PULSED MODE OPERATION AND LONGITUDINAL PARAMETER MEASUREMENT OF THE ROSSENDORF SRF GUN *

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Abstract

The Rossendorf SRF gun with a 3½ cell cavity has been operated since 2007. It has produced CW beam with the electron energy of 3 MeV and the average current up to 16 μA. The electron beam of the gun has been successfully injected into the ELBE superconducting linac since 2010. The Nb cavity has shown constant quality during the operation and for the Cs_2Te photocathode life time of months could be obtained.

Recently the gun started to run in the pulsed mode with higher gradient. The longitudinal parameters have been measured in this mode. The dark current arose from the high gradient is studied. The main field emission source has been found to be the half cell. In this paper the new status of the SRF gun will be presented, and the latest results of the beam experiments will be discussed.

INTRODUCTION

The Rossendorf superconducting rf photo injector (SRF gun) developed within a collaboration of the institutes HZB, DESY, MBI and HZDR has been put into operation in 2007. It is designed for medium average current beam and operation in CW mode with high repetition rate [1]. As a practical test stand for the SRF gun technology, the SRF gun is also developed to provide low emittance and low energy spread beam for the radiation source ELBE. During the 09/10 winter shutdown, the beam line connecting the SRF gun to the ELBE linac was installed [2] and the first beam from the SRF gun was successfully guided to ELBE in 2010 [3]. The maximum bunch charge injected and accelerated in ELBE reaches 120 pC with 50 kHz (6 μA).

The superconducting cavity, the main part of SRF gun, consists of three TESLA cells and one optimized half-cell. The Cs_2Te cathode is inserted in the half cell isolated with 1mm vacuum gap. Additionally, a resonant superconducting choke filter surrounding the cathode is served to prevent RF leakage. During the gun operation, the cavity quality limits the achievable gradient and thus the beam parameters [4]. The gun is routinely operated at 16.2 MV/m peak field and produces CW beam with a kinetic energy of 3 MeV.

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RF PULSED MODE OPERATION

In order to reach higher gradients with the present cavity and simultaneously keep the low load to the liquid helium system, the input RF power is pulsed. The typical repetition rate varies from 1 Hz to 10 Hz, and the pulse length can be adjusted from 5 ms to 20 ms. Recently, operation with 22 MV/m peak field was performed in the RF-pulsed mode. Compared with the CW mode, the beam energy reaches higher energy up to 4 MeV and the beam emittance becomes also better.

The main problem for the high gradient is that the dark current increases rapidly to μA level in macro pulse, which equates the photocurrent. Moreover, the dark current beam has the same energy as the photocurrent. The main source of the dark current is believed to be the field emission from the rear wall of the cavity half-cell.

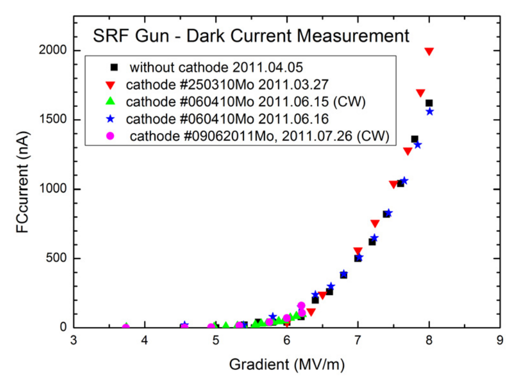

Figure 1: Dark current versus acceleration gradient measured in the Faraday cup downstream of the gun. The black squares show the empty cavity without any cathode. Three cathodes have been measured in the cavity.

In Fig. 1 several dark current measurements are compared. All of the curves have the same trend: The dark current starts obviously from 6 MV/m and increases quasi-exponentially with the gradient (the cavity peak field is 2.7 times the value of the acceleration gradient) and reaches μA at about 7.5 MV/m. The operation mode, CW or pulsed RF, has no influence. The black squares show the empty cavity without any cathode, which is the field emission from the Nb wall. The cathodes have much less emission than the cavity itself.

From Fowler-Nordheim formula, the field emitted current for an alternating field can be expressed by [5]

$$I = \frac{5.7\cdot 10^{-12}\cdot 10^{4.52\phi^{-0.5}}\cdot A\cdot(\beta E)^{2.5}}{\phi^{1.75}}\exp\left(-\frac{6.53\cdot 10^{9}\cdot\phi^{1.5}}{\beta E}\right) \quad (1)$$

Here, E is the amplitude of the local surface field in V/m, β is the field enhancement factor, ϕ denotes the work function in eV, and A the effective emission area in m^2.

From (1), the slope in the Fowler-Nordheim plot

$$\frac{d(\ln I/E^{2.5})}{d(1/E)} = -\frac{2.84\cdot 10^{9}\cdot\phi^{1.5}}{\beta} \quad (2)$$

delivers the field enhancement factor. The work function of Nb is 4.3 eV. From the measurement a linear fit could be performed as shown in Fig. 2 which gives an enhancement factor β of 500.

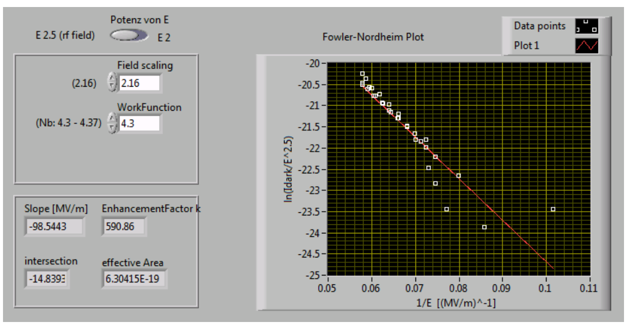

Figure 2: Fowler-Nordheim plot of the field emission in the SRF gun cavity.

LONGITUDINAL PARAMETERS

Method description

The method for determination of the longitudinal beam parameters is the measurement of the energy spread after the first accelerator module as a function of the cavity phase. Figure 3 shows the layout the SRF gun and the ELBE beam line. The electrons from the gun are guided through the achromatic dogleg into the first accelerator module. The longitudinal phase space measurement requires a precise measurement of the beam energy spread, which is realized with the Browne-Buechner (BB) spectrometer behind the first module.

As known, the longitudinal beam ellipse can be written by

$$\tau = \begin{pmatrix} \tau_{11} & \tau_{12} \\ \tau_{21} & \tau_{22} \end{pmatrix} \quad (3)$$

In this matrix, $\sqrt{\tau_{11}} = \sigma_t$ is the rms bunch length, and $\sqrt{\tau_{22}} = \sigma_E$ is the rms energy spread. For the RF phase variation the second cavity of module 1 is used. Its transport matrix is:

$$R_{C2} = \begin{pmatrix} 1 & 0 \\ -\omega_{RF} V_{C2}\sin(\varphi_{C2}) & 1 \end{pmatrix} \quad (4)$$

The longitudinal beam ellipse at the exit of the cavity 2 is given by:

$$\tau(1) = R_{C2}\tau(0)R_{C2}^{T} \quad (5)$$

The matrix multiplication gives the following relationship for energy spread as the function of the cavity phase and gradient:

$$\sigma_E^2(1) = \tau_{22}(0) - 2\tau_{12}(0)V_{C2}\sin(\varphi_{C2}) + \tau_{11}(0)(V_{C2}\sin(\varphi_{C2}))^2 \quad (6)$$

Based on the equation (6), the energy spread σ_E is measured with the BB spectrometer for various cavity phases ϕ_{C2}. A quadratic fit delivers the matrix elements, and then the rms bunch length, rms energy spread and the correlation can be determined.

Measurement Results

Figure 4 shows the measurements of the rms energy spread of the gun versus the gun phase. The beam energy is 3 MeV. The red dots give the measurement results directly from the gun diagnostic beam line, which has the same trend and a similar minimum point as the results determined with BB spectrometer in the ELBE beam line.

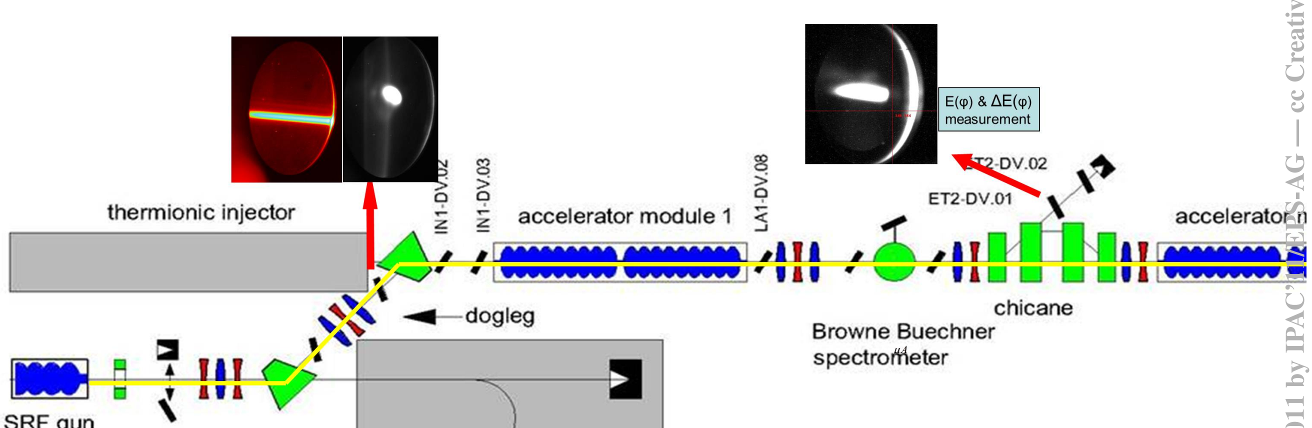

Figure 3: Layout the SRF gun and the ELBE beam line. The electron bunches extracted from the gun are guided through the achromatic dogleg and then are accelerated by the accelerator modules.

The minimum energy spread is reached when the photo electrons are emitted at a phase around 5°.

The rms bunch length is presented in Fig. 5. The bunch length is between 3 and 4 ps, shorter than the rms laser pulse length of 6.2 ps, which is closer to the ASTRA simulation result than the measurement with the method of Cherenkov radiation (12~32ps). The minimum bunch length appears at the gun laser phase of 5°~10°.

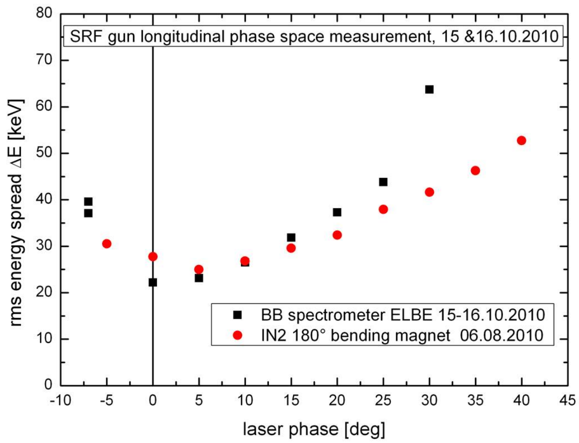

Figure 4: measured curves of the rms energy spread versus the gun phase. The red dots give out the measurement results from the gun diagnostic beam line and the black squares show the result with BB spectrometer in the ELBE beam line.

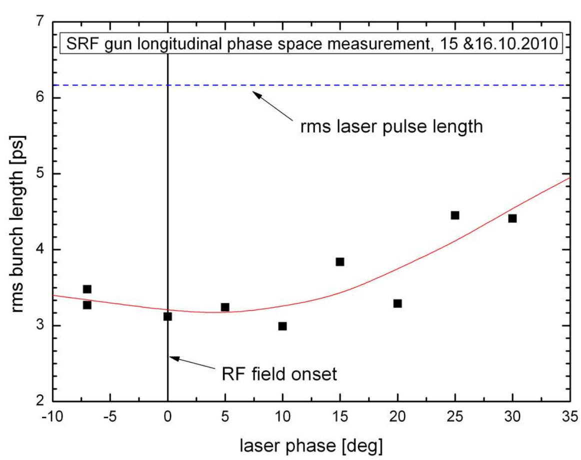

Figure 5: rms bunch length versus the gun laser phase. The blue dotted line shows the rms laser pulse length 6.2ps.

The phase space at the gun exit was obtained from these results and a transport matrix calculation of the dogleg. In Fig. 6 the red ellipse shows an example of the longitudinal phase space at the exit of the gun cavity with laser phase -7°.

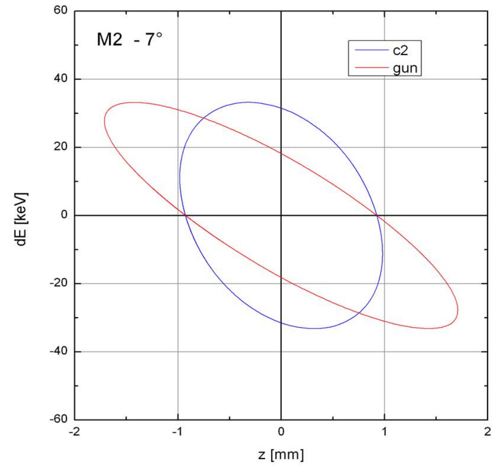

Figure 6: an example of the longitudinal phase space at the exit of the gun cavity with laser phase -7° (red).

SUMMARY AND OUTLOOK

During the SRF gun operation, one of the main purposes is to gain more experience about this new type electron source. With SRF gun and ELBE accelerator, plentiful experiments have been performed to measure the dark current from the gun and the beam longitudinal parameters.

The low Q-value of the present gun cavity limits the beam quality. Cooperating with JLab we have fabricated and tested two 1.3 GHz 3.5 cell photo-injector cavities of polycrystalline niobium and large grain niobium, respectively [6]. The cavity with the better performance will replace the present cavity in the SRF gun.

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