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STATUS OF THE SRF GUN OPERATION AT ELBE*

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Abstract

The superconducting RF photo-injector (SRF gun) at FZD is the first operating electron injector of its kind. The gun with a 3½-cell cavity and a frequency of 1.3 GHz produces an electron beam of 3 MeV with a maximum bunch charge of about 400 pC. Also the design values for the acceleration gradient could not be reached with the cavity which is in use at present, the SRF gun will improve the beam quality for ELBE users. In the winter shutdown of 2009/10 the beam line was installed which connects the SRF gun with the ELBE accelerator. The paper reports on the first tests and on the progress in applying the SRF gun for ELBE operation.

INTRODUCTION

A superconducting radio-frequency photo-electron gun (SRF gun) was developed and commissioned [1] for the ELBE electron accelerator at FZD [2]. This gun type is capable to deliver high-brightness beams in continuous wave (CW) mode. The SRF gun is installed in the ELBE accelerator hall together with a sophisticated diagnostic beam line [3] and an UV driver laser system [4]. For the liquid He supply and gas return the gun cryostat is connected to the ELBE helium refrigerator allowing a continuous operation at 2.0 K (31 mbar) with a typical He heat load of 40 W. A CW klystron with 10 kW delivers the RF power at 1.3 GHz. The SRF gun cryostat comprises the 3½-cell niobium cavity in the liquid He tank as well as several subsystems, such as two cavity tuners, main power coupler, cavity support and alignment, cathode tuner, support and cooling system for the photo cathode, and diagnostics for cryogenics and RF. An essential point in the SRF gun design represents the use of a normal conducting photo cathode which is hold at 77 K by liquid nitrogen cooling. Starting with a Cu photo cathode in 2007, the gun is now in operation with Cs_2Te photo cathodes of high quantum efficiency (QE).

FZD hosts a photo cathode laboratory with the equipment for the preparation an evaluation of semiconductor photo cathodes. The lab has clean-room installations to ensure that the photo cathodes do no have particle contaminations. The Cs_2Te layers at the cathodes are produced by vapor deposition in a UHV vacuum chamber with a pressure of about $1*10^{-9}$ mbar. The deposition can be done with the standard process (subsequent deposition of Te and Cs) or the co-evaporation process (co-evaporation means that Te and Cs is deposited at the same time with an atomic ratio of 1:2). The QE can be measured during the preparation process as well as later to determine the storage life time of the cathode. A small UV-laser with a power of some mWs power serves for these measurements. Details of the preparation process and the photo cathode properties are given in [5]. In order to preserve the high QE of the prepared cathode, the transport and storage of the photo cathodes must be carried out in ultra high vacuum. Therefore special cathode transfer systems exist allowing to load and to unload cathodes from the transport carriers in the cathode lab and at the SRF gun.

A serious issue of the SRF gun is the cavity gradient. As reported earlier [6] the cleaning of the gun cavity turned out to be much more difficult than that for a standard acceleration cavity. Thus, the design gradient could not be reached and the cavity is still limited by field emission. At present, the acceleration gradient of the gun for stable operation is 6 MV/m which correspond to a peak field in the TESLA cells of 16 MV/m. Nevertheless, the most important information is that the measurement of the unloaded quality factor showed no degradation of the cavity performance after more than 500 hours operation with Cs_2Te photo cathodes inside. In order to improve the cavity gradient, a new large grain 3½ cell Nb cavity with optimized shape and a new cryomodule are under development [7]. The beam quality for the gun is hoped to benefit from the higher accelerating field in the cavity.

Until end of 2009 the SRF gun had solely been operated together with the diagnostic beam line simultaneously to the ELBE user operation. The gun was optimized and the diagnostics commissioned. Measurements were carried out with respect to cryogenics, RF properties, photo cathodes, and beam parameters and are published elsewhere [8]. During the 2009/2010 winter shutdown, the beam line which connects the SRF gun to the ELBE linac was installed. A photograph of the beam line is presented in Fig. 1.

The first beam from the SRF gun was successfully guided to ELBE in February 2010. Now the SRF gun can be operated in two modes: injecting the beam into the ELBE linac, or in separate operation together with the diagnostic beam line.

BEAMLINE SETUP

The beam line layout of SRF gun and ELBE linac is presented in Fig. 2. The beam line (dogleg), recently installed, connects the SRF gun injector with the ELBE linac. Usually ELBE is operated with the thermionic injector which is situated in straight direction upstream

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the main linac. The SRF gun is installed parallel to the thermionic injector. Downstream the SRF gun a solenoid for emittance compensation is placed followed by a screen station, a movable Faraday cup for current measurements, and a quadrupole triplet. The new beam line starts about 1.5 m from the SRF gun exit with a 45° dipole magnet, which deflects the beam towards the ELBE linac, followed by a quadrupole triplet and ends with a second 45° magnet in the thermionic injector in front of the first acceleration module of ELBE.

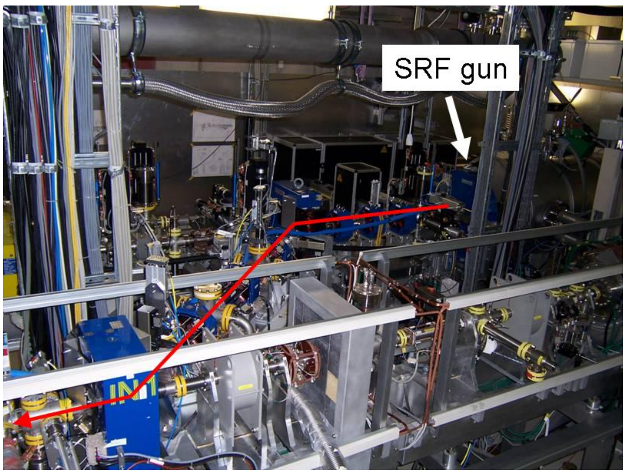

Figure 1: Photograph of the new beamline connecting the SRF gun with the ELBE accelerator.

The superconducting ELBE main linac consists of two acceleration modules with two TESLA-type cavities in each module. For the SRF gun injection tests, the ELBE main linac was used till the OTR screen FL1-DV.01 following the switching magnet in the left 45° beam line for energy and energy spread measurements (s. Fig. 2). For beam current measurements the beam was guided to the straight direction afterwards the switching magnet to the beam dump ET1-CB.01. The magnetic chicane was not used in the measurements performed up to now. But energy and energy spread was determined after the first acceleration module using the first chicane magnet and the following screens ET2-DV.01 and ET2-DV.02. If desired the Browne Buechner spectrometer can be used for more accurate results in the future. The SRF gun diagnostic beamline and the dogleg have YAG screens, in front of the first linac module there are two chromox screens, and in the ELBE linac are OTR screens. The dogleg and the ELBE linac are equipped with a beam-loss interlock system based on cable-like ionization chambers. The system prevents any damage by switching off the drive laser of the SRF gun.

SRF GUN PARAMETER

In the experiments discussed in the following, the SRF gun was operated with an acceleration gradient of 6 MV/m always in CW mode. Additionally a DC voltage of -5 kV was applied to the photo cathode. This DC voltage reduced the multipacting effect, which occasionally occur at the photo cathode during RF ramp up. Furthermore, it slightly improves the beam parameter. The Cs_2Te photo cathode in use was introduced in the gun in May 2010 with a fresh QE of 15 %. But the QE dropped down within several days and is now stable at about 1 %. The 263 nm laser beam was delivered by the Nd:YLF laser system with a 26 MHz oscillator, a regenerative amplifier, and frequency quadrupling [4]. The average output power maximum was about 300 mW. The pulse repetition rate was chosen to 125 kHz (variable between 1 kHz and 250 kHz). The laser pulse is Gaussian in time with about 15 ps FWHM and had a nearly Gaussian lateral profile with 3.5 mm FWHM.

Starting with a laser phase scan at low laser power as it is shown in Fig. 3, the laser phase delay was adjusted in such a way that the origin of the laser phase corresponds to the zero crossing of the RF wave. The DC voltage at the cathode courses a somewhat earlier onset of the emission current. The laser phase scan carried out with a higher laser power is shown in Fig. 4. This is the power level which belongs to the beam currents injected to ELBE. The high-current peak is now smaller and at a higher phase value due to the effect of space charge forces

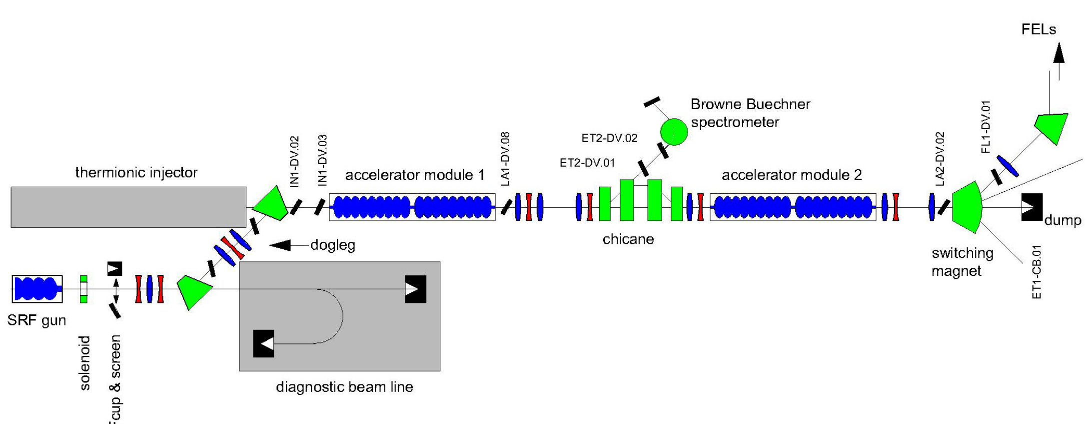

Figure 2: Beam line layout of the SRF gun, dogleg section, and ELBE main accelerator.

in front of the cathode.

The corresponding final electron energy and energy spread measured in the SRF gun diagnostic beam line are presented in Figures 5 and 6, respectively. For the SRF gun, it is typical that the electron energy has a broad maximum at low laser injection phases. The energy spread, mainly correlated energy spread, is small for low laser phases and increases with higher laser phases and higher bunch charges. Since a low energy spread is important for the transmission in the dogleg, a low laser phase of 10° was used in the experiments.

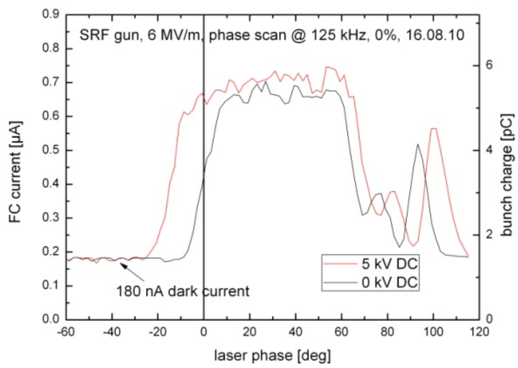

Figure 3: Laser phase scan at low bunch charge. The laser pulse energy is constant in the scan at 0.06 µJ.

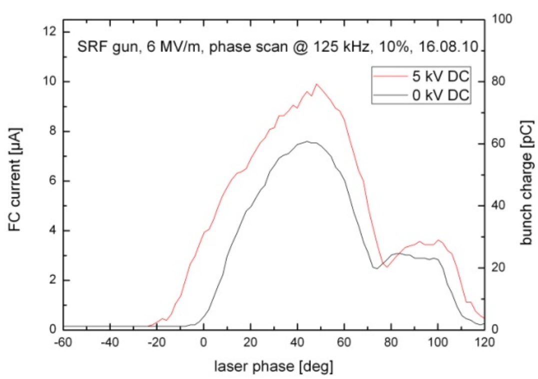

Figure 4: Laser phase scan at higher bunch charge. The laser pulse energy is constant in the scan at 0.15 µJ.

ELBE INJECTION

The injection into the ELBE linac was carried out step by step, increasing the bunch charge from about 1 pC to 60 pC. At the lowest bunch charge the quadrupole triplet in the dogleg was adjusted towards an achromatic beam transport and maximum acceptance.

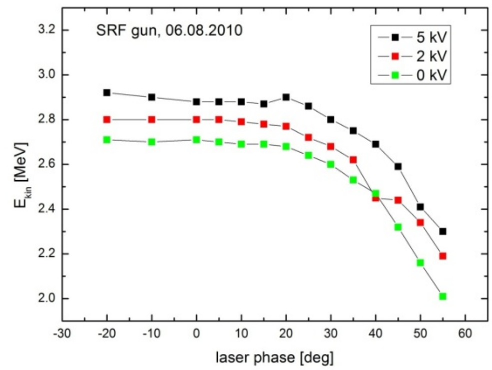

Figure 5: Measurement of the kinetic electron energy as function of laser phase for an acceleration gradient of 6 MV/m (16 MV/m peak field) and different DC voltages at photo cathode.

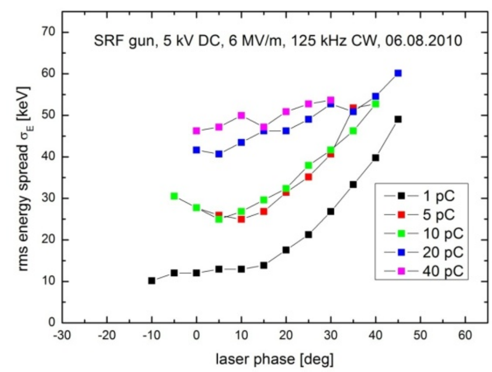

Figure 6: Energy spread at the SRF gun as function of laser phase for different bunch charges at an acceleration gradient of 6 MV/m (16 MV/m peak field) and a DC voltage of -5 kV applied to photo cathode.

After that, the on-crest phases of the first acceleration module were determined searching for maximum energy using the first chicane dipole. The first cavity was used to compensate the correlated energy spread of the gun, as it is shown in Fig. 7. The on-crest phase (maximum energy) in this measurement was found to be at 28°. The lowest energy spread turned out to be about -10° away. Finally the on-crest phases of the cavities of the second module were determined by means of energy measurement after the switching magnet.

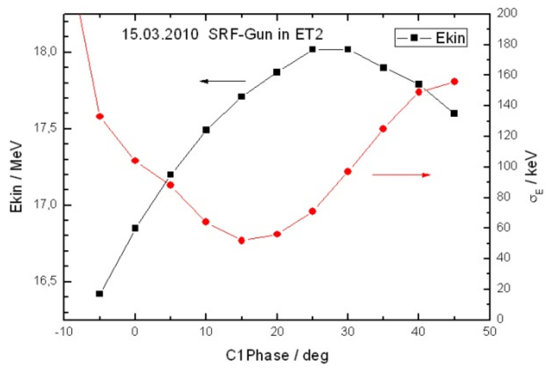

Figure 7: Measurement of the energy and the rms energy spread after the first acceleration module using the first dipole magnet of the chicane and the YAG screen ET2-DV.01. The phase of the first cavity was varied and the second cavity phase was hold on-crest.

The transmission was obtained by comparing the beam currents measured in the Faraday cup near the SRF gun and in the beam dump downstream the switching magnet as described above. Another indicator was the beam-loss monitoring system. The results of the current measurements are presented in Fig. 8. Up to 7.5 µA beam current (60 pC) the transmission was measured to be equal one within measurement accuracy and no beam loss was monitored. For higher currents we found a strongly increasing beam loss in the dogleg section.

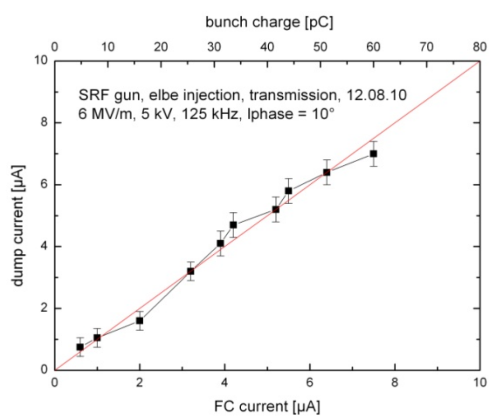

Figure 8: Transmission measurement for the SRF gun injection experiment. This measurement compares the current measured in the Faraday cup downstram the gun with the current measured in the beam dump after the switching magnet.

During this measurement, the current values of the beam optical elements like solenoid, quadrupoles, and dipoles were optimized. We did not vary the laser phase and did not play with the cathode position up to now. The cathode position is important for a proper RF focusing in the gun [9, 10]. It is also not clear if the beam loss is caused by a too large energy spread or by beam instabilities. These questions will be investigated in following measurement shifts.

SUMMARY

The Rossendorf SRF gun is now connected to the ELBE linear accelerator. The operation of the SRF gun as injector for ELBE has been demonstrated. The Cs_2Te photo cathodes used in the gun showed sufficient quantum efficiency and long lifetime. The vacuum and mechanical problems connected with the cathode exchange have been solved. A cathode exchange can now carried out in a short time without warming up the gun. Up to now, we do not found any cavity degradation, which may occur due to the operation of a normal conducting photo cathode in the superconducting cavity.

The handicap of the gun is the low acceleration gradient of 6 MV/m obtained with the present cavity. It has a strong influence on the beam parameter. Nevertheless, the gun is able to provide beam for ELBE and will be tested for user operation.

In order to overcome the low-gradient problem, a new large grain 3½ cell niobium cavity with optimized shape has been designed, fabricated and will be tested soon.

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