GENERATION OF SUB-PICOSECOND ELECTRON BUNCHES IN SUPERCONDUCTING RF PHOTOCATHODE INJECTOR

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Abstract

A multi-cell superconducting photocathode laser driven RF gun having a longitudinally shorted first cell (the length of the first cell is 0.15 lambda instead of 0.25 lambda) can generate shorted electron bunches with very low longitudinal emittance [1]. These bunches could be considerably longitudinally compressed by additional compressing scheme having a buncher cavity and drift space after them or four dipole achromatic chicane placed just after the buncher cavity. The first scheme with drift space is longer on two meters but has appreciably better effectiveness to compress a bunch. The buncher is composed from 3900 MHz multi-cell TESLA like cavity. Chicane has a modernised geometry to compensate transversal emittance dilution of a bunch. Bunch dynamic calculations in two such compressing schemes (optimized at 10 MeV of bunch energy) show that a bunch rms length down to 7 micrometers (0.02 picoseconds, the laser pulse FWHM duration is 2.5 picoseconds) with a peak current of 1500 A can be reached. The optimised characteristics of two compressing schemes with two different RF injectors (with 3.3 and 5.3 cells) are presented.

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INTRODUCTION

Development of a simple and reliable source of short electron bunches is an essential problem. Short electron bunches of a sub-picosecond length may be used in free electron lasers for obtaining the light spontaneous radiation with very short wave length (from crystalline undulator for example) and high radiation power because of CW operation of superconducting RF injector.

There are very important for longitudinal compressing initially to have a short electron bunches with low longitudinal emittance. Such bunches may be obtained in multi-cell superconducting RF gun having a very short first cell with convex photocathode attractive on itself electric field pattern. The phase-dependent delay in such RF gun plays an establishing role in forming short bunches with low longitudinal emittance [1, 2].

Two compressing scheme having TESLA like buncher multi-cell superconducting cavity with 3900 MHz frequency are used in dynamic calculations: first - with drift space up to distance of 5 meters from the cathode, and four dipole achromatic chicane placed just after the buncher cavity – second one.

Though the first scheme with drift space is much easier and more cheaply, and besides is more effective than second one (it gives 7 microsecond bunch length instead of 9), however second one was optimized with all carefulness, as in a sequence of time it was first and, as then it seemed, unique. Therefore it seems it is useful to show these calculations too.

SUPERCONDUCTING RF GUN

To perform the simulations we used two different variants of RF gun – with 3.3* and 5.3 cells [1] shown in figure 1 and 2. The energy gain is: 25 MeV/m with 6.14 Mev of bunch energy in first variant and 20 MeV/m and 9.77 MeV in second one. Electron beam downstream RF gun has a divergence of 0.8 and 0.6 mrad/mm correspondingly. Both variants have given approximately identical results of bunch characteristics downstream of the drift space (see table 3).

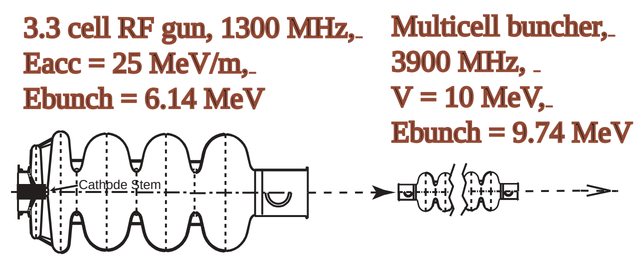

Figure1: The variant of first compressing scheme having a higher accelerating gradient E_{acc} of 3.3 cell RF gun and buncher with acceleration of bunch energy up to 9.74 MeV.

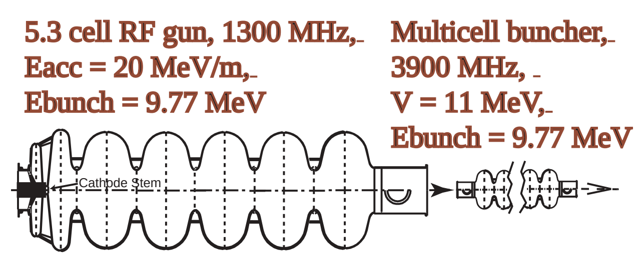

Figure 2: The variant of first compressing scheme having a lower accelerating gradient E_{acc} of 5.3 cell RF gun and unaccelerating buncher (V – cavity RF acc. voltage).

BUNCHER

The buncher in these compressing schemes plays a double role. The basic one is increase of an energy spread of a linear bunch energy distribution (energy of particles linearly increases lengthways on the bunch from its head

* 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.

to a tail). To reduce the drift space length, it is necessary to increase the energy spread at the expense of increase of cavity voltage. Other important role of buncher cavity is to compensate divergence of electron beam so that all trajectories of particles downstream of the cavity were parallel to an axis. There is transverse focusing action in the multi-cell cavity, and to the compensation of divergence of 0.6 or 0.8 mrad/mm of incoming electron beam about 10 MV cavity RF voltages is required.

To perform the simulations we used the geometry of TESLA 1300 MHz cavity scaled as 3:1 for the buncher 3900 MHz cavity. The number of cells in such cavity can be more than 9 to reduce RF field amplitude in the cavity because RF power almost is not transmitted in a beam. The dynamic calculations with number of cells 9, 11 and 13 have shown the same results. Peak RF electric field at the axis of the cavity with 9, 11, 13 cells are correspondingly 55, 45, 38 MV/m.

Our choice of 3900 MHz was essentially motivated by the fact that at lower frequency the intensity of transverse focusing effect will be higher therefore cavity voltage will less to compensate beam divergence, and drift space length will become inadmissible large.

RESULTS

To obtain the shortest electron bunch in compressing scheme the effect of following parameters to this length was studied: laser spot size, launch RF phase (or laser jitter), laser pulse duration, RF voltage and RF phase of buncher cavity. In figure 3 the example of optimization of together laser spot size and launch RF phase for scheme of figure 2 is shown. Dynamic calculations launched 16 times for 4 different values of each parameter, and then spline interpolation of the results is made to find the optimum. The optimized parameters of compressing schemes of figure 1 and figure 2 together and their bunch characteristics are presented in tables 1, 2, 3.

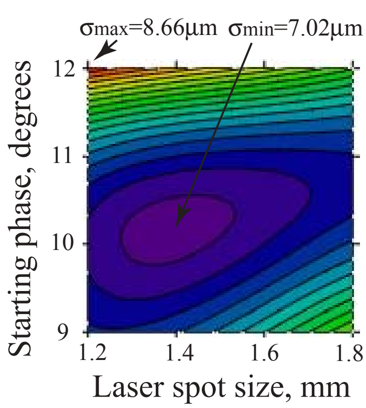

Figure 3: The spline interpolated results of 16 calculations of rms bunch length (σ) for the scheme of figure 2.

The sensitivity of rms bunch length to main parameters of figure 2 scheme can be written as follows:

$$\sigma\,[\mu m] = 7.02 + 2.94\cdot\Delta\sigma_L^2\,[mm] + 0.31\cdot\Delta\varphi_L^2\,[^\circ] - 0.68\cdot\Delta\sigma_L\cdot\Delta\varphi_L + 8.08\cdot\Delta V^2\,[MeV] + 4.59\cdot\Delta\Phi^2\,[^\circ] + 9.13\cdot\Delta V\cdot\Delta\Phi$$

Where σ – rms bunch length, µm; σ_L – laser spot size, mm; φ_L – Launch RF phase, degree; V – buncher cavity voltage, MV; Φ – operation RF phase of buncher cavity.

Table1: The optimized parameters of the compressing schemes.

Injector	Fig.1	Fig.2
Acceleration gradient in RF gun, MeV/m	25	20
Launch RF phase, degree	37.0	11.09
Laser spot size, mm	1.0	1.72
Laser pulse duration (FWHM), ps	3.0	5.6
RF voltage of buncher cavity, MV	10.11	10.77
RF phase of buncher cavity, degree	17.18	0.0
Target distance from cathode, m	5.1	5.04

Table 2: Bunch characteristics downstream of RF gun.

Injector	Fig.1	Fig.2
Bunch charge, pC	50	50
Bunch rms length, µm	131.0	173.4
Bunch energy, MeV	6.14	9.76
Energy spread, %	0.56	0.46
Longitudinal rms emittance, KeV·mm	0.663	0.843
Transversal normalized emittance (rms), mm·mrad	1.13	1.34
Beam divergence, mrad/mm	0.797	0.595

Table 3: Bunch characteristics at target distance.

Injector	Fig.1	Fig.2
Bunch rms length, µm	6.28	7.02
Max. bunch radius, mm	7.14	7.93
Bunch energy, MeV	9.74	9.77
Energy spread, %	1.05	1.70
Longitudinal rms emittance, KeV·mm	0.645	1.169
Transversal normalized emittance (rms), mm·mrad	2.43	3.97
Peak current, A	1445	1266

CHICANE SCHEME

In this compressing scheme a four dipole achromatic chicane is placed just after the buncher cavity. The sketch of the chicane geometry is shown in figure 4.

The elements of the geometry specified in the figure play the following role for optimization:

- By curvature radiuses of extreme dipole magnets (R1, R2) the transverse emittance dilution has compensated.
- By curvature radiuses of the central magnet tips (R) a curvature of a bunch front in horizontal and in a vertical plane has leveled.
- By inclination (β1) of the first dipole magnet tip the convexity of a bunch front has corrected.
- By inclination (β2) of the second dipole magnet tip the convergence dilution in a horizontal plane of a beam has compensated.

The optimized values of geometry elements are presented in table 4.

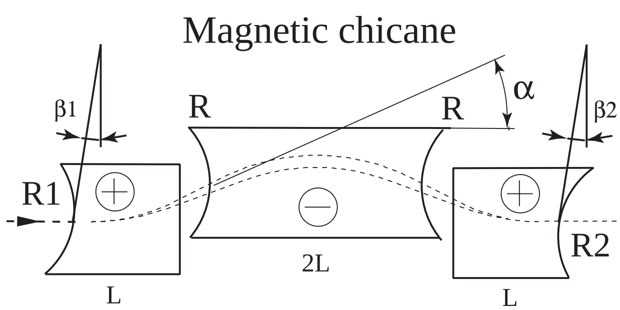

Figure 4: Sketch of magnetic chicane geometry. The fringe magnetic field taken in account in the simulation.

Table 4: The optimized elements of chicane geometry.

α	L	β1, β2	R1, R2	R
4.97˚	250 mm	9˚	200 mm	207 mm

The bunch characteristics computed by PARMELA for 10000 particles has shown in table 5.

Table 5: The bunch characteristics of magnetic chicane scheme.

The bunch downstream of…	Fig.2 gun	Chicane
Bunch rms length, μm	111.6	8.425
Max. bunch radius, mm	7.2	8.1
Bunch energy, MeV	9.72	9.305
Energy spread, %	0.319	1.224
Longitudinal rms emittance, KeV·mm	0.78	0.96
Transversal normalized emittance (rms), mm·mrad	1.41	4.1

REFERENCES

[1] V.N.Volkov, D. Janssen" Ultra short electron bunches with low longitudinal emittance in a multi-cell superconducting RF guns ," these conference.

[2] 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.