A SUPERCONDUCTING RF PHOTO-INJECTOR FOR OPERATION AT THE ELBE LINEAR ACCELERATOR*

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Abstract

For the ELBE superconducting linear accelerator at FZD a radiofrequency photoelectron injector with a superconducting cavity (SRF gun) is under development. The SRF gun combines the excellent beam quality which can be delivered by RF photoinjectors with the possibility of continuous wave operation.

The superconducting niobium cavity of the injector consists of 3½ cells and contains a Cs_2Te photocathode which is normal-conducting and cooled by liquid nitrogen. The RF frequency of the cavity is 1.3 GHz. The final electron energy will be about 9.5 MeV and the average electron current will be 1 mA. In the past years the SRF photo injector has been designed and fabricated. Several critical subsystems have been tested. For the cavity, the results of the RF measurements will be shown. An UV driver laser system has been developed which fulfils the different requirements (77 pC @ 13 MHz, 1 nC @ 500 kHz) for the future operation at ELBE. A photo cathode preparation system was developed and installed. The equipment is now in operation and the first series of Cs_2Te photo cathodes have been produced.

INTRODUCTION

In 2004 a R&D program for the development of a superconducting radiofrequency photoelectron injector (SRF gun) was initiated at Forschungszentrum Dresden-Rossendorf (FZD). This project continues the earlier efforts in SRF gun development [1, 2] with the aim to develop a fully operable SRF photo injector for the ELBE superconducting linear accelerator [3].

Compared to the thermionic injector in use, 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. Furthermore a second operation mode is now planned at ELBE with a bunch charge of 1 nC and a repetition rate of 500 kHz. Beside the essential beam quality improvement for ELBE, the project should demonstrate the operation of a SRF gun at an accelerator facility for the first time, and the gun will serve as a test bench for R&D studies in this field (beam parameter measurements and optimize operation, long term studies, investigation of photo cathodes, study of emittance compensation methods). For that reason a sophisticated diagnostics beamline has been designed and constructed [4]. In particular, the operation with 2.5 nC bunch charge will be studied which is essentially important for future application of the SRF gun at the BESSY FEL [5]. The Table 1 gives an overview of the SRF gun parameters and planned operation modes.

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[1)]

1) 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 electron beam is used in two FELs for the generation of infrared radiation, to conduct nuclear physics and radiation physics experiments, and to produce neutrons and positrons.

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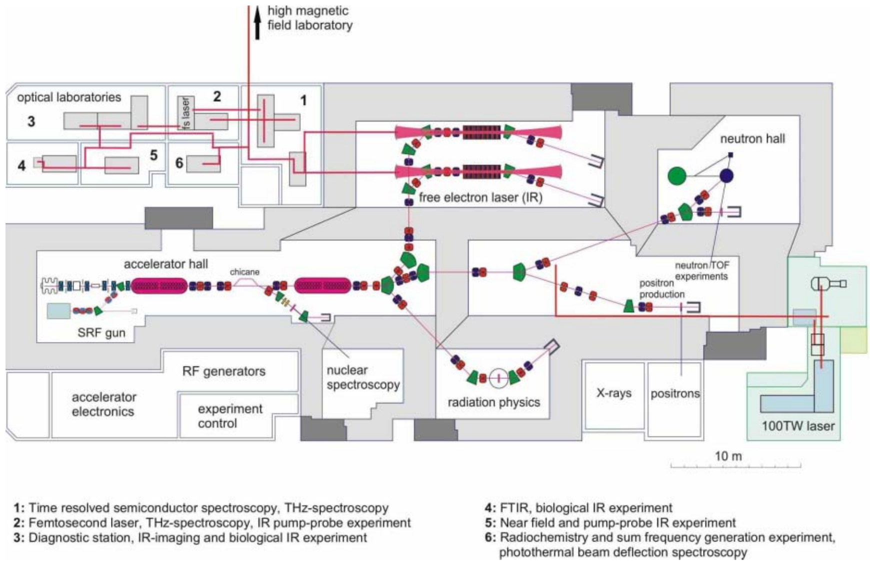

Fig. 1: Layout of the Radiation Source.

The SRF gun project is a collaboration of BESSY, DESY, MBI and FZD. A detailed description of the SRF gun design is given in Ref [6]. We will spend the rest of the paper reporting the progress of the SRF gun construction during the last year and showing the

PHOTOCATHODE PREPARATION

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. Due to the good experience in normal-conducting RF photoinjectors, Cs_2Te seems to be the preferred material for SRF photoinjectors too. For a CW electron current of 1 mA and a typical quantum efficiency of 1 %, the UV laser power must be about 1 W. Suitable driver laser systems with such power have been developed [7].

A photocathode preparation system for the deposition of the Cs_2Te layers has been designed and constructed. 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 [8]. 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.

NIOBIUM CAVITY

The 3 ½ cell niobium cavity has been the most critical component. A 3D drawing of this cavity is shown in Fig. 2. After fabrication, the two cavities, one of Nb grade RRR 300 and one of grade RRR 40 (model for technological and RF tests) were warm tuned at FZD and then prepared at DESY (100 µm BCP etching inside, 20 µm etching outside, and 800 °C backing in the UHV oven). After these treatments a second warm tuning was performed.

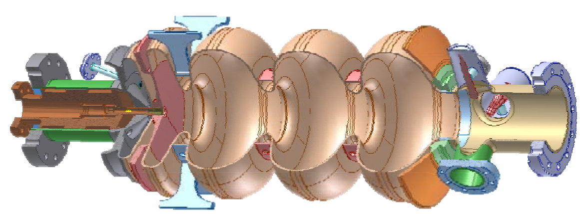

Fig. 2: 3D model of the SRF gun cavity.

Following the tuning, the RRR 300 cavity was moved to DESY for low temperature RF tests. For these measurements the cavity was cleaned by buffered chemical polishing (40µm BCP) and high pressure rinsing (HPR). 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 R_{res}=3.4 nΩ.

The results of the Q versus E measurements at 1.8 K of the first vertical test measurements are shown in Fig. 7. For comparison, the values are plotted as function of the peak field in the TESLA cells. All together, four vertical tests were carried out. As shown in the figure, field emission started early and the quality factor decreases. Further increasing of rf power results in strong field emission and Q-switches, which are probably caused by thermal breakdown at activated field emitters. The behaviour of the Q-switches is most likely due 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 this experience, 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.

Caused by the shortage of time the 4th preparation and the vertical test had to be the base for further assembly. As in the tests before, the limit in the gradient results from field emission. Beside particle pollution the reason could be 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. So its removal will result in a 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.

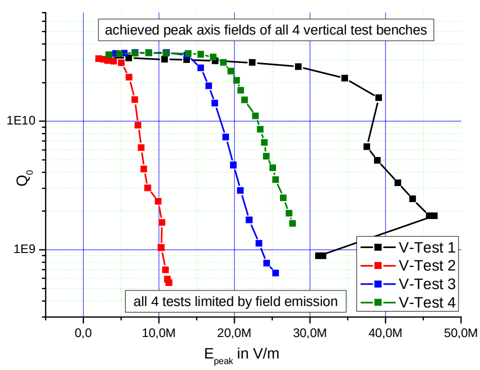

Fig. 3: A comparison of the four vertical test measurements of the SRF gun cavity.

A further indication that the field emission problem limiting the gradient of the cavity is located in the half-cell delivers 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. 4. As can be seen, especially the $\pi/4$ mode is mainly located in the half-cell. In the results for the four modes shown in Fig. 5, 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.

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).

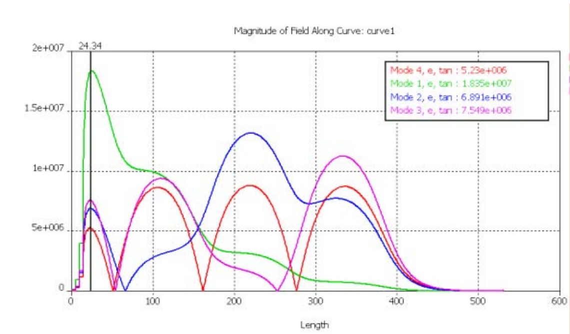

Fig. 4: Field distributions of the four pass band modes.

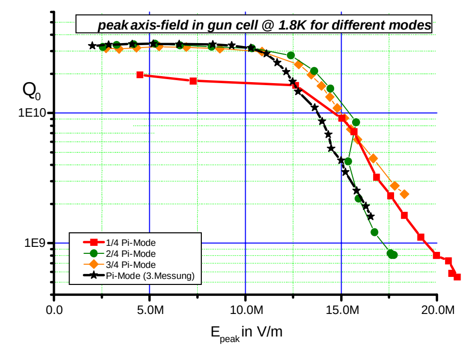

Fig. 5: Measured curves for the four pass band modes. In the graph Q_0 is plotted versus the peak field in the half-cell.

In the class 10 clean room of the FZD the 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.

CRYOMODULE

The design of the SRF gun cryostat is presented in Fig. 6. 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.

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 is in the upper part of the module. 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 a check of all components the cryostat was assembled with exception of the He tank and the cavity in the workshop end of 2006. In May 2007, the final assembly started after delivery of the cavity welted in the

He tank and the following work in the clean room described above. Fig. 7 shows the still open cryostat vessel with the He tank covered with super-isolation.

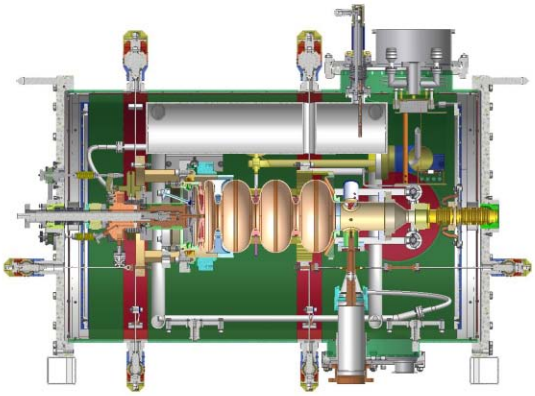

Fig. 6: Design of the SRF gun cryostat.

Fig. 7: Photograph of the vacuum vessel and the He vessel during moving in.

INSTALLATION

During the summer shut-down of ELBE in July 2007, the SRF gun cryostat was installed in the accelerator hall and connected to the He refrigerator. The cool-down was successfully carried out on August 3-4. First measurements with low power RF were performed in order to check the RF installation, the tuning systems and to characterize the cavity. Beside the cryostat, the first part of the diagnostics beamline with the solenoid, the laser input port and a beam dump was installed (see Fig. 8).

SUMMARY AND OUTLOOK

A SRF photo-injector has been installed at the ELBE in summer 2007. The next steps on the way are the commissioning of the high power RF system, and installation of the 500 kHz driver laser. Then the first beam can be produced with the SRF gun. In the following shut-downs of ELBE in autumn and winter, the diagnostics beamline and the cathode transfer system will be installed, which will then allow beam parameter measurements with Cs_2Te photocathodes.

In the future the SRF gun will improve the beam quality for ELBE users (higher bunch charge, lower transverse emittance).

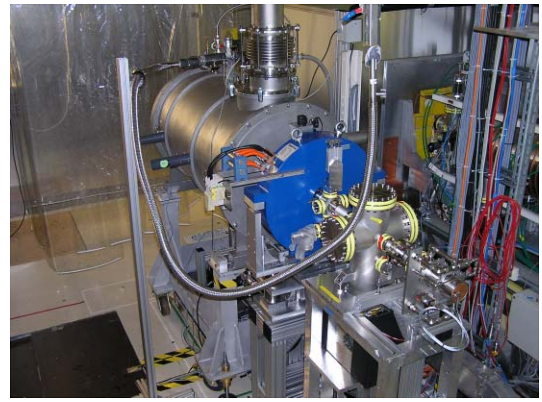

Fig. 8: Photograph of the SRF gun installed in the accelerator hall.

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