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RF gun cell length effect on the electron beam dynamics. Optimization study with a genetic algorithm

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Abstract

In the last ten years some modified versions of the UCLA/BNL/SLAC 1.6 cell S-Band RF Gun [1] have been developed. These versions had the principal purposes to reduce the surface field and to enlarge the modes separation. Three operations were performed to achieve these results: a reshaping of the iris, a variation in the iris aperture and a variation in the first half cell length. The effects of the length is strongly linked to the beam-dynamics that characterize the RF-Gun and to the final value of the achievable brightness. In this paper five different versions of a RF-Gun are studied, in each case only the length of the Half-Cell have been changed. The reference RF-Gun design is the LCLS version [2]. For each different RF-Gun we have optimised the beam brightness at the and of the SPARC linac, by using a genetic algorithm [3].

1. Introduction

Starting from the end of 90's some very accurate study of 1.6 cell S-Band RF Gun had been done. One of the more important reference work is the PhD Thesis of D. Palmer [1], where was presented a very accurate study – theoretical and numerical – of the emittance compensation process in the 1.6 RF-Gun, for bunches with both Gaussian and Flat-top tempotal profile.

	Gaussian σ_z = 2.5 psec	Flat-top FWHM$_z$ = 10 psec
$\epsilon_{n,rms}$ (π mm mrad)	1.95	1.18
B_z (kG)	3.284	3.312
θ_o (°)	51.6	62.3
$\epsilon_{n,rms}$ (π mm mrad)	1.57	0.95
B_z (kG)	3.250	3.259
R_o (mm)	0.71	0.65

Tab. 1 – 2-D PARMELA [4] results for both Gaussian and flat-top longitudinal laser profiles $\varepsilon_{n,rms}$ versus B_z (Gun Solenoid) and θ_0 (injection phase) with a fixed value of $R_0 = 0.9$ mm (laser radius on the cathode) and $\varepsilon_{n,rms}$ versus B_z and R_0 using the θ_0 found earlier.

The numerical results of D. Palmer presented in the Tab.1 show that the use of Flat-Top pulses is much better that Gaussian ones. This conclusion is well-motivated by both theoretical, numerical and experimental evidence [5], so almost all the 1.6 Gun designs studied and produced up today, are focused to improve the final brightness for flat-top case.

We took as a reference the distributions of electrons closed to the most studied case: 1nC of charge, 10ps temporal length (FWHM) of extracting laser for a flat-top distribution or $\sigma_t = 2.8$ ps for a Gaussian distribution and 1.0 mm of laser radius on the cathode (transversally uniform).

In this report, five different versions of a 1.6 RF-Gun are compared, in term of beam dynamic, where was changed only the length of the first Half Cell (HC). The Gun reshaping has been performed by Superfish [6], while the beam dynamics simulations have been done using an our genetic code [3], that drives the tracking code Astra [7]. The used reference Gun, here named 061_HC, has been presented in the SLAC note [2] where, in the Appendix, is included the used Superfish input file. The value we have compared, for the different Gun versions, is the rms normalize emittance at the end of the SPARC linac, which is composed by three SLAC type S-band TW acceleration structures.

We used a genetic code able to make a fine tuning of parameters, finding the values that better match the beam to the accelerating structure. This method permits to reach the best emittance minimum at the accelerator exit. This one is not just a problem to find the best machine working point by moving linear parameters, but as a matter of fact it is a problem linked to the space-charge, and its non linearity, which plays a fundamental role in the emittance compensation process.

The main result of this analysis is that flat-top bunches show a lower normalized emittance minimum for short HC, while lengthening the HC there is a degradation of the emittance, with a variation range of about 0.8 mm-mrad. In a completely different way Gaussian bunches show a lower emittance minimum for longer HC, furthermore the correlation of emittance versus HC length is much stronger covering a range of about 1.8 mm-mrad.

2. The genetic code

We have developed a versatile genetic code to solve the problem of the generation of a very high quality electron bunch. Genetic algorithms (GA) are a family of computation models inspired by biological evolution and refer to a model developed and investigated by Holland [13] and DeJong [14] in 1975. These algorithms encode solutions to specific problems on a simple chromosome-like data structure and apply iterated recombination operators. They are particularly suitable to solve problems that have nonlinear character and where it is not possible to treat each parameter as a variable which can be fixed independently from all the other ones.

The evolution toward better solutions is regulated by a fitness function that evaluates the goodness of solutions in each generation and allocates to the best ones a larger survival opportunity.

As the applications we will present here will require electron beams with high brightness, the fitness function should contain directly the beam brightness; so the genetic code launches the code Astra which integrates the beam dynamics equations for each beam line configuration up to 12 m, comparing the goodness of solutions by the fitness function.

3. The RF-Gun tested

As in the introduction mentioned we tested five different versions of a 1.6 RF-Gun, changing the length of the HC starting from the SLAC Gun presented in the reference [2], here named as 061_HC. The other RF-Guns tested keep the names 047_HC, 054_HC, 068_HC and 076_HC.

047_HC means a RF-Gun identical to the reference one but with HC length equal to $0.47 \cdot \frac{\lambda_{rf}}{2}$, where $\frac{\lambda_{rf}}{2}$ is the Gun periodicity. The other RF-Gun versions have been named by following the same rule; in Tab. 2 are reported the exact length values.

Each shape is retuned to the reference resonant frequency of 2.856 MHz with a flat-field.

Gun name	Half cell length [cm]
047_HC	2.470
054_HC	2.849
061_HC*	3.228
068_HC	3.608
076_HC	3.987

*the reference one

Tab. 2 – Name of the simulated guns and the exact length

4. Numerical results

The characteristics of the simulated bunches are showed in the Tab. 2, while the beam-line is sketched in the figure 1. The simulations have been performed by injecting the bunches on the phase of maximum acceleration for the three TW structures, and setting the accelerating gradients to the values of 22, 22, 11 [MeV/m].

	Gaussian	Flat-top
Charge extracted [nQ]	1.0	1.0
Extraction laser temporal length [ps]	2.8 (σ)	10 h.e.
Extraction laser radial dimension [mm]	1.0	1.0

Tab.2 Beam characteristics at the extraction.

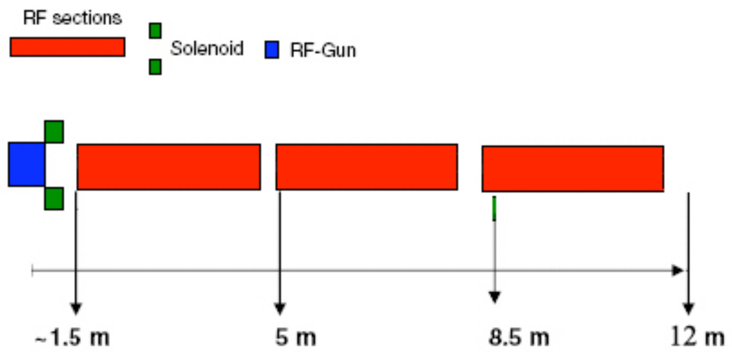

Figure 1 – Sketch of the beam-line simulated

The results of the analysis is summarized in the fig. 2, where is pointed out the strongly different behaviour of the Guns for the two different initial distribution, Gaussian and flat-top. The image reports also the final energy reached by the beams, the injection phases, the Gun accelerating field and the final energy spread (in %). The injection phases are relatives to the phase of maximum energy (at the Gun exit), which are plotted in fig. 3. In fig. 4 is plotted the bunch lengthening that, with fig. 2, helps the reader to compare the brightness values of the different cases.

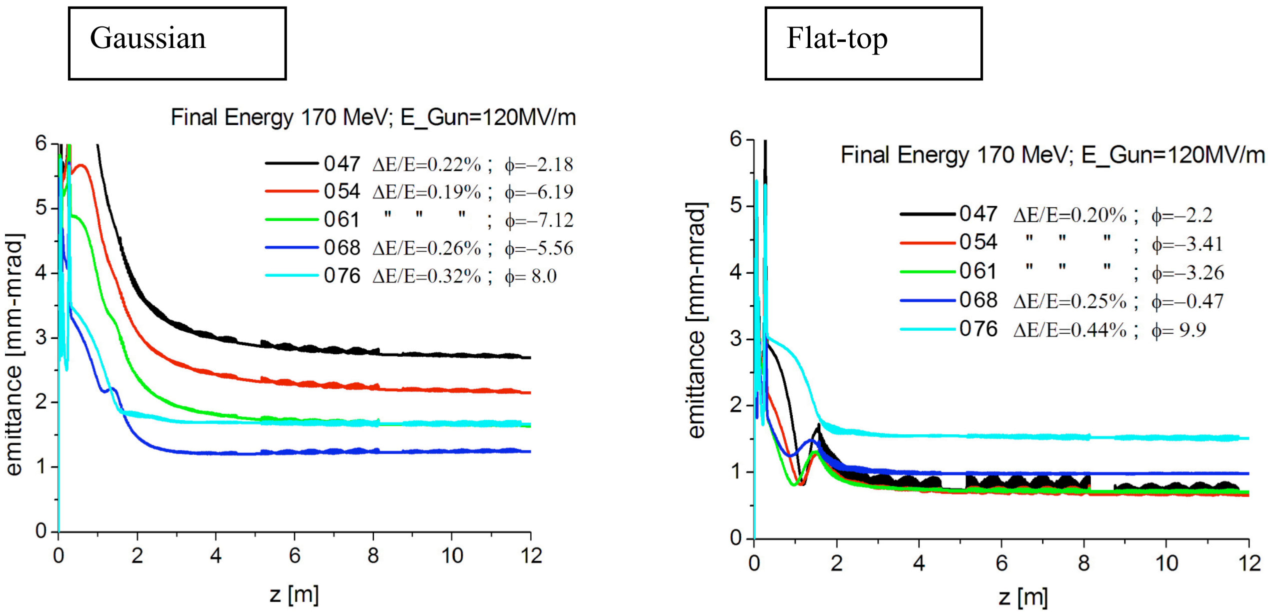

Figure 2 – Rms normalized emittance behaviour along the SPARC linac for a Gaussian bunch and for a flat-top bunch. Different colours show different HC lengths

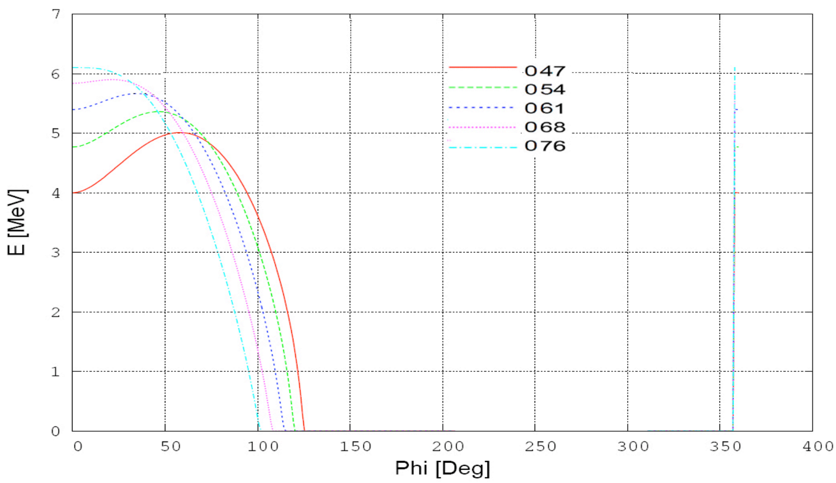

Figure 3 – Energy of the beam versus the injection phase for the Gaussian distribution

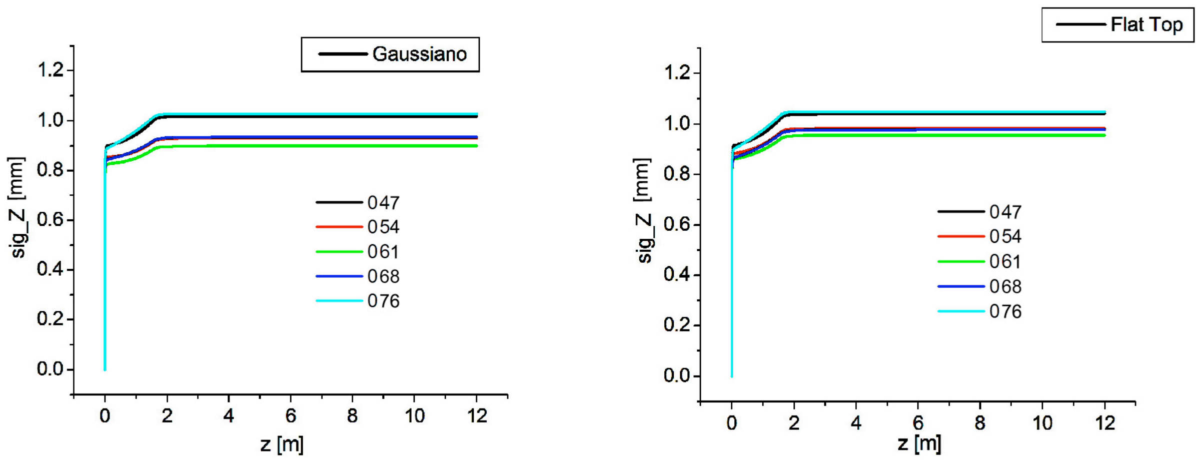

Figure 4 – σ_z of the beams along the SPARC linac, for Gaussian and flat-top distributions

5. Conclusions

The different behaviour showed by Gaussian and flat-top bunches, by varying the HC length, is quite interesting. What has to be kept in consideration for small HC lengthening, is how the Gun shows a low loss in performance with flat-top bunches, instead of a strong performance improvement for Gaussian bunches. This behaviour could justify a possible choice to build a Gun of 07_HC type where the final emittance is close to 1 mm-mrad for the both distributions. It is also important to point out how the generation of a flat-top distribution at the cathode, with a really narrow rising time, is not a easy matter; bunches generated to show a flat-top longitudinal profile often are not so far from a Gaussian like distribution.

The study here presented just a starting point and we foreseen to improve the work including also the effects of the starting radials dimension of the two distribution on the cathode, a very important parameter in the emittance compensation. The study will be performed with the same tools here presented.

References

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