ULTRASHORT ELECTRON BUNCHES WITH LOW LONGITUDINAL EMITTANCE IN MULTI-CELL SUPERCONDUCTING RF GUNS

V.N.Volkov, Budker Institute of Nuclear Physics, Russia

Abstract

Ultra short bunches with low longitudinal emittance obtained using multi-cell superconducting RF gun having a longitudinally shorted first cell (down to 0.15 lambda) with a divergence of an accelerating RF field pattern near the photocathode are discussed. The optimised RF gun parameters and bunch characteristics computed by PARMELA are presented. Such 10 MeV ultra short electron bunches with low longitudinal emittance compatible for additional longitudinal compression scheme having RF buncher cavity and drift space or magnetic chicane downstream of them [1].

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INTRODUCTION

Recently we have found out an unique opportunity of superconducting multi-cell RF guns shown in figure 1 to produce electron bunches with very small transversal emittance [2, 3]. This relies on transversal focusing configuration of RF electric field pattern constructed near the photocathode by spherical surface of the cathode stem tip and displacements of it into the back wall of first cell as shown in figure 2a.

There is still other unique ability of such RF guns to produce ultra short electron bunches with very small longitudinal emittance. This relies on inverse of the first configuration of a field with defocusing or divergence of RF electric field pattern near the cathode (as shown in figure 2b) and significantly shorted length of the first cell.

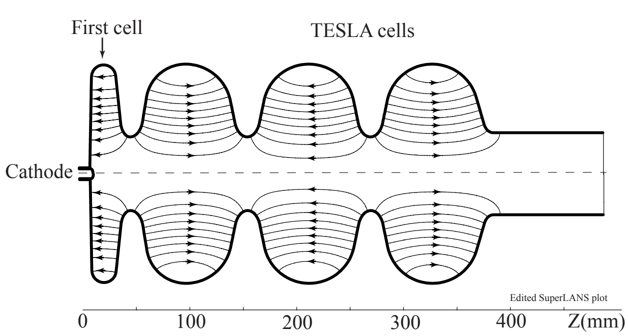

Figure 1. The geometry of superconducting RF gun cavity for producing of ultra short bunches with small longitudinal emittance or bunches with small transversal emittance.

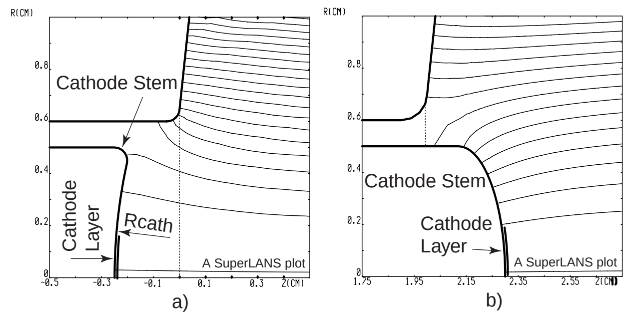

Figure 2. Configuration of part of RF gun geometry near the cathode producing RF electric field pattern with two different operations: a) to produce a bunch with small transversal emittance; b) to produce ultra short bunch with small longitudinal emittance.

BASIC

The effect of bunch compression in a multi-cell superconducting RF gun was described in [4]. A short electron bunch injected from laser driven photocathode is being accelerated by the electric field in the first cell and then enters to the second cell. The RF field in the second cell at that instant has a negative strength and change the sign later because of very short accelerating gap of first cell. Therefore the bunch at the beginning of the second cell decelerates and then accelerates again in the second cell and then only accelerates in the other cells. The head of the bunch enters to the second cell earlier when strength of electric RF field is more negative. Therefore the bunch head accelerates less than the tail and exposes to longer delay. I.e. compressing effect lies on phase-dependent delay of particles. The electron bunches in this compression method obtain a very low energy spread and low longitudinal emittance.

We have to note the phase-dependent delay play an important role to obtain the low longitudinal emittance of a bunch also. The particles launched from centre of the cathode enter to the second cell earlier than those launched from periphery of the cathode because of divergence of RF electric field pattern (defocusing) near the cathode. Therefore the periphery trajectories of the particles are directed under some angle to the axis and have therefore more length. The periphery particles have obtained more energy in second cell but the central particles have obtained more energy in the other cells because the RF electric field is greater at the axis (more strongly it occurs in a beam pipe of a final cell). As a result all the particles from centre and periphery obtained the same accelerating energy downstream of the cavity. This fact is the cause of low longitudinal emittance of bunches.

SIMULATIONS

Incoming data

The energy gain in 3.3* RF gun cavity is 25 MV/m. The laser pulse length (FWHM) is 3 ps. Laser time intensity was modeled by a Gaussian distribution. We have found the minimal value of bunch length at a distance of 400 mm from exit of the cavity. Bunch charge: 1 pC, 10 pC and 100 pC. The RF field in RF gun cavity has calculated by SuperLANS cod. Bunch dynamic has computed by PARMELA for 10000 particles.

Optimizing of the launch RF phase and the laser spot size to minimize bunch length

The spline interpolated results for bunch length with charge of 1, 10, 100 pC are shown in figures 3, 4 and 5.

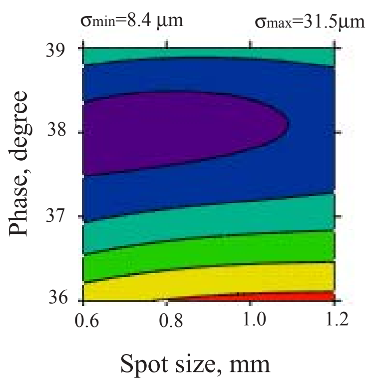

Figure 3. The bunch length as dependence of launch RF phase and laser spot size for bunch charge of 1 pC (spline interpolated data). The optimal RF phase is 38.288˚ and optimal spot size is 0.734393 mm. The minimal bunch length is σ_{L1} = 8.3952 µm.

$$\sigma_{L1}\,[\eta m] = 8.395 + 17.483798 \cdot \delta D^2 + 8.4371 \cdot \delta\varphi inj^2 - - 9.292102 \cdot \delta D \cdot \delta\varphi inj$$

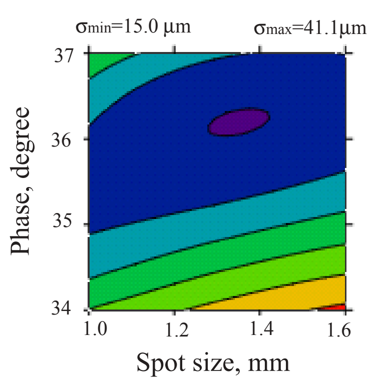

Figure 4. The bunch length as dependence of launch RF phase and laser spot size for bunch charge of 10 pC (spline interpolated data). The optimal RF phase is 36.448˚ and optimal spot size is 1.35 mm. The minimal bunch length is σ_{L10} = 15.013 µm.

$$\sigma_{L10}\,[\eta m] = 15.013 + 37.928679 \cdot \delta D^2 + 7.449166 \cdot \delta\varphi inj^2 - 14.319715 \cdot \delta D \cdot \delta\varphi inj$$

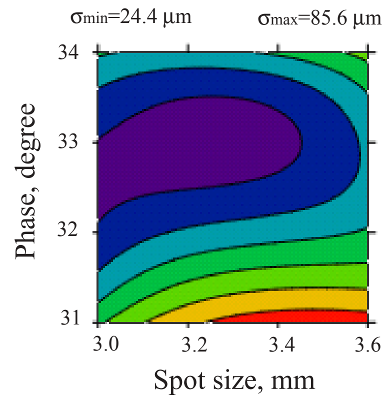

Figure 5. The bunch length as dependence of launch RF phase and laser spot size for bunch charge of 1 pC (spline interpolated data). The optimal RF phase is 33.281˚ and optimal spot size is 3.251 mm. The minimal bunch length is σ_{L100} = 24.373 µm.

$$\sigma_{L100}\,[\eta m] = 24.37 + 109.2551 \cdot \delta D^2 + 21.173782 \cdot \delta\varphi_{inj}^2 - -12.26148 \cdot \delta D \cdot \delta\varphi_{inj}$$

The minimal bunch length and optimal injection phase and optimal laser spot size for three different bunches are shown in table 2.

Table 2. The minimal bunch length and optimal pair of launch phase and laser spot size.

Bunch charge, pC	1	10	100
Launch phase, deg.	38.28	36.44	33.28
Laser spot size, mm	0.734	1.350	3.250
Minimal bunch length (rms), µm	8.39	15.01	24.37

Dynamic results

In the table 3 bunch characteristics computed by PARMELA are shown.

Table 3. The bunch dynamics characteristics.

Charge, pC	1	10	100
Bunch rms length, µm	8.39	15.01	24.37
Bunch energy, MeV	6.16	6.13	6.12
Energy spread, %	0.225	0.207	0.36
Longitudinal rms emittance, KeV·mm	0.11	0.189	0.54
Transv. norm. emittance (rms), mm·mrad	0.184	0.644	6.51

* The whole part of this numerical designation displays an amount of complete (unit) cells in RF gun cavity, and fractional (.3) testifies that length of the first short cell makes 30 % from complete length.

Minimum of longitudinal emittance

There are a minimum of bunch longitudinal emittance at other optimal pairs of injection phase and laser spot size shown in table 4. But this pair is close to the previous one.

Table 4. The minimal bunch longitudinal emittance at optimal pair of launch phase and laser spot size.

Q, pC	1	10	100
$\varepsilon_{\parallel}$[KeVmm]	0.105	0.16	0.364
$\varphi_{inj\text{-}opt,}$ deg.	39.25˚	34.25˚	32.23˚
$D_{opt,}$ mm	0.6	1.6	2.82

REFERENCES

[1] V.Volkov, D.Janssen. Generation of sub-picoseconds electron bunches in superconducting RF photocathode injector (these conference).

[2] D.Janssen, V.Volkov, RF focussing – an instrument for beam quality improvement in superconducting RF guns, Nucl. Instr. And Meth. In Phis. Res. A452 (2000) 34-43.

[3] RF Focussing - an Instrument for Beam Quality Improvement in Superconducting RF Guns, V.Volkov,D.Janssen, 7th European Particle Accelerator Conference, Austria Centre Vienna, June 2000, p.2055-2057.

[4] Generation of sub-picoseconds electron bunches from superconducting 5.3 cell rf gun and coherent wiggler radiation, V.N.Volkov, D.Janssen, PAC2001, June 18-22, 2001, Chicago, Illinois, USA.

[5] X.J.Wang, I.Ben-Zvi, *Longitudinal emittance compensation in a photocathode rf gun injector*, PAC97, 1997, 2793-2795.

[6] L.Serafini, R.Zhang, C.Pelegrini, *Generation of sub-picosecond electron bunches from RF photo injectors*, Nucl. Instr. And Meth. In Phis. Res. A387 (1997) 305-314.

[7] K.J.Kim, *RF and Space-Charge Effects in Laser-driven RF Electron Guns*. Nucl. Instr. And Meth. In Phis. Res. A275 (1989) 206.