RUNNING EXPERIENCE OF THE SUPERCONDUCTING RF PHOTOINJECTOR AT FZD*

R. Xiang#, A. Arnold, H. Buettig, D. Janssen, M. Justus, U. Lehnert, P. Michel, P. Murcek, A. Schamlott, Ch. Schneider, R. Schurig, F. Staufenbiel, J. Teichert, FZD, Dresden, Germany,

T. Kamps, J. Rudolph, M. Schenk, Helmholz-Zentrum Berlin, Germany,

G. Klemz, I. Will, MBI, Berlin, Germany

Abstract

More and more electron accelerator projects for FELs, ERLs or 4th generation light sources require "super" electron beams with high brightness, low emittance, and high average current. Under this background, much attention is paid on the research and development of new electron sources. A Superconducting RF photoinjector within a collaboration of HZB, DESY, FZD, and MBI is designed to improve the beam quality for ELBE IR-FEL users, and at the same time to test this kind of promising injector concept. The main design parameters of this gun are the final electron energy of 9.5 MeV, 1 mA average current, and transverse normalized emittances (rms) of 1 mm mrad at 77 pC and 2.5 mm mrad at 1 nC bunch charge. In this paper the results of the RF and beam parameter measurements with Cs_2Te photo cathodes will be presented, and the experience for the gun running gained at the first beam experiment will be concluded, including the life time and the compatibility of the normal conducting photocathode in SC cavity, the cavity properties after the cathode's inserting.

INTRODUCTION

The SRF gun developed within the collaboration of HZB, DESY, MBI and FZD has been put into operation in FZD since 2007 [1]. This new type of injector allows CW operation and at the same time is designed for low emittance beam, thus it is the promising candidate for high current and high brightness electron source.

The first beam was produced on November 12, 2007 [1] with a copper cathode, and in March 2008 the first cesium telluride (Cs_2Te) photocathode was transported into the gun. From September 2008 to February 2009, the SC cavity was taken out from the cryomodule and a frequency adjustment was performed in the clean room. The latest photocathode was inserted into the gun on May 8, 2009 and since then the gun has been operated with the same cathode for more than 560 hours and provided beam for more than 100 hours with the integrated charge of 0.8 C. During the beam time the acceleration gradient was set as 5.5 MV/m which belongs to 15 MV/m peak field in the cavity and about 7 MV/m at the cathode. The average current was mostly 1 µA ~16 µA.

Figure 1 shows the SRF gun cryomodule, which comprises the SC cavity, tuners, Helium tank, LN_2 vessel, magnet shield, photocathode, HOM couplers, main power coupler, and so on. The 1.3 GHz niobium cavity consists of 3 TESLA cells and a special designed half-cell and an additional choke cell. The ELBE-type main coupler for 10 kW serves for the gun [2]. Details of the SRF gun design have been published elsewhere [3].

In the centre of the half-cell cavity, a normal conducting photocathode is installed on a special supporter, which is isolated from the SC cavity by a vacuum gap and cooled with liquid nitrogen. The Cs_2Te layer is deposited on the front surface of the Molybdenum tip. The most attention-getting question is the compatibility of the cathode and the cavity. In our experiments the photocathode has long lifetime and relatively stable QE, at least in the case of illuminated by the laser with low and medium energy intensity. On the other hand, the RF measurement result shows that the cavity has the same quality before and after the cathode inserting.

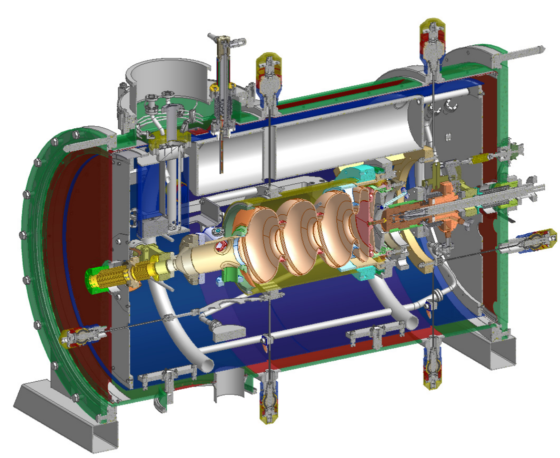

Figure 1: Design of the SRF Gun cryomodule.

* 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.

#r.xiang@fzd.de

PHOTOCATHODE

Up to now three cathodes have been employed in the SRF gun (see table 1). Cathode #090508Mo finished its short service because of the vacuum crash during the cavity warming up. The second cathode, #070708Mo, was drawn out from the gun before the cavity was warmed up and taken out for frequency adjustment. The third cathode, #310309Mo is working till now in the gun.

Table 1: cathodes serving in SRF gun

Cathode NO.	Serving time	Q.E. in gun
#090508Mo	2008-5-23 to 2008-6-23	0.05%
#070708Mo	2008-7-21 to 2008-9-19	0.1%
#310309Mo	2009-5-8 till now	1.1%

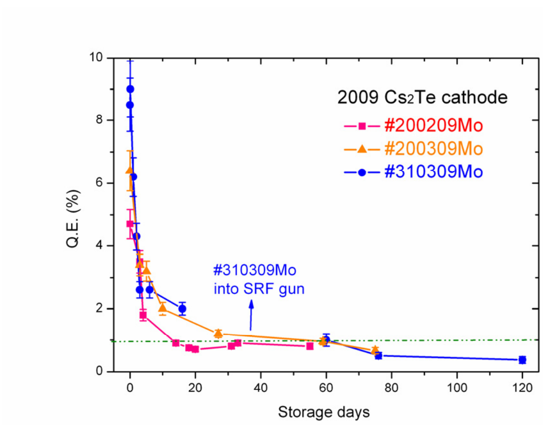

Figure 2: Long-term behavior of Cs_2Te photocathodes

Benefiting from the vacuum improving in the cathode transfer system, the life time of photocathode working in the gun is found comparable with the ones stored in the preparation chamber. To be a reference, the long term behaviour of the same group Cs_2Te photocathodes produced in 2009 are presented in Figure 2. The blue curve is the QE of cathode #310309Mo, which has been in operation in the gun up to now. The preparation environment was the same for all of the three cathodes, and the substrata were the same material and treated in the same way. #200309Mo (orange) was co-evaporated [4] and the other two were standard prepared. The slower decrease of #200309Mo (orange) may be attributed to the co-evaporation, which was found to be a good way to produce Cs_2Te photocathodes with good QE and good life in short preparation duration. According to the gun specification, 1% QE is sufficient for operation and the life time could be longer than 60 days. The power of the drive laser was ≤ 300mW, and the pulse energy is ~2.4 µJ. The pulse length of the drive laser was 15ps, so the peak power intensity could reach 5.66kW/mm^2. Moreover, even after the light contamination a QE healing of photocathode could be performed by means of surface cleaning with a high intensity laser.

Another important parameter for the photocathode in the injector is the dark current. Figure 3 shows the dark current measured in the SRF gun with cathode #310309Mo and the imagines of the cathode at different RF gradient. This dark current is considered due to field emission and comes from two sources: the gap between the cathode and cavity and the cathode itself. The detectable dark current starts from 6 MV/m independent of the DC bias on the cathode. This threshold is higher than the one measured in 2008 with cathode #070708Mo, which was 5 MV/m, so the dark current threshold could be modified by improving the cathode surface condition and changing the shape of cathode tip, for example, applying a round edge with small radius for cathode tip.

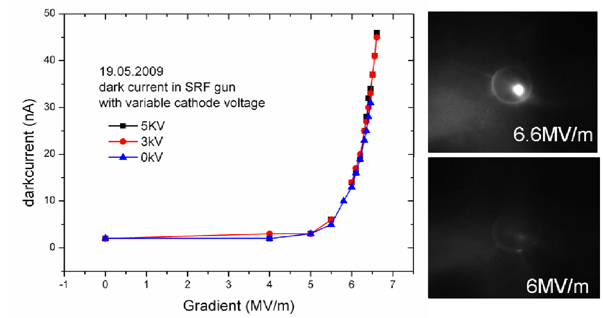

Figure 3: Dark current measured in the SRF gun with cathode #310309Mo

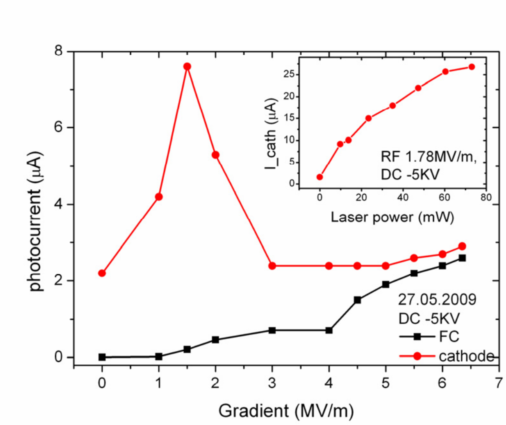

Figure 4: photocurrent scanning vs. cavity gradient and the laser power. The current was measured from different positions: Faraday cup (black curve) and the cathode (red one). The inset window shows the cathode current scan vs. laser power at the gradient of 1.78MV/m, where the high current appeared.

Figure 4 is a photocurrent scanning vs. cavity gradient, in which an unusual current peak emitting from the cathode (red) appears in the low gradient zone. But it is not accelerated through the gun because the signal of Faraday cup is clearly normal. In fact the multipacting happened in the same gradient. In the inset window the current intensity of this peak increases with the laser power illuminating the cathode, i.e. the number of the primary photo-electrons. So we assume that this peak comes from the second electron emission and probably also the ion back bombardment on the cathode area. The good news is that this phenomenon didn't appear in the normal running of SRF gun which was set at higher gradient, thus it is less harmful for the photocathode emitter film.

RF MEASUREMENT

After helium tank welding, cryostat assembly and gun commissioning an acceleration gradient of 5.5 MV/m was obtained which corresponds to a peak field of 15 MV/m. About 5 W RF power was dissipated on the cavity wall. Several results of the regularly measured cavity performance (unloaded quality factor Q_0 vs. acceleration gradient E_{acc}) are summarized in Fig. 5. A high power processing carried out in September 2008 could improve the gradient to 6.5 MV/m (17.6 MV/m peak field, in green curve). The most important information is that the 8^{th} measurement (blue curve) with cathode inside after one year operation verifies the 2^{nd} measurement (orange curve) from 2007, which was the virgin Q_0 of the cavity. No visible degradation of the cavity performance could be found after about 500 hours operations and with Cs_2Te cathodes inside.

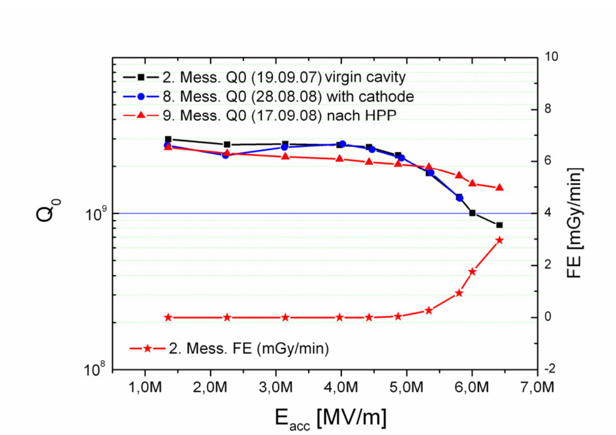

Figure 5: Unloaded quality factor Q_0 vs. acceleration gradient and the corresponding field emission dose. The figure shows the 2nd measurement in September 2007, the 8^{th} measurement with cathode inside in 2008 and the 9th measurement after high power RF processing (HPP) of the cavity.

In order to increase the quality factor of the SRF-Gun cavity high power RF processing (HPP) was done in September 2008. The RF klystron was pulsed with a low duty cycle (30ms/1000ms) to reduce the load to helium tank. Within the short pulses a maximum field of E_{peak} = 25 MV/m was reached. The 9th measurement in Fig. 5 (red curve) shows that this results in a stable CW operation up to Epeak=17.6 MV/m or Eacc = 6.5 MV/m which is a reduction of the dissipated power by a factor of two at the same field level. The higher gradient increased the maximal particle energy up to 3 MeV [5].

Simulations showed that the coaxial channel between half-cell hole and cathode stem is the most critical place for multipacting in the cavity. Indeed multipacting was found at that position during ramping-up the RF. With a DC bias of the cathode up to -7 kV the effect could be eliminated. The strength and duration of this effect were different for the individual cathodes, which will be studied more systematically.

At the exit of cavity two Higher Order Mode (HOM) couplers are installed to damp the dangerous HOM excited by the electron beam. Measurement shows that the couplers work efficiently with average current at least up to 1mA, which is required for the ELBE FEL-mode. The other important results about SRF cavity running, such as microphonics, Lorentz detuning, cavity tuners, pressure sensibility and in-situ fundamental mode field distribution, have been detailed reported before [5].

BEAM PARAMETERS

The diagnostic beam line has been installed and tested with the SRF gun, including viewscreens for beam profile measurement, beam position monitors (BPM) and steering coil pairs, Faraday cups and intergrating current transformer (ICT), C bend magnet for energy and energy spread measurement, slit mask emittance measurement, Cerenkov radiator with streak camera and electro-optical sampling for electron bunch temporal structure. A detailed description of the beamline is given in Ref. [6].

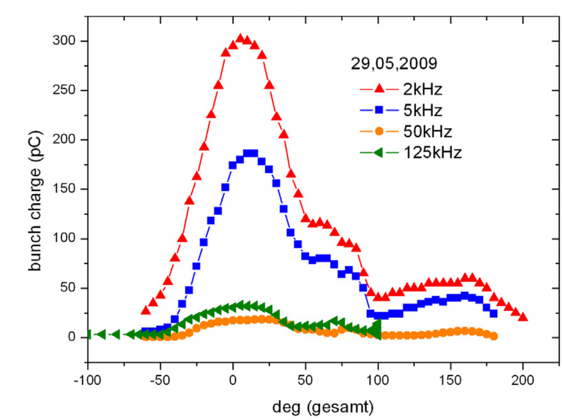

Figure 6: Laser phase scan with 55 mW laser power at different laser pulse repetition rates.

Because up to now the achieved acceleration gradient and the field at the cathode are much lower than the designed parameters and the electron beam dynamic is mainly determined by the space charge effect, the beam parameters are obviously different from the first designed ones. Figure 6 shows the laser phase scan for different laser repetition rates between 2 kHz and 125 kHz at constant laser power of 55 mW. The bunch charge (current) was measured with a Faraday cup about 1 m downstream from the gun. At the optimum laser phase 300 pC/bunch could be produced, and this optimum phase is independent of the cathode position (the cathode can be tuned in the range of ±3 mm). The maximum average current achieved was 18 µA at 125 kHz repetition.

Table 2: Measurement results and designed parameters of the FZD SRF gun

	present cavity			new high gradient cavity	
	measured	FEL mode	high charge mode	FEL mode	high charge mode
Max. energy	3 MeV	3 MeV		≤ 9.5 MV/m	
peak field	17.6 MV/m	18 MV/m		50 MV/m	
laser rep. Rate	1-125 kHz	13 MHz	2-250 kHz	13 MHz	≤500 kHz
laser pulse length (FWHM)	15 ps	4 ps	15 ps	4 ps	15 ps
laser spot size	1~6 mm	5.2 mm	5.2 mm	2 mm	5 mm
bunch charge	≤ 300 pC	77 pC	400 pC	77 pC	1 nC
average current	18 μA	1 mA	100 μA	1 mA	0.5 mA
peak current	20 A	20 A	26 A	20 A	67 A
transverse norm. emittance (rms)	3±1 mm·mrad @ 80 pC	2 mm·mrad	7.5 mm·mrad	1 mm·mrad	2.5 mm·mrad

At the gradient of 5.5MV/m, the beam energy was measured with dipole magnet as max. 2.2 MeV and energy spread as 25keV. The launch phase is then chosen according to the synthesis of bunch charge, energy, and transverse emittance scanning.

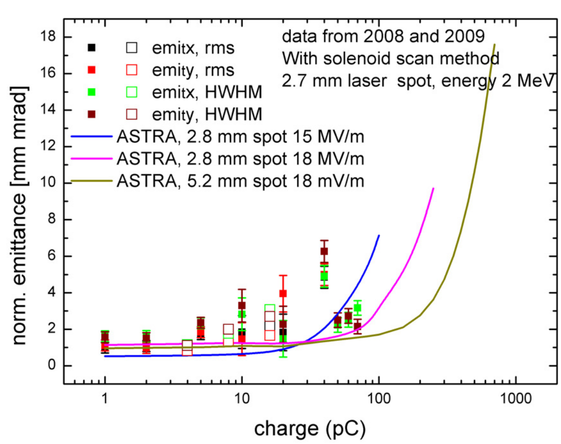

Figure 7: Normalized transverse emittance vs. bunch charge at optimum laser launch phase. The bold points are the measured data in 2008, and hollow points are the ones in 2009. The curves show the ASTRA simulations with various laser spot size and rf gradient.

The transverse emittance has been measured with the solenoid scan method using the gun solenoid and two following screens downstream. The acceleration gradient was 5.5 MV/m, the laser spot diameter 2.7 mm. Measurements were carried out till 70 pC. For higher bunch charges this method is not suitable. The results of the emittance measurements as a function of bunch charge are presented in Fig. 7. The measurement agrees sufficiently with the ASTRA simulation performed with similar parameters (blue curve, with 2.8 mm Laser spot, 15 MV/m peak field). Further simulations (magenta and red curve) show that an increase of the acceleration gradient up to 6.5 MV/m (18 MV/m peak field) and an optimized laser spot of 5.2 mm diameter would allow bunch charges up to 400 pC with transverse emittances ≤ 8 mm·mrad, which is acceptable for ELBE [7]. The hardware and software for the slice mask method for the emittance measurement have been installed and the measurement is going on.

A summary of the beam parameter measurements is given in Table 2. Besides the measured data, the parameters of the two operation modes with the existing cavity are listed parallel: the FEL mode with high repetition rate for the ELBE IR-FELs and the high charge mode for neutron and positron users. In the last columns the simulated parameters with the new high gradient cavity are presented. This new cavity is now in the process of fabricating in JLab.

SUMMARY AND OUTLOOK

A Superconducting RF photoinjector within a collaboration of HZB, DESY, FZD, and MBI is successfully installed and tested in FZD ELBE hall. With this facility, plentiful experiments have been performed to measure the photocathodes properties and the cavity quality to verify the SRF gun basic concepts. At the same time, beam parameters measured with Cs_2Te photocathodes affirm the feasibility of SRF gun applying for ELBE users. During the gun operation, one of the main purposes is to gain more experience about this new type electron source, and to prepare the employment in ELBE linac from the end of 2009.

REFERENCES

[1] J. Teichert, et al., FEL08, Korea, Aug24.-29, 2008. J.Teichert, et al., EPAC08, Italy, Jun23.-27., 2008.
[2] H. Buettig et al., Nucl. Instr.and Meth. in press
[3] A. Arnold, et al., NIM. A 577, 440 (2007).
[4] G. Suberlucq, Proc.CTF3 Rev., CERN, Oct 2001
[5] A. Arnold, et al., PESP 2009, VA, Oct 1-3, 2008.
[6] T. Kamps, et al., Rev. Sci. Instr. 79, 093301 (2008)
[7] J. Teichert, ERL2009, Ithaca, New York, June 8-12, 2009