COMMISSIONING RESULTS OF THE 2ND 3.5 CELL SRF GUN FOR ELBE

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Abstract

As in 2007 the first 3.5 cell superconducting radio frequency (SRF) gun was taken into operation, it turned out that the specified performance has not been achieved. However, to demonstrate the full potential of this new type of electron source, a second and slightly modified SRF gun II was built in collaboration with Thomas Jefferson National Accelerator Facility (TJNAF).

We will report on commissioning and first results of the new gun, which includes in particular the characterization of the most important RF properties as well as their comparison with previous vertical test results.

INTRODUCTION

At the superconducting (SC) electron linear accelerator of the ELBE radiation facility [1] a new superconducting electron photo injector has been installed in May 2014. This new SRF gun II is replacing the previous one which had been in successful operation from 2007 until April 2014. Although SRF gun I could not reach the design specifications, it was successfully operated for R&D purposes and also some dedicated user experiments at ELBE accelerator had been done [2].

For SRF gun II a new niobium cavity has been built, treated and tested at JLab [3]. At the same time a new cryomodule has been designed and built at HZDR [4]. In November 2013, the cavity was shipped to HZDR and assembled into the cryomodule. About half a year later, the gun was installed into the ELBE accelerator hall and since June 2014 it is under commissioning for first RF and beam tests.

The main goal of SRF gun II is to achieve medium average current (1 mA) and low emittance (1 mm mrad) at a moderate bunch charge (77 pC) as well as to test new semiconductor cathodes.

COLD MASS DESIGN

The design of the new cold mass for SRF gun II is shown in Figure 2. Most of the components are identical to the previous SRF gun I [5]. The 1.3 GHz Nb cavity, for example, consists of three TESLA cells and a specially designed half-cell. Another superconducting cell, called choke filter, prevents leakage of the RF field into the cathode support system. The normal conducting (NC) photocathode is installed in this system, which is isolated from the cavity by a vacuum gap and cooled with liquid nitrogen. This design allows the application of NC photocathodes with high quantum efficiency (QE) such as Cs_2Te.

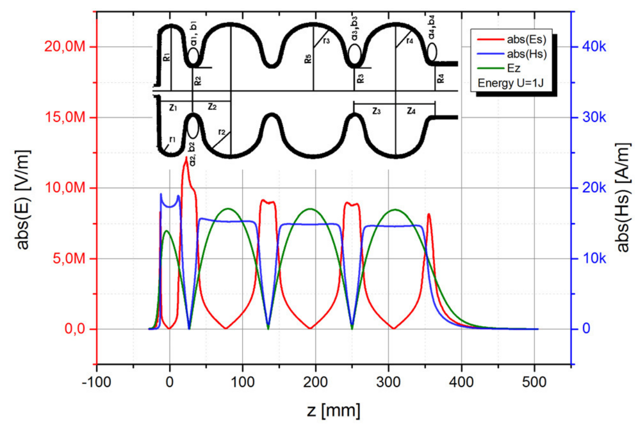

Figure 1: Electric and magnetic surface field as well as on-axis electric field distribution of the accelerating mode normalized to 1J stored field energy.

New is the integration of a SC solenoid in the cryomodule. Compared to the NC solenoid of SRF gun I which was placed downstream the gun, the new design is much more compact and the distance to the cavity is smaller. The SC solenoid is placed on a remote-controlled x-y table to align its center to the electron beam axis. Additional µ-metal shields hold the solenoid remanence field and the stepper motors fields near the cavity on a 1 µT level. Details of the SC solenoid design and testing are published in [6].

Table 1: Updated Design Parameters for 3.5 Cell Cavity

stored energy, U	34.8 J
quality factor, Q_0	10^{10}
dissipated power, P_c	28.5 W
geometry factor, G	224 Ω
normalized impedance, r	167.5 Ω
acceleration voltage, V_{acc}	9.75 MV
acceleration gradient, E_{acc}	19.5 MV/m
$E_{z,max}/E_{acc}$	2.56
B_{peak}/E_{acc}	7.4 mT/(MV/m)

The cavity itself differs in an improved half-cell stiffening and in a slightly changed on-axis electric field distribution. In contrast to the original design, the field in the half cell was increased from 60% to 80% compared to the field strength in one of the three TESLA like cells.

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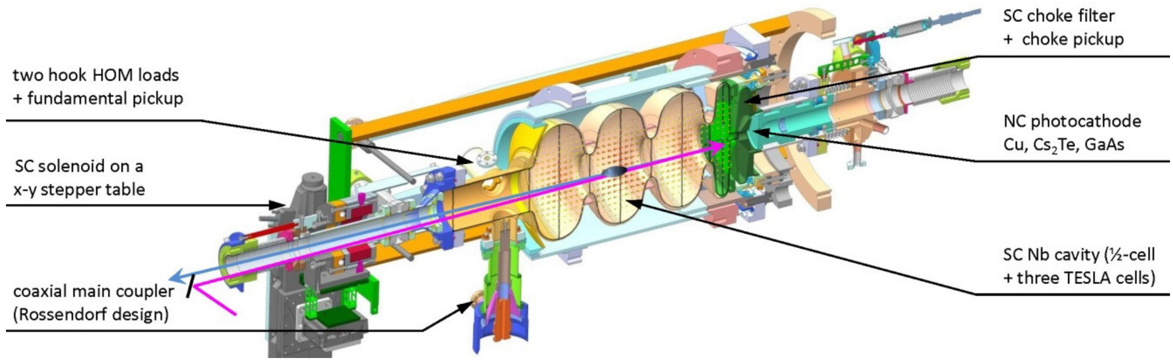


Figure 2: 3D drawing of the ELBE SRF gun II cold mass.

This was done to gain field strength at the cathode surface because vertical tests revealed that the designed field strength will be missed. The resulting electric and magnetic fields as well as the updated cavity parameters are given in Figure 1 and Table 1, respectively.

Table 2: Frequency and Bandwidth of all TM_{010} Modes

π-mode	1/4	2/4	3/4	4/4
f_0 / MHz	1267.667	1282.794	1294.762	1300
b /Hz	17	147	271	140

PASSBAND, FIELD DISTRIBUTION, EXTERNAL COUPLING FACTORS

After the cavity cool down, all four TM_{010} pass band frequencies f_0 and the bandwidth b have been measured (see Table 2). These are then used in combination with the latest bead pull results to estimate the field profile of the accelerating π-mode (see Figure 3). An appropriate in-situ method is described in [7].

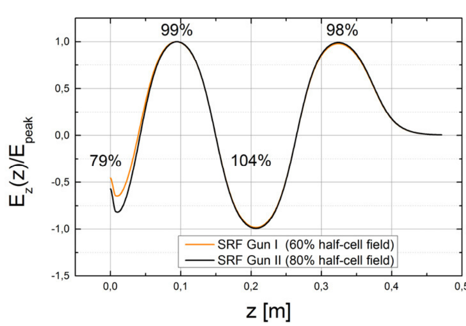
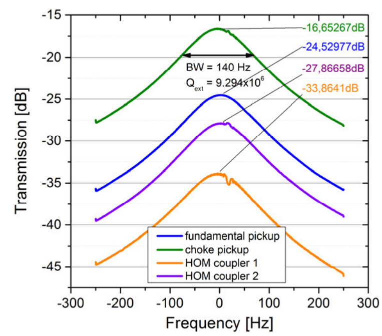


Figure 3: Evaluated on-axis field profile of the π-mode. The electric field is normalized to the nominal peak field in the TESLA like cells.

In order to evaluate the external coupling factors of all antennas, the transmitted power from both HOM couplers as well as from the choke pickup was measured and compared with the vertical result of the fundamental field probe (see Figure 4). In contrast, the coupling of the Rossendorf type main coupler (FPC) was characterized by a bandwidth of BW=140 Hz. All these values are in good agreement with the designated ones.



antenna	Q_{ext}
FPC	**9.3×10^{06}**
f-pickup	2.7×10^{11}
choke	4.3×10^{10}
HOM1	2.3×10^{12}
HOM2	5.8×10^{11}

Figure 4: Transmitted power from all four feed through and therewith the calculated external coupling factors for the π-mode.

TUNING SYSTEM

The SRF gun II is equipped with the same double tuning system as its predecessor. Thus, the half-cell can be tuned separately from the rest of the cavity [5]. This is necessary because of the different mechanical stiffness of both parts, but allows also a field flatness adjustment even after the helium vessel welding was done.

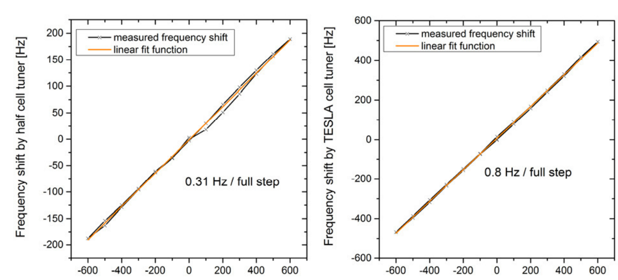


Figure 5: Frequency resolution of the half-cell (left) and the TESLA cell tuner (right). Both are free of hysteresis.

The tuners have been characterized at the cold cavity, too. It turned out that both of them have an excellent frequency resolution and a negligible hysteresis (see Figure 5). At the same time the system provides a wide tuning range to compensate tolerances and thus completely fulfils the requirements for the new gun cavity. All tuning parameter are summarized in Table 3.

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Table 3: Measured Tuning Garameters for SRF Gun II

tuner parameter	unit	half cell	full cells
force path	mm	±15	
load path	mm	±0.30	±0.30
frequency const.	kHz/mm	257	650
tuning range	kHz	±77	±195
mech. resolution	nm/step	1.25	1.25
frequ. resolution	Hz/step	0.31	0.80

Q_0 VS. E_{ACC} AND LORENTZ FORCE DETUNING COEFFICIENT

In order to evaluate the performance of a cavity it is most common to measure the intrinsic quality as a function of the accelerating gradient. For a strongly over coupled cavity, both quantities have to be determined by the dissipated and transmitted power as well as by the external quality factor of the fundamental pickup (see Eq.1 and 2). The cavity length L in our case is 0.5 m.

$$E_{acc} = \frac{1}{L}\sqrt{2rQ_tP_t} \quad (1)$$

$$Q_0 = \frac{Q_tP_t}{P_{diss}} \quad (2)$$

The result of the first horizontal measurement is shown by the green dots in Figure 6. Obviously, the cavity lost performance compared to the last vertical test, but nevertheless the useable gradient could be doubled in contrast to the SRF gun I.

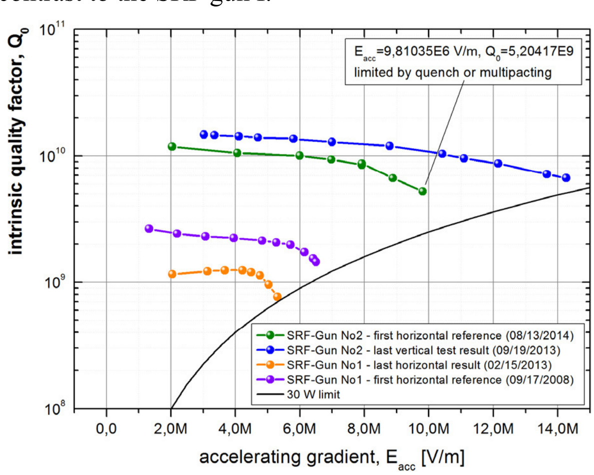

Figure 6: Intrinsic quality factor as a function of the accelerating gradient in the cavity.

Despite this promising result, it was found that the Lorentz force detuning coefficient is a factor of two higher than expected from the old gun (see Table 4). This is surprising, because at the same time the helium pressure sensitivity (having a value of 150 Hz/mbar) is a factor of two lower. Especially, at high gradients this might be a problem for the phase controller and thus simulations are ongoing to understand what happened.

Table 4: Measured Lorentz Force Detuning Coefficients for both SRF Guns Compared to a Standard TESLA 9 Cell

	SRF gun I	SRF gun II	TESLA
k_{acc} / Hz/(MV/m)^2	5	9.7	1
k_{peak} / Hz/(MV/m)^2	0.69	1.5	0.25

CONCLUSION

The results of the first commissioning period of SRF gun II are very promising. The RF performance is much better than for SRF gun I. And also first beam parameter measurements using a Cu cathode show good agreement with simulations as well as they confirm the proper operation of all subsystems [8].

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