PROGRESS OF THE ROSSENDORF SRF GUN PROJECT*

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Abstract

A superconducting rf photo electron injector (SRF gun) is under development at the Forschungszentrum Rossendorf. The project aims at several issues: improvement of beam quality for the ELBE superconducting electron linac, demonstration of feasibility of this gun type, investigation of critical components, and parameter studies for future application . In 2005, a substantial progress has been made. The two 3½-cell niobium cavities for the gun have been delivered from the company ACCEL. The main parts for gun cryostat like vacuum vessel, cryogenic and magnetic shields are ready. Test benches for the cathode cooling system and the cavity tuner are being assembled. The photo cathode preparation lab has been arranged, and the diagnostic beam line has been designed After delivery of the gun cavities, their rf properties are being measured at room temperature and the warm tuning is being carried out.

INTRODUCTION

In the research center Rossendorf (FZR) a superconducting RF photo-injector (SRF gun) with a 3 ½-cell niobium cavity is under development and will be installed at the ELBE electron accelerator. This gun will allow for continuous wave operation with a final electron energy of 9.5 MeV up to an average current of 1 mA. The goal of this project, carried out in a collaboration of BESSY, DESY, MBI and FZR, is to build a fully functioning superconducting photo-injector. Beside the significant beam quality improvement expected for the ELBE accelerator, the operation at ELBE will allow long term studies of important issues of SRF injectors like low-temperature operation and lifetime of photocathodes, or cavity quality degradation. Because of its attractiveness, the capability for the future applications in FEL light sources and energy recovery linacs will be demonstrated. Therefore the SRF 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. Beam parameter studies will be performed with a new diagnostic beam line [1]. The ELBE mode is determined by the existing and constructed far infrared FELs which need 13 MHz bunch repetition rate, as well as the maximum average current of the ELBE accelerator. For this mode the new gun will improve the beam quality essentially in comparison to the existing thermionic injector at ELBE (about 8 mm mrad normalized transverse emittance at 77 pC). The high charge mode is impossible with the existing injector, but it is essential for neutron physics experiments at ELBE where time-of-flight measurements require 1 ns 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 normalconducting RF photo injectors (e.g. the EUROFEL project at DESY) where the beam parameter should be measured and compared. For the soft x-ray BESSY FEL project [2] a bunch charge of 2.5 nC is envisaged and the SRF gun will be evaluated with respect to future application.

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	ʜ1MHz	1 kHz
bunch charge	77 pC	1 nC	2.5 nC
transverse emittance	1.5 µm	2.5 µm	3.0 µm

The paper will report on the current realization status of the different subsystems of the SRF gun. The further time schedule of the project is to finish the installation of the gun in autumn 2006, and to generate the first beam in 2007.

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CRYOMODULE

The cryomodule design of the SRF gun is based on that of the ELBE cryomodules operated in CW. The He tank design and level control, RF coupler, cavity support, and tuner design are adopted. The module will be connected with the 220 W He refrigerator of the ELBE accelerator and will be operated at 1.8 to 2 K. The static thermal loss is expected to be less than 20 W.

In Fig. 1 the design of the cryomodule is shown. It consists of a stainless steel vessel of about 1.2 m length. Below the He port a heater pot exists. From there the He flows through the two-phase supply tube and the chimney into the He tank. The heaters are installed for He level control and balances the variable dynamic load of the cavity. The 80 K shielding is performed with liquid nitrogen. Liquid N_2 is also used in the cathode cooling system. The liquid N_2 tank in the upper part of the module must be refilled after about 5 h from an outside dewar. The cavities are passively shielded against ambient magnetic fields by means of a cylindrically shaped mu-metal sheet, closed at both sides, which is placed between the 80 K shield and the vacuum vessel. The 10 kW CW main power coupler is completely adopted from the ELBE accelerator module. Two tuners will be installed, one for the half-cell and one for the three TESLA cells. Like in the ELBE module, the tuners are dual spindle-lever systems. Modifications were necessary due to different tuning ranges and the available place, since both tuners are at the cathode end of the cavity. Specific features of the tuners are that the lever bearing points are flexible connects without any rotational parts and that the use of two levers ensures a force-free spindle bearing point. The drive motors and the low-vibration gears are outside the vacuum vessel. From outside it is also possible to move the cathode cooling system which allows to adjust the cathode with respect to the cavity. The He tank with the cavity is supported by thin titanium spokes. In the beam line tube, the cathode exchange tube, the rf coupler, and in the tuner shafts thin-walled stainless-steel bellows are integrated to lower the heat transport.

The main parts of the cryomodule like the vacuum vessel, the support frame, power coupler, the 70 K shield, and the magnetic shield have been fabricated and delivered. The screening behaviour of the magnetic shielding was measured. In the cavity region, the earth magnetic field is sufficiently reduced to less than 1 µT. A functional test at 80 K of the tuning system is under way.

CAVITIES

The SRF gun cavity consists of three full cells, a specially designed half-cell and the choke filter. The three full cells have TESLA shapes [3]. The back wall of the half-cell has a slightly conical shape and a centred hole for the photocathode. The photocathode is normal conducting and will be cooled with liquid nitrogen, as it was successfully tested in the first operating SRF gun [4].

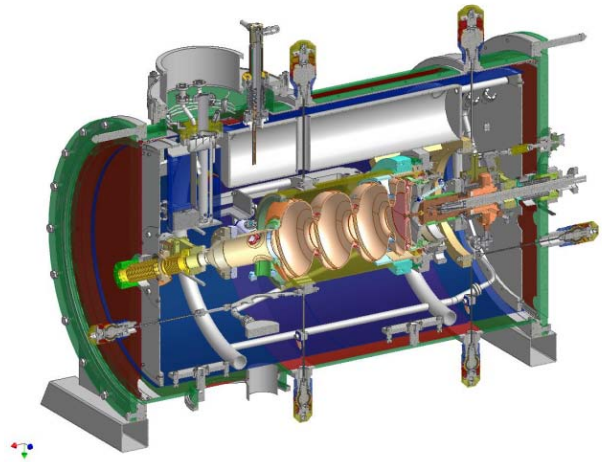

Figure 1: 3-D view of the SRF gun cryomodule.

A circular vacuum gap prevents the heat transport from the photocathode to the cavity. Therefore the heat loaded in the cathode does not burden the helium bath. On the other hand, to prevent RF power losses through the coaxial line formed by this geometry, an additional superconducting niobium choke filter is attached. The cavity has an rf power coupler, two higher-order mode couplers and a pick-up adopted from the TESLA cavity [3], and one extra pick-up especially for the cathode half-cell.

The production of two Nb cavities by ACCEL, with RRR 300 and 40 respectively, was finished in March 2005. Fig. 2 shows a photograph of the cavity. The shape, especially of the half-cell, does not allow to use existing tuning machines for TESLA cavities. Therefore a new cavity tuning machine with integrated bead pull measuring device was built at FZR [5], shown in Fig. 3.

Figure 2: Photograph of the 3 ½ cell Nb cavity.

For the first warm tuning step after fabrication and before chemical treatment, the designed field profile with 10% accuracy and a –mode frequency of 1.2991 GHz [6] was envisaged. In order to tune the cells, the single iteration tuning method proposed by Cooper [7] has been applied. The tuning was first exercised with the "test" cavity made of Nb RRR 40. But it turned out that the later tuning of the softer RRR 300 cavity was much easier. The first warm tuning of both cavities is now finished.

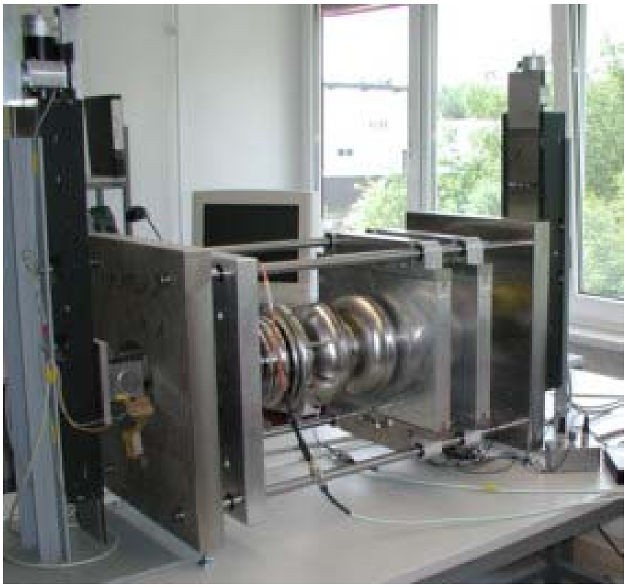

Figure 3: Field profile measuring (bead pull) and warm tuning machine.

The SUPERFISH code was used to calculate the axial electric field profiles and frequencies of the four pass band modes for the ideally tuned cavity and to estimate df/dl of the cells. Figure 4a shows the measured field profiles of the RRR 300 cavity before tuning. From the data analysis it was found that the half-cell had to be pushed about 1 mm, and the three TESLA cells had to be pulled some tens of mm. Starting with the half-cell the single iteration tuning was carried out. The final field profiles are shown in Fig. 4b. A good agreement of the field amplitudes and pass band frequencies with the simulation results has been obtained. In the design, the –mode field profile has equal amplitudes in the TESLA cells and 64 % in the half-cell, in order to have nearly equal maximum surface field strength in all cells.

The next steps are the buffered chemical polishing (BCP) and the 800 °C annealing which will be performed at DESY. After final treatment, the aim is to reach the TESLA 500 specification [3], i.e. E_{peak} = 50 MV/m in the TESLA cells, E_{peak} = 32 MV/m in the half-cell, and a qualitiy factor of $Q_0 = 1 \times 10^{10}$.

PHOTOCATHODES

Cs_2Te photocathodes will be used in the SRF gun and a quantum efficiency of at least 1% is required. The standard preparation method and co-evaporation will be adopted [8]. The Cs_2Te photo layers will be deposited in a separate preparation chamber and then the cathodes will be transferred to the SRF gun in an UHV storage chamber. The photocathode preparation system, as shown in Fig. 4, has been assembled and tested. At present, the parts are cleaned and after it, the system will be installed in a clean room.

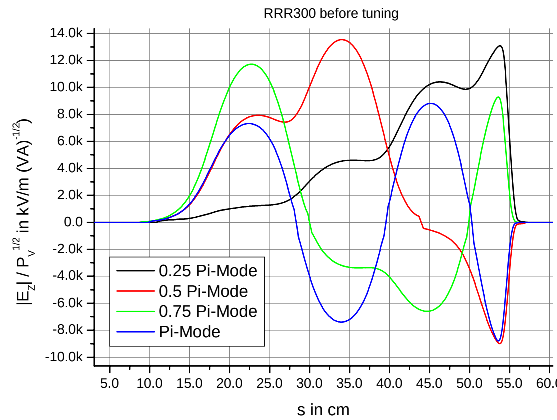

Figure 4a: Measured field profiles of the pass band modes of the RRR 300 cavity before tuning. The half-cell is at the right side.

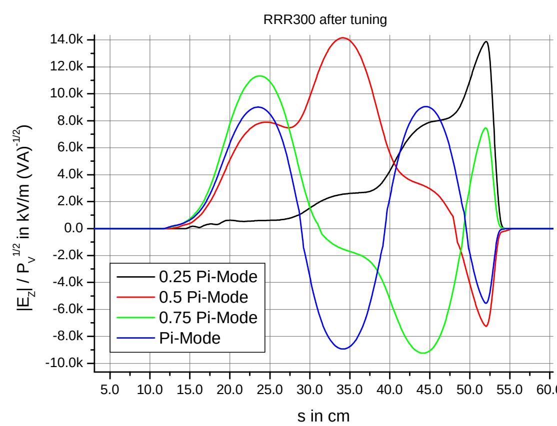

Figure 4b: Measured field profiles of the pass band modes of the RRR 300 cavity after tuning.

In the SRF gun the normal conducting photocathode is fixed in a cooling element by a bayonet socket system. A spring affords the force between the touched cone areas of the photocathode and the cooling element which is connected to the liquid N_2 reservoir. The design and fabrication of the cathode cooling system is finished. Since it is an essential subsystem of the gun, its functionality was checked in a test bench. Corresponding to the estimated power input from the RF field, the cathode was heated with 10 W. This causes a temperature increase from 77 K to 99 K at the cathode [8]. Thus, the radiation power flow from the cathode to the cavity is negligibly small.

Both, the SRF gun and the cathode preparation chamber will have the same cathode transfer system. A storage chamber for six photocathodes belongs to each of these systems. The storage chambers have their own ion getter pumps and will be also used for the photocathode transport between preparation lab and gun. One of these cathode transfer systems is still fabricated and will be assembled and tested in autumn 2005.

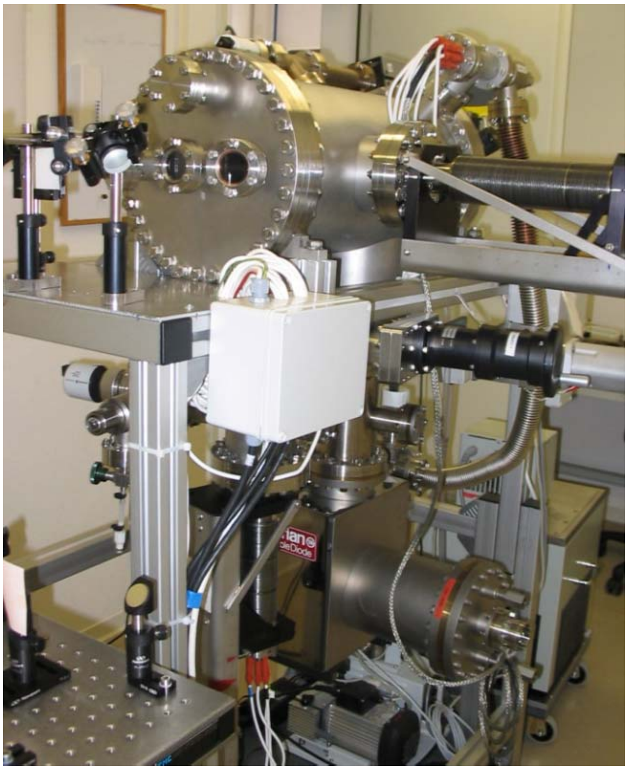

Figure 4: Photocathode preparation chamber.

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