STATUS OF THE 3 ½ CELL ROSSENDORF SUPERCONDUCTING RF GUN

D. Janssen#, H. Büttig, P. Evtushenko, U. Lehnert, P. Michel, Ch. Schneider, J. Stephan, J. Teichert, Forschungszentrum Rossendorf, Dresden, Germany
V. Volkov, S. Kruchkov, O. Myskin, BINP SB RAS, Novosibirsk, Russia

Abstract

The status of the Rossendorf superconducting RF gun is discussed. This gun allows continuous wave operation with an energy of 9.5 MeV and an average current of 1mA. The 3½ cell niobium cavity contains a normal conducting photocathode. A special choke flange filter at the cathode side prevent the RF leakage of the cavity. The design of the cavity, the tuner, the RF coupler the LHe-vessel together with the cryostat is finished and now in manufacturing. In the paper three features are discussed, which follows from the special demands of the 3½ cell superconducting RF gun. The first feature is the tuning system. For the cavity two different tuners are necessary, one for the half cell (gun cell) and one for the accelerating cells. The second feature is the tuning of the cathode. The beam properties depend very sensitive on the cathode position. Therefore a special cathode tuner has been developed, which allows to move and to adjust the cathode position inside the cavity. The third no conventional feature is the excitation of a second RF mode inside the cavity. This is a magnetic mode (TE mode) which replaces the static magnetic field in normal conducting RF guns and decreases the transverse emittance of the beam by more than a factor of two.

INTRODUCTION

The success of many evolving future accelerator applications is contingent upon the development of an appropriate source to generate the electrons.

Today photo cathode RF guns are the most advanced type of electron injectors. They are able to produce high peak currents and low emittances, which is necessary for FEL application. However their low duty factor can limit the performance of superconducting accelerators. Efforts are under way to increase the duty factor of RF guns for the price of cooling problems, high demands on klystron power and low power conversion efficiency. The more elegant way is to combine the high brightness of RF guns with the low RF losses of superconducting technology.

Superconducting RF (SRF) photo injectors offer great promise for cw mode operation with high average current. At present four groups are working on SRF photo injector projects. There are the Peking University [1], Advanced Energy Systems (AES) [2], Brookhaven National Laboratory (BNL) [3] and Forschungszentrum Rossendorf (FZR) [4]. In 2002, the successful operation of a SRF injector with a half cell cavity was demonstrated at FZR for the first time [4].

The design and treatment of superconducting cavities with there specific geometry, the much more complex tuning system and the RF choke flange filter causes additional difficulties and requires new technical solution.

#janssen@fz-rossendorf.de

These new technical solutions enter in the design of a new injector in Rossendorf, working with a 3 ½ cell superconducting cavity. The first overview about the design of this injector has been represented in [5]. In the sec. 2 and 3 we will discuss some new developments.

A disadvantage of the superconducting technology is its sensitivity to external magnetic fields. It is not possible to apply a static magnetic field of the required strength for emittance compensation as described in the case of normal conducting RF guns. In [6] it has been shown, that the focussing by the static field can be replaced by RF focussing, which is applicable also in the case of superconducting RF guns. The RF focusing is achieved by pulling the cathode backward, somewhat behind the back plane of the cavity. After extensive beam dynamic calculations for different bunch charges this concept is integrated into the gun design of the new 3 ½ cell Rossendorf injector.

A new idea to compensate the emittance growth in the RF gun is to apply a magnetic RF field, which is an eigenmode of the cavity. This mode can be excited together with the accelerating RF field in the superconducting cavity. First results concerning magnetic modes in superconducting cavities are published in [7]. The excitation of magnetic modes in the Rossendorf 3 ½ cell gun cavity and the influence of these modes on the beam dynamics is described in sec. 3 together with first experimental results.

DESIGN, FIELD AND BEAM PARAMETERS OF THE NEW ROSSENDORF GUN

The superconducting cavity inside the He vessel is shown in Fig. 1. A choke filter, which prevent the leakage of RF power is connected with the gun cell by a small superconducting tube. This tube contains the cathode, which is isolated by a vacuum gap of 1mm from the surrounding cavity. The cathode is cooled down to LN_2 temperature and exchangeable. The length of the gun cell is small in comparison to the following TESLA like cells. This has the advantage, that the optimal phase angle for the start of the electron bunch is near 90° where the electric RF field has its maximum. In contrast to the TESLA cavities the two HOM coupler the main coupler and the pic-up probe are arranged in a single plane outside the He vessel. Possible "cross over talking" of this arrangement has been discussed in [8]. A second pic-up allocated on the cathode side of the cavity allows the measurement of the field amplitude in the gun cell.

Fig.2 shows some details of the cryostat. It contains a magnetic and only one LN_2 shield to protect the cavity from the magnetic earth field and from heat transfer. The LHe and the LN_2 supply have a common port and the cavity support system contains special damping elements against microphonics. The drivers for the tuning system are arranged outside of the cryostat.

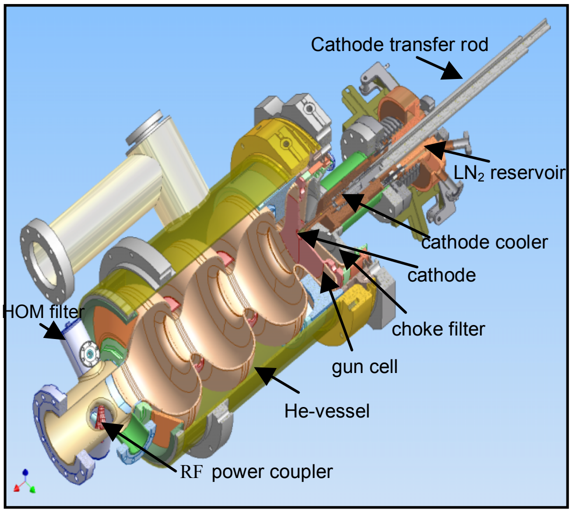

Figure 1: 3 ½ cell cavity of the Rossendorf superconducting RF gun

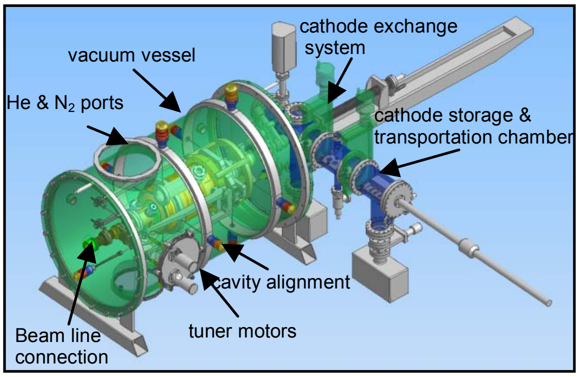

Figure 2: Cryostat of the Rossendorf superconducting RF gun

In the following we will discuss two features of the design, which are not standard. The first feature results from the circumstance, that the cavity of the RF gun contains two different type of cells, the gun cell and the TESLA cells with two different stiffness. Therefore it is not possible, to get the same frequency and approximately the same field amplitude in all cells of the cavity, using one tuner only. To avoid this difficult, our design of the gun contains two tuner and two pic-up probes for field measuring, one for the gun cell and one for the TESLA cells respectively. The tuners are able to change the thickness of the gun cell by ± 0.25 mm and that of the TESLA cells together by ± 0.3 mm, which corresponds to a frequency shift of ± 137 kHz for the gun cell ± 286 kHz for the TESLA cells. Furthermore we are able to adjust the choke flange cell at LHe temperature inside the cryostat.

In Fig.3 and Fig.4 the principle of the tuning system is shown, which is adapted from the cryostat of the Rossendorf ELBE project [10].

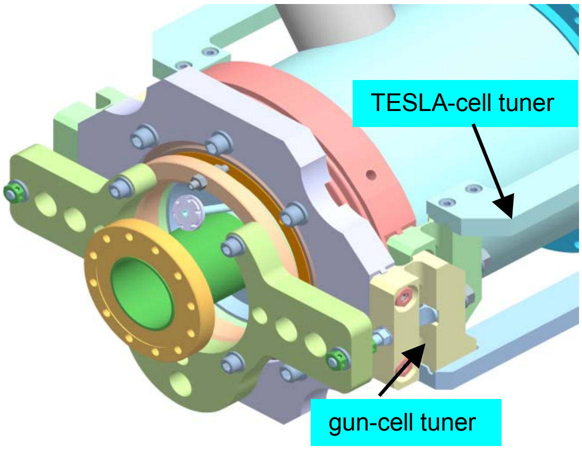

Figure 3: Tuner system of the cavity

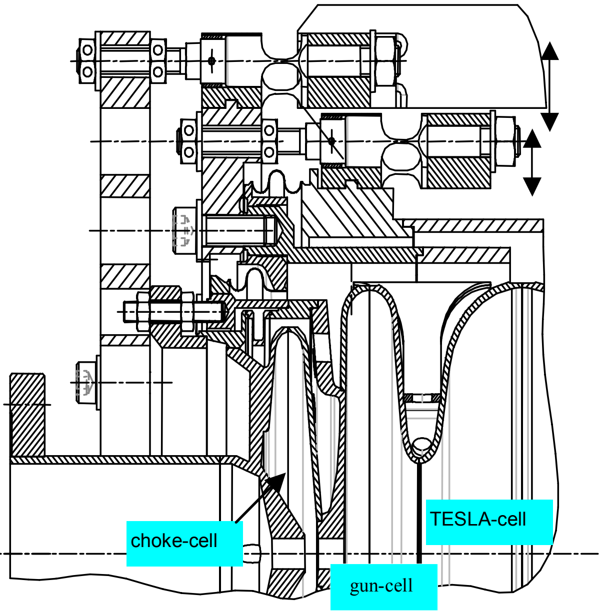

Figure 4: Sectional view of the tuning system

Now we will discuss the second feature, which is not standard.

For this gun the results of beam dynamic calculation are published in [5]. Accelerating a bunch with a charge of 1nC to an energy of 9.5 MeV, a transverse emittance of 2.5 mm mrad has been obtained. The axis RF field, used in this calculation is given in Fig.5. Immediately after the cathode the radial component of the electric field is negative and has a minimum. This behaviour results from the position of the cathode, which is located 2 mm behind the back wall of the gun cell. The negative value of the radial field focus the beam after the cathode, where the energy is small. This effect of “RF focusing” has been described in [6]. The RF focusing replaces in the superconducting cavity the static magnetic field, which is used inside the cavity of normal conducting RF guns for beam focusing and emittance reduction.

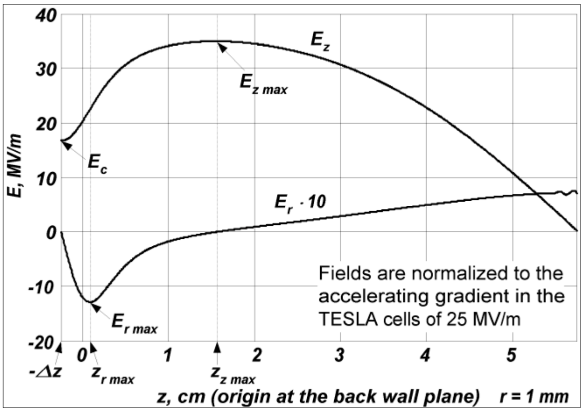

Figure 5: RF field near the axis of the gun cell

The focusing by the RF field and also the axial alignment of this field are very sensitive with respect to the cathode position. So the second special feature of our design work is a cathode tuner. This tuner allows to adjust the cathode with respect to the cavity axis and to move it ±1mm in axial direction. The scheme of this tuner is given in Fig. 6.

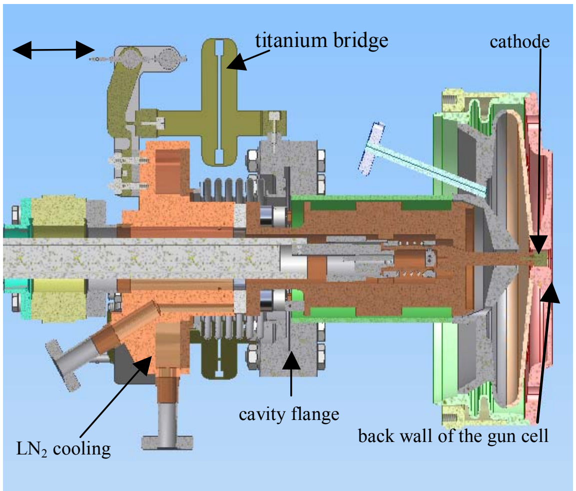

Figure 6: Cathode tuner of the Rossendorf superconducting RF gun

Three movable titanium bridges connect the flange of the cavity with the LN_2 cooling system. This cooling system has a ridged connection with the cathode and the steering of the bridges follows outside of the cryostat.

EMITTANCE COMPENSATION WITH A MAGNETIC MODE

In the proceeding section we discussed the compesation of transverse emittance of the superconducting gun by the RF focusing of the beam. Another possibility to prevent the growth of transverse emittance is to excite together with the accelerating TM mode a magnetic RF mode (TE mode) inside the superconducting cavity. This possibility has been extensively discussed in [7]. In the case of the Rossendorf gun cavity we use the TE_{021} mode. The corresponding RF field, which has been calculated by the code SUPERLANS is shown in Fig. 7. The field of the TE mode is concentrated in the last TESLA cell and can easy excited by a coupling loop in the beam pipe. At the cathode surface the magnetic field is equal to zero.

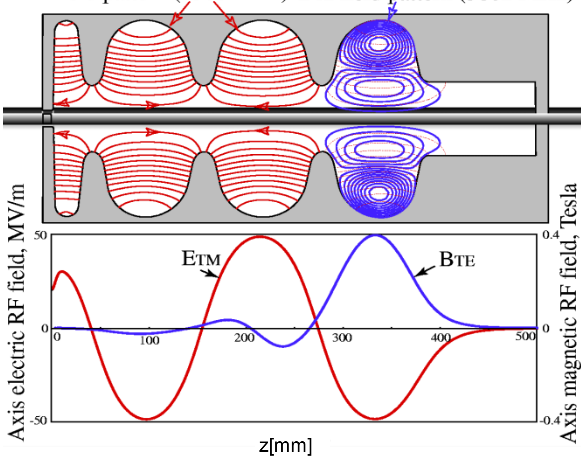

Figure 7: Field pattern and axis fields of the electric and magnetic mode inside the Rossendorf gun cavity

In superconducting cavities the quench limit for the surface magnetic field is 0.18 T [9]. Fig.8 shows the surface magnetic fields of the Rossendorf gun cavity.

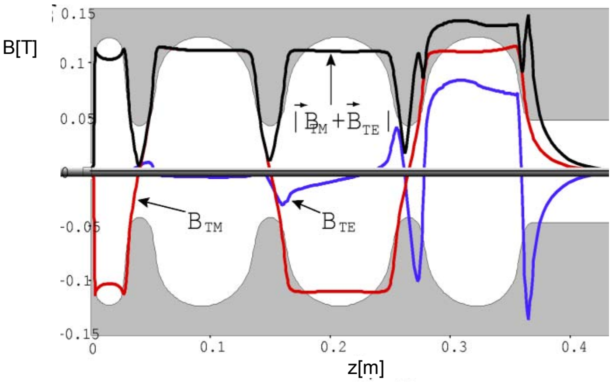

Figure 8: Surface magnetic field of the TE mode, the TM mode and the vector sum of both fields for the Rossendorf gun cavity

The peaks of the magnetic TE mode are disposed between the peaks of the accelerating TM mode. The resulting field, which is the vector sum of both modes has an maximum amplitude comparable with that of the separate modes.

Table 1: Parameter and results of the tracking calculation

Beam parameter		Field parameter		Laser parameter	
ε_x[mm mrad]	0.78 – 0.98	B_{TMsurf}[mT]	115	Puls length [ps]	20
σ_x [mm]	3.06	B_{TEsurf}[mT]	136	Raise time [ps]	1
ε_z[keV mm]	72.4	$\lvert B_{TM}+ B_{TE}\rvert_{surf}$[mT]	144	Spot size [mm]	2.6
Δz [mm]	2.79	$E_{TM,axis}$ [MV/m]	50	Bunch charge[nC]	1
E_{av} [MeV]	8.82	φ_{TM}[grad]	75		
ΔE_{rms} [keV]	53.9	φ_{TE}[grad]	0 - 180		

After the calculation of the RF fields we did tracking calculation using the ASTRA code. The parameters and results of this calculation are given in Table 1. An electron bunch of 1 nC starts with a length of 20 ps at the cathode. At a distance of 4.44 m it has a length of 9.3 ps and its transverse emittance changes between 0.78 and 0.98 mm mrad in dependence on the phase of the TE mode. This dependence is explicitly shown in Fig.9.

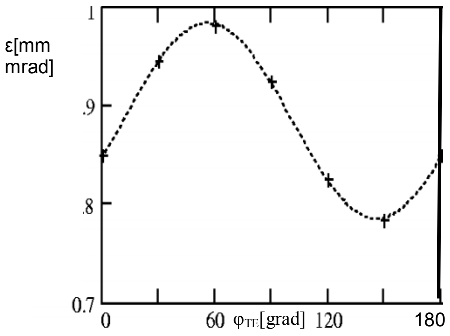

Figure 9: Dependence of the transverse emittance from the start phase with respect to the magnetic mode.

The results of this calculation are the following:

- By exciting an magnetic mode in the last cell of the gun cavity the transverse emittance decreases by more than a factor of two.
- The frequency of the magnetic mode is not necessary a harmonic of 1.3GHz. The transverse emittance depends only weak on the phase of the magnetic mode.
- The sum of the surface magnetic fields of the TM mode and the TE mode is clearly below the quench limit.

The last statement is confirmed by Fig.10. Here the first measurement of the peak magnetic surface field for a TE and a TM mode in a single cell cavity is represented

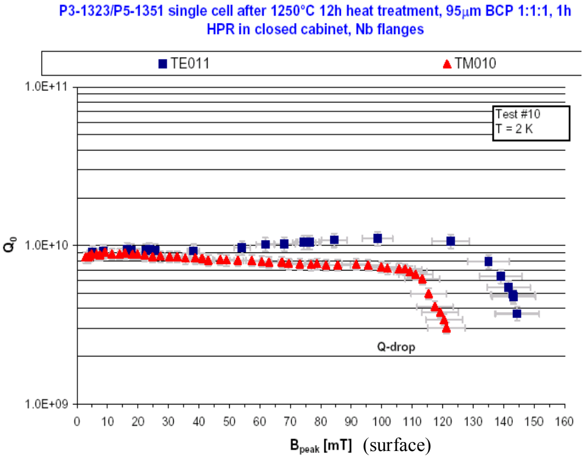

Figure 10: Quench limit and Q values for the TM and the TE mode in a single cell cavity.

SUMMARY

- The cathode and the cavity tuner are new elements in the design of superconducting RF guns.
- The magnetic RF mode replaces the static magnetic field and decreases the emittance by a factor of more than two.
- The new Rossendorf superconducting RF gun is in manufacturing, first components are finished.

REFERENCES

[1] K. Zhao, et al., NIM A475 (2001) 564.
[2] H.Bluem, et al, EPAC'04, Lucern, Swiss, July 5-9, 2004
[3] T. Srinivasan-Rao, et al., PAC'03, Portland, USA, May 12-16, 2003.
[4] D. Janssen, et al., NIM A507 (2002) 314
[5] D. Janssen, et al., FEL'03, Tsukuba, Japan, Sept. 8-12, 2003, NIM A(2004) in print.
[6] D. Janssen, V. Volkov, NIM A452 (2000) 34-43.
[7] D. Janssen, V. Volkov, EPAC'04, Luzern, Swiss, July 5-9,2004
K. Flöttman, D. Janssen, V. Volkov, Phys. Rev. ST accepted
[8] Yongxiang Zhao, Michael Cole, PAC'03, Portland, USA, May12-16, 2003
[9] K. Saito, Proc. of the PAC'03, p.462, Portland, Oregon, USA, May12-16, 2003
[10]F. Gabriel, et al., NIM B 161-163 (2000) 1143.
[11]G.Ciovati, P.Kneisel, privat communication