BEAM DYNAMICS IN RF-GUN CAVITY WITH A MODIFIED FIRST CELL

V.Volkov, M.Karliner, V.Petrov, I.Sedlyarov, A.Tribendis
Budker Institute of Nuclear Physics, Novosibirsk, Russia and
D.Janssen, P. vom Stein, Research Center Rossendorf, Dresden, Germany

Abstract

The results of beam dynamics simulation with bunch charges up to a few tens pC in superconducting linear accelerator for ELBE project [1] are presented. The accelerator consists of 3+1/2 TESLA cells RF-Gun and two 9-cell TESLA cavities. It is shown that the change of a flat back wall of the half-cell with cathode in its center by a conical back wall results in reduction of transversal bunch sizes and also of its emittance at the accelerator exit by a factor of 20.

1 INTRODUCTION

In the RF-gun a superconducting accelerating cavity with the laser driven photocathode on the back wall of the cavity first cell is used. The projects of similar superconducting RF-guns were discussed elsewhere [2,3,4,5,6] but only a “pure” half cell with the flat back wall was used as the cavity first cell.

The goal of this paper is to find out an influence of the shape of the first cell on the beam dynamics in RF-gun cavity and to study the possibility to achieve extremely low full beam emittance.

The shape changed as following: a) from flat back wall of the half first cell to the conical one; b) modifying the full length of the first cell with respect to generally adopted λ/4.

For this purpose, the beam dynamics in the 3+1/2 RF-Gun cavity with gradually modifying first cell and in the accelerator consisting of an RF-gun and two standard 9-cell TESLA cavities at the frequency of 1300 MHz was simulated.

2 CALCULATION TECHNIQUE

All the calculations have been carried out with the use of the program **TRAJECT** [7]. The program calculates the beam dynamics only for a small charge at which the effects of the beam spatial charge are negligible. A high calculation speed of the program gives a possibility to sort out by iteration cycle an optimal regime of beam injection and cavity excitation. The calculation results agree with PARMELA’s calculation if the bunch charge is no more then few tens of pC [1]. RF fields in the cavities are calculated with the use of program **SLANS** [8].

The rms length of the beam is given to be 10 ps.

In the transverse direction the current density is distributed by the rectangular law. If the current transverse distribution Gaussian, the beam emittance would be 4 times higher than that in this case [2].

The photocathode radius **ro** is given to be 1.5 mm.

The normalized transverse beam emittance **εn** is calculated by the known formulas [9].

The dynamics simulations were executed for the field gradient of **Eacc = 15 MV/m -** as an attainable in reality in supercondacting accelerating cavities at 1300 MHz.

5 versions of the first cell have been taken fo calculations: 0°, 10°, 15° back wall and 10° back wall with λ/4±10 mm length of first cell.

In the paper the calculations results for two versions of accelerators are given: for the gun with a flat back wall in the first cell and with a 10° conical wall (Figure). Here the injection phase ϕ of bunch from the cathode is equal to the optimal one which results in minimum of a beam energy spread at the RF-Gun exit. The phases of excitation of first and second TESLA cavities are being optimal too.

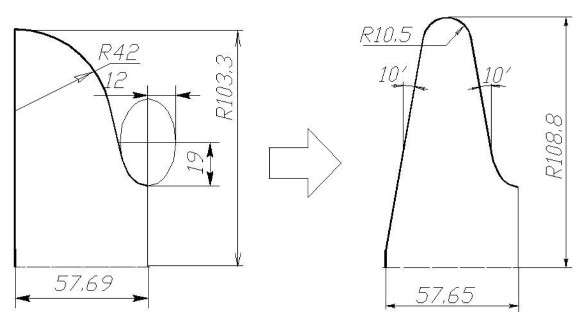

Figure 1. Accelerator RF-gun first cells.

3 RF-GUN CALCULATION RESULTS

The calculation results of a beam dynamics show that the presence of the conical back wall in the first cell causes an explicit **focusing effect** such that the beam radius decreases in average along the whole cavity and if the conical angle is more than 15 degrees, the beam of the RF-gun output is focused.

The peak field in the first modified cell is located at the surface near the hole and it is approximately the same as the peak field in the other cavity cells.

There are two **optimal** injection phases which appear when the gradient field in the cavity is more than some **threshold gradient.** The beam has a minimum transversal emittance for one optimal phase and has a minimum longitudinal emittance for another one. Its values differ 2 times approximately. The difference between these phases increases with the first cell length as it changes from generally adopted λ/4. So we always can find proper cell length which provide the coincidence of both minima simultaneously at only one optimal phase. It is assumed that the minimum of the beam energy spread coincides with minimum of a longitudinal emittance. We have found that the optimal first cell length is less than λ/4 by 2÷4 %.

The optimum injection phases increase monotonously with the growth of the field gradient at the cathode and so we can determine a value of threshold gradient as the field gradient at the cathode when the beam has a zero optimal phase. It's values are **9.9÷19.0 MV/m** for all 5 RF-gun variants. Table 1 shows other results.

Table 1. RF-gun calculation results.

Ec	**εn**	**σW**	**Δφ**	**φ**
Ethresh	.007÷.02	.015÷.03	-	-
20	.07÷.27	.07÷.36	5÷100	22÷54
40	.44÷.56	.25÷.45	2÷43	49÷69

Ec -Peak field at the cathode, **MV/m.**
εn -Normalized transverse emittance of a beam, **π mm mrad.**
σW -Rms energy spread of the beam particles., **%.**
Δφ -Differences between optimal phases which leads to a minimum transversal emittance in one case and to a minimum longitudinal emittance in another case, **%.**
φ -Optimum phase of beam emission, **degrees.**

4 ACCELERATOR CALCULATION RESULTS

The beam transverse emittance is decreased significantly at the accelerator exit if a conical back wall is used (Figure 2 and Table 2). This effect occurs due to the focusing influence of the first cell. In the first cell the beam is not relativistic and following acceleration 'freezes' the influence of the geometry of the first cell.

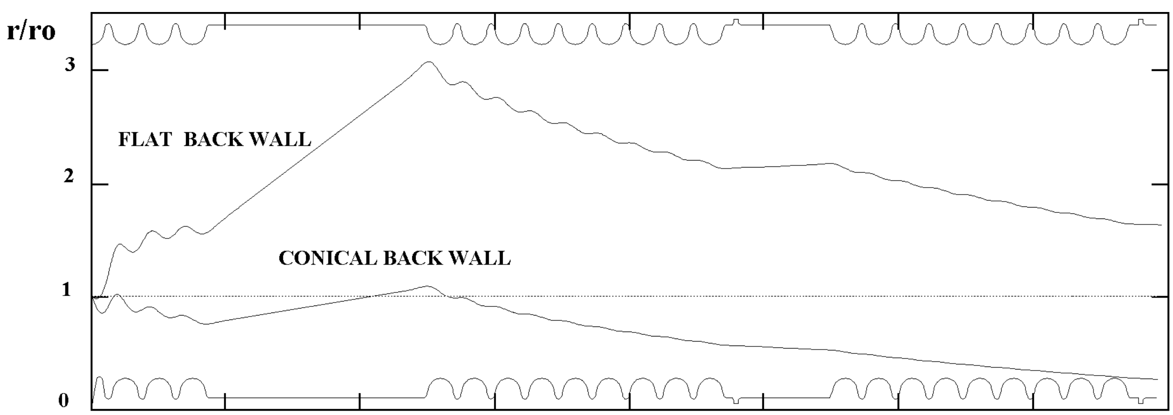

Figure 2. Beam radius in the accelerator: with flat back wall and with conical back wall.

Table 2.1. Beam parameters in the accelerator having RF-gun with first cell's flat back wall.

Ec (E) MV/m	**φ (φrf)** degree	**εn** mm mrad	**σW×2** %	**W** MeV	**σL×2** ps	**r/ro**	**Focus** m	
30	49.00	.488	.659	6.548	16.63	1.772	-0.90	RF-gun
(30)	(-66.42)	7.133	0.648	21.48	16.62	2.138	-24.3	1 cavity
(30)	(-70.02)	**10.81**	0.643	36.43	16.62	**1.630**	20.76	2 cavity

Table2.2. Beam parameters in the accelerator where RF-gun has first cell's conic back wall of 10°

19.6	34.6	0.206	0.440	6.061	13.38	0.800	-1.90	RF-gun
(30)	(-67.12)	0.478	0.420	21.00	13.33	0.552	4.500	1 cavity
(30)	(-71.62)	**0.605**	0.417	35.96	13.33	**0.264**	2.030	2 cavity

Ec -Peak field at the cathode. **E** -peak field at the cavity axis, E=2×Eacc. **φ** -Phase of beam emission.
ϕrf -RF exciting phases in TESLA cavities**. εn** -Normalized transverse emittance**. σW** -Rms energy spread.
W -Beam energy**. σL** -rms length**. r/ro** -Beam radius/photocathode radius, **ro = 1.5 mm**. **Focus** - Average distance from the structure beam tube end to the point where all beam electron trajectories are converged.

Also there are two optimal phases of excitation for the first TESLA cavity which result in a minimum of the beam transversal emittance in one case and a minimum of longitudinal emittance in another. In order to close these phases it is necessary to decrease the injection phase in RF-Gun down to 29º from 34°. I.e. the injection phase for the accelerator has to be less than the one for an isolated RF-Gun by 15%. The best beam parameters for phases optimized in this way are shown in Table 2.3.

Table 2.3. The best beam parameters in accelerator having the 10°conical first cell in RF-gun for optimized injection (ϕ) and excitation phases (ϕrf1, ϕrf2)

ϕ deg.	**ϕrf1** deg.	**ϕrf2** deg.	**εn** mm mrad	**σW** %
29	-61.5	-67	0.211*)	0.168

The emittance and other beam parameters, except σW, are weakly dependent of exciting phase of the second TESLA cavity. Figure 3 depicts the dependence of the particle energy distribution in the beam on their position in a beam and on the misalignment by ±20° of exciting phase ϕrf2 from its optimal value in the second TESLA cavity.

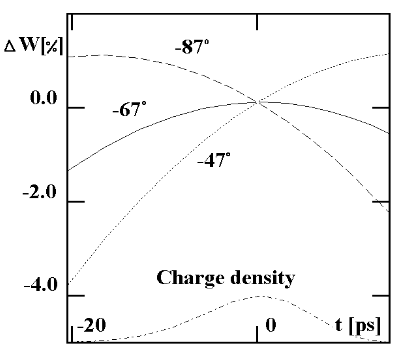

Figure 3. Beam energy distribution at the accelerator exit

Table 3. Beam parameters at the accelerator exit as a functions of RF excitation phase ϕrf2.

φrf2 degrees	**εn** mm mrad	**σW×2** %	**W** MV
-87.0	0.22	-1.311	35.12
-67.0	0.211	0.336	35.96
-47.0	0.191	1.527	35.07

5 CONCLUSION

The use of a conical shape of the back wall of the first cell in a 3+1/2 cavity for an RF-gun leads to focusing of the beam if the conical angle is more than 15°.

The application of such an RF-gun with the first cell's conical back wall in an accelerator consisting of a couple of TESLA cavities complementary leads to a decrease of beam transversal emittance down to 0.21*) π mm mrad and energy spread (σW) down to 0.17 %.

A beam will have an extremely low emittance, if the field gradient in the cavity is more than some threshold gradient by 10÷19 MV/m.

There exists an optimal length of the RF-gun first cell which is less than λ/4 by 2÷4 %.

There exists an optimal accelerator injection phase which is less than the one for an isolated RF-gun by 10÷20 %. In both this cases the beam have a minimum of transversal and longitudinal emittance simultaneously.

The calculations were carried out for beam charge up to few tens of pC but focusing effect of conical back wall is also very actual for greater charge as it is shown by PARMELA calculations in [1].

6 REFERENCES

[1] P.vom Stein et al., *The DROSSEL Project for the Development of a Supercondacting RF-Gun* (Presented here).

[2] K.J.Kim, Nucl. Instr. and Meth. A275 (1989) 201.

[3] J.Edighhoffer et al., Nucl. Instr. and Meth. A358 (1995) 18-19

[4] C.Pagani et al., Nucl. Instr. and Meth. A340 (1994) 17-25.

[5] L.Serafini/ Nucl.Instr.and Meth.in Phys.Res. A 340 (1994) 209-213

[6] A. Michalke. Ph.D. Thesis. Wuppertal University, rep.WUB-DIS 92-5.

[7] V.N.Volkov, BINP, Novosibirsk, RUSSIA. e-mail: VNVOLKOV@inp.nsk.su, tel.: +7-3832-35-91-06

[8] D.G.Myakishev,V.P.Yakovlev, *An Interactive Code SuperLANS for Evaluation of RF-Cavities and Acceleration structures*, Proc.of the 1991 Particle Accelerator conference, Vol.5, p.3002-3004

[9] P.M.Lapostolle, IEEE Trans. Nucl. Sci. NS-18 (1971) 1101

*) We should note for Gaussian transverse charge distribution of the beam it's emittance mast be large by 4 times, i.e. 0.84 π mm mrad [2].