The superconducting RF photoinjector at ELBE – first operational experience

J. Teichert[1], A. Arnold[1], H. Buettig[1], D. Janssen[1], M. Justus[1], U. Lehnert[1], P. Michel[1], P. Murcek[1], A. Schamlott[1], Ch. Schneider[1], R. Schurig[1], F. Staufenbiel[1], R. Xiang[1], T. Kamps[2], J. Rudolph[2], M. Schenk[2], G. Klemz[3], I. Will[3]

1) FZD, Dresden, Germany
2) BESSY, Berlin, Germany
3) MBI, Berlin, Germany

Abstract

A radio frequency photo injector with a superconducting acceleration cavity (SRF gun) for installation at the Radiation Source ELBE was developed within a collaboration of BESSY, DESY, FZD, and MBI. This new and promising injector type allows CW operation and has the potential for the production of high brightness electron beams. The gun cryostat, the electron diagnostic beamline, and the driver laser with optical beamline were installed in summer and fall 2007. In November the first beam was produced with a Cu photo cathode Results of RF and beam parameter measurements with Cu and Cs_2Te photo cathodes will be presented.

Contribution to the “Polarized Electrons and High Brightness Electron Beams Workshop”
PESP 2008, Newport News (USA), 1-3 October 2008

Work supported by European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number RII3-CT-2003-506395)

The Superconducting RF Photoinjector at ELBE – First Operational Experience

J. Teichert[a], A. Arnold[a], H. Büttig[a], D. Janssen[a], M. Justus[a], U. Lehnert[a], P. Michel[a], P. Murcek[a], A. Schamlott[a], C. Schneider[a], R. Schurig[a], F. Staufenbiel[a], R. Xiang[a], T. Kamps[b], J. Rudolph[b], M. Schenk[b], G. Klemz[c], and I. Will[c]

[a]Forschungszentrum Dresden-Rossendorf, P.O. Box510119, 01314 Dresden, Germany.
[b]BESSY, Albert-Einstein-Str. 15, 12489 Berlin, Germany.
[c]Max-Born-Institut, Max-Born-Str.2A ,12489 Berlin, Germany.

Abstract. A RF photo injector with a superconducting cavity (SRF gun) for installation at the Radiation Source ELBE was developed within a collaboration of BESSY, DESY, FZD, and MBI. This new and promising injector type allows CW operation and has the potential for the production of high-brightness electron beams. The gun cryostat, the electron diagnostic beamline, and the driver laser with optical beamline were installed. In November 2007 the first beam was produced. Results of the beam parameter measurements with Cs_2Te photo cathodes are presented.

Keywords: electron source, photo electron injector, superconducting cavity, SRF gun, radio frequency acceleration, cesium telluride photo cathode.
PACS: 07.77.Ka, 29.25.Bx, 29.27.Ac, 29.27.Fh.

INTRODUCTION

One of the main concerns in the development of electron guns for future accelerator based light sources is the combination of high beam brightness and high average current. State-of the-art normal conducting RF photo injectors have demonstrated very high brightness at large bunch charges. The success based on direct generation of short electron bunches by laser pulses and the immediate strong acceleration of the electrons from the surface of the photo cathode in the RF field. By exploiting superconducting technology the RF power losses can be minimized and operation in continuous wave (CW) mode with high average current is possible. In the Research Center Dresden-Rossendorf (FZD) a superconducting RF photo injector (SRF gun) with a 3½-cell niobium cavity has been developed. The SRF gun is installed at the superconducting electron accelerator ELBE, a user facility for the production of electro-magnetic radiation (infrared, x-rays, gamma radiation) and secondary beams (neutrons, positrons).

The SRF gun project at FZD, carried out in collaboration with BESSY, DESY, and MBI, has two main goals: the installation of a high-brightness photo-injector for ELBE, and contributing to the SRF gun development as a promising future technology. Now the new SRF gun has opened an unique opportunity for experimental studies like long term studies of photo cathodes operation and lifetime, cavity quality degradation, or emittance compensation methods.

On November 12, 2007, the first accelerated electron beam was generated which was extracted from a Cu photo cathode. In March 2008 the cathode transfer system was mounted and the first set of Cs_2Te photo cathodes was produced. Since May 2008 the gun has been operated with these cathodes. This paper reports on the operational experience and on beam parameter measurements within the first operation run until October 2008. The RF properties of the SRF gun cavity are presented in a separate paper [1]. An overview of the SRF gun design is published in ref. [2].

PHOTO CATHODES AND DRIVE LASER

During the commissioning and the first measurement period two types of photo cathodes were used: a Cu cathode and later semiconductor cesium telluride (Cs_2Te) cathodes. The Cu cathode was mounted into the cavity during the assembly of the cryomodule. It was used during the commissioning until the cathode transfer system was installed. The quantum efficiency (QE) was about 1×10^{-6}, which was rather low. However, an electron beam could be produced and observed on YAG screens.

After installation of the cathode transfer system, the first set of Cs_2Te photo cathodes for the SRF gun was produced in May 2008 in the preparation lab with QE of 4-5 %. After transfer to the gun the QE dropped down to 0.05 %. The first Cs_2Te cathode was in operation for 44 h. This cathode and all the others of the first set were damaged due to an accidental venting during the summer shut down.

A second set of Cs_2Te photo cathodes was prepared and transported to the SRF gun in July 2008. One was installed in the gun and was in operation for about 350 h until the end of the measurement period. Its QE after preparation was 3 %. Again the QE measurement in the SRF gun after insertion delivers a much lower value of about 0.1 %. Although the vacuum of 10^{-9} mbar in the transportation chamber was now good enough the worse vacuum during cathode exchange in the transfer chamber causes the drop-down. Nevertheless the QE was high enough to produce bunch charges up to 200 pC and to conduct the beam parameter measurements. The QE measurement was regularly repeated without any further significant changes during the whole measurement period.

The cathode cooling, support and transfer system worked properly. The cooling of the cathode with liquid N_2 was efficient. As desired the cathodes can be exchanged without warming-up.

In order to fulfill the requirements of the SRF gun specifications, a UV laser system with two channels has been developed. The two channels have different oscillators, but jointly used amplifier and UV conversion. At present, the 500 kHz channel is used for the experiments. The frequency-quadrupled Nd:YLF system for CW operation consists of a mode-locked oscillator with 26 MHz, a regenerative amplifier, and a two-stage frequency conversion. The Pockels cells in the amplifier allow variable repetition rates up to 500 kHz. The laser has a Gaussian temporal beam shape with a width of 15 ps FWHM. The laser spot is enlarged with a telescope on the laser table. Then the beam is cut with an aperture to obtain a circular flat top profile with 2.7 mm diameter.

BEAM PARAMETER MEASUREMENTS

For the electron beam characterization a diagnostic beam line has been installed [3]. The beam properties were measured using the following parameters: cavity acceleration gradient of 5 MV/m, photo cathode about 2.5 mm retracted, 5 kV DC voltage at the cathode, and the gun was operated in CW.

In a laser phase scan the arrival time of the laser pulse onto the cathode is varied with respect to the RF phase while measuring the bunch charge in a Faraday cup at constant laser pulse energy. In Fig. 1 such a measurement is shown for the whole phase range from -180° to 180°. The RF field is given by $B_z(z) = B_{z0}(z)\sin\varphi_{RF}$ and the z-axis corresponds to the beam direction. Due to its negative charge, electrons are emitted in the phase range -180° to 0°, whereas emission is suppressed between 0° and 180°. This behavior is clearly seen in the measured curve. The curve delivers important information on synchronization, phase jitter, and proper operation of the laser system. But the main purpose of the measurement is the determination of the optimum laser launch phase.

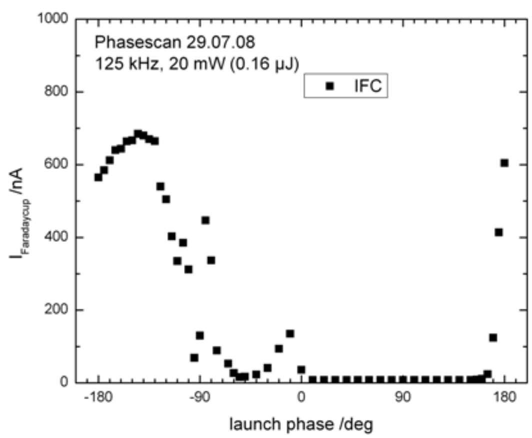

FIGURE 1. Laser phase scan with low bunch charge measured for a full RF period from -180° to 180° (T = 1/f = 769.2 ps). The dark current measured in the phase range between about 0° and 180° is 8 nA.

The phase scan has been carried out for different laser pulse repetition rates from 125 kHz down to 1 kHz with nearly the same laser power of 20 mW for each scan. Whereas the average current is about the same, the bunch charge is increasing with lower laser pulse rate. With increasing laser pulse energy and correspondingly higher electron bunch charge, the space charge effect in front of the cathode becomes more and more important. As visible in Fig. 2, this effect smoothes the curve structures and causes the saturation in the bunch charge. Except these space charge effects, the behavior of the curves is independent of the laser repetition rate which confirms the proper laser synchronization.

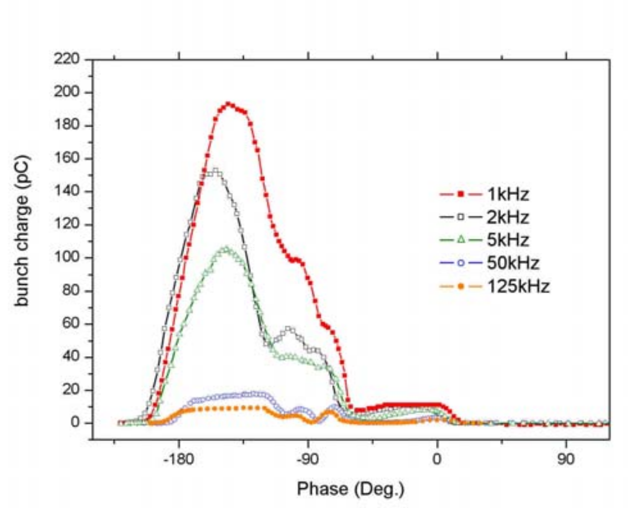

FIGURE 2. Bunch charge versus laser launch phase measured for different laser repetition rates.

The beam energy as a function of launch phase is presented in Fig. 3 with a maximum beam energy of 2.06 MeV. The comparison with the laser phase scan in Fig. 2 shows that the energy drops down at phases > -160° whereas the emission current is still constant until -120°.

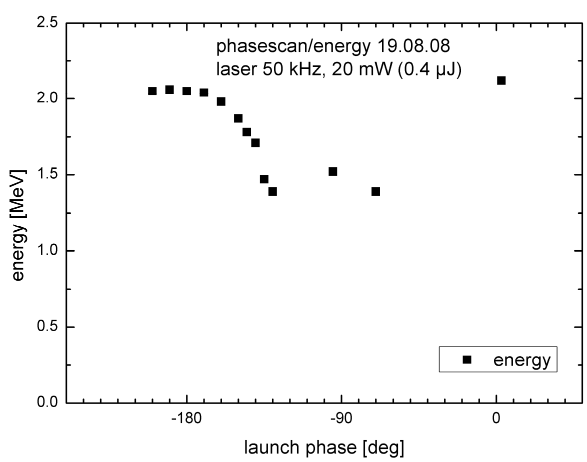

FIGURE 3. Electron beam energy versus launch phase measured by means of the 180° bending magnet in the diagnostic beam line.

The transverse emittance have been measured with the solenoid scan method. For these measurements the gun solenoid and two following screens have been used. Between the solenoid and the screens there is only a drift space of 38 cm and 170 cm, respectively. The magnetic axial field distribution of the solenoid was precisely measured. Thus the focal strength in dependence on the excitation current I can be calculated. The measured beam size $\sigma^2_{x,y}$ on the screen is a parabolic function in I^2 containing the phase space ellipse parameters. From a quadratic fit these parameters and the emittance can be determined. In order to establish the operation phase of the gun, the tranverse emittance was first measured as a function of laser phase.

Considering also the other results the laser operational phase was set to -160°. For this laser phase the transverse emittance as a function of bunch charge has been measured with the results in Fig. 4. Measurements were carried out till 70 pC. For higher bunch charges the method could not be applied. The strong space charge effect causes a solenoid current dependence of the beam size which could not be fitted with the theoretical curve. Furthermore the beam shows an increasing halo. To measure the beam size CCD camera images with 8 bit and 660 x 495 pixels were produced, the camera gain was adapted, back ground subtracted and a region of interest (RoI) selected. In the RoI the beam spot size was obtained by a direct rms analysis or by a Gaussian fit to the projected profiles. All theses measurement points are shown in the figure.

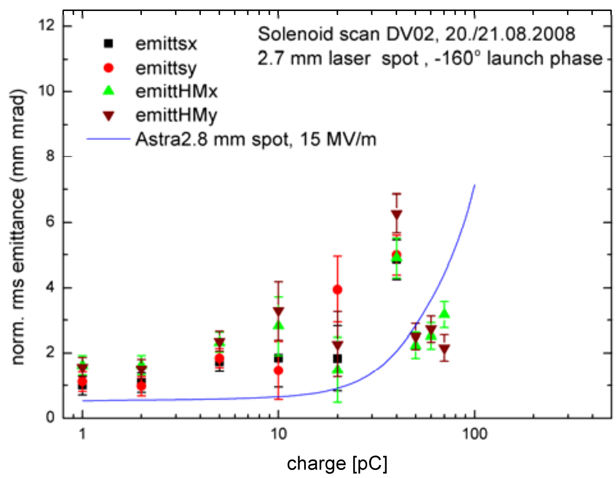

FIGURE 4. Normalized transverse emittance as a function of bunch charge at -160° laser launch phase measured with the solenoid scan method using beam spot on screen 2. Measurement in horizontal (x) and vertical (y) direction, direct rms beam spot size (emittHM), and Gaussian fit (emits).

In Fig. 4 the curve shows an ASTRA simulation result with parameters corresponding to the present experimental situation. The peak value of the RF field was chosen to 15 MV/m, the cathode 2 mm retraced, for the launch phase the optimum value was taken for each bunch charge. In the simulation bunches could be accelerated up to a bunch charge of about 100 pC. For higher bunch charges particle loss occurs due the space charge in front of the cathode. The transverse emittance starts with about 0.5 mm mrad and increases to about 7 mm mrad at 100 pC. This simulation agrees rather well with the experimental data. Especially there is a good agreement in the predicted space charge limit.

For the next runs of the SRF gun in 2009 it is planned to deliver beam to the ELBE accelerator for user operation. Thereby bunch charges above 100 pC are important. It is obvious that the present low acceleration gradient of the gun is the crucial point. As reported in [1] the acceleration gradient could be increased to about 18 MV/m peak field by means of RF high power processing. Furthermore the space charge effect can be reduced by a larger laser spot size. Both changes can improve the electron beam parameters. For a prediction ASTRA simulations have been carried out with 18 MV/m peak field. The cathode position, laser launch phase and laser spot size have been optimized. It turned out that for the higher field and enlarged laser spot of 5.2 mm diameter the space charge limit at the cathode is about 750 pC. The limitation is the transverse emittance now. If 10 mm mrad are acceptable, bunch charge up to about 500 pC can be delivered.

ACKNOWLEDGMENTS

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.

REFERENCES

1. A. Arnold, et al., "Rossendrof SRF-Gun Cavity Characteristics," these proceedings.
2. A. Arnold, et al., "Development of a Superconducting Radio frequency Photo Electron Injector," Nucl. Instr. and Meth. A **577**, 440-454 (2007).
3. T. Kamps, et al., "Electron beam diagnostics for a superconducting radio frequency photoelectron injector," Rev. Sci. Instrum. **79**, 093301 (2008).