoemission Properties of Lead”, Proc. of EPAC´04, Lucerne, Switzerland, 2004, p. 1126.
[23] Triveni Rao, these proceedings.
[24] A. Arnold, et al., “Development of a Superconducting Radio Frequency Photo Electron Injektor”, Nucl. Instr. and Meth. A 577, 440 (2007).
[25] A. Arnold, et al., „First RF Measurements at 3.5 Cell SRF-Photo-Gun Cavitiy in Rossendorf”, Proc. FEL 2006, Berlin, Germany, p. 567
[26] J. Teichert, et al., “Status of superconducting module development suitable for cw operation: ELBE cryostats”,Nucl. Instr. and Meth. A **557,** 239 (2006).
[27] D. Janssen and V. Volkov, “RF focussing – an instrument for beam quality improvement in superconducting RF guns”, Nucl. Instr. and Meth. A 452 (2000) 34.
[28] F. Staufenbiel, et al., these proceedings.
[29] K. Flöttmann, D. Janssen and V. Volkov, “Emittance compensation in a superconducting rf gun with a magnetic mode”, Phys. Rev. Special Topics AB **7**, 090702 (2004).
[30] I. Will, et al., „Photocathode Laser for the Superconducting Photo Injector at the Forschungszentrum Rossendorf”, Proc. FEL´06, Berlin, Germany, 2006, p. 564.