BEAM DYNAMICS STUDY OF A C-BAND LINAC DRIVEN FEL WITH S-BAND PHOTO-INJECTOR

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Abstract

The successful operation of the SCSS FEL driven by a C-band linac has demonstrated that C-band is a mature technology and it is very attractive in terms of gradient and compactness.

In this paper it is described a beam dynamics study, made with the Homdyn code, for a C-band linac driven FEL with S-band photo-injector. The key point is to match the longitudinal phase space of the S-band photo-injector with the C-band linac using the velocity bunching technique. The result is a brightness up to 10^{15}A/m^2, obtained with a low emittance and a relaxed peak current.

INTRODUCTION

The aim of a photo-injector and a linac for the production of FEL radiation is a high transverse brightness beam. Transverse brightness is defined as [1]:

$$B_{\perp} = \frac{2I}{\varepsilon_{nx}\varepsilon_{ny}} \qquad (1)$$

where I is the bunch peak current and ε_{nx}, ε_{ny} are the transverse normalized emittances of the bunch; thus high brightness means low emittances and high current.

Low emittances are obtained in the photo-injector by using the so called "emittance compensation" technique [2]; that is the electrons, produced on a cathode, are rapidly accelerated in a RF cavity, thus decreasing emittance growth due to space charge forces. Space charge and RF induced correlation along the bunch are compensated using a solenoid just outside the RF gun. The bunch is then injected in the following accelerating section fulfilling the invariant envelope condition [3, 4]. The resulting emittance is thus frozen outside the linac to its minimum value.

High current can be obtained by reducing the bunch length. This can be done with a magnetic compressor and, at low energy, with the velocity bunching technique [5].

Finally the bunch reaches the required energy and energy spread in the following linac sections.

In the design presented in this paper the photo-injector, that is the RF gun and the first three accelerating sections are S-band structures, while the remaining accelerating sections, needed to reach the energy of 1.2 GeV as required for a FEL radiating in the nanometer wavelength range, are C-band structures, that is a hybrid linac solution has been considered.

This hybrid design can evolve with the substitution of the S-band injector with a C-band one when it will be an available and mature technology. This choice will take advantage of the very high peak fields on the cathode that can be obtained in the gun [8].

BEAM DYNAMICS STUDY OF THE HYBRID S-C BAND SOLUTION

The beam dynamics study of the photo-injector and linac described here has been performed with the Homdyn code.

Homdyn is a fast code [4] whose main approximation consists in supposing the bunch as a uniformly charged cylinder divided in slices. The evolution of each slice, longitudinally and transversally, is described by differential equation where electromagnetic fields are assumed to be linear. Moreover transverse and longitudinal wake fields are included [6]. On the other hand CSR and microbunching effects in the magnetic compressor are not yet included.

Scaling laws for high frequency technology

The launching beam parameters considered in this work are 5.67 ps long bunch with a radius of 0.64 mm and a charge of 200 pC, corresponding to an initial current around 35 A. The assumed thermal emittance is 0.6 µm/mm for a copper cathode. As a reference design, the SPARC S-band (2856 MHz) photo-injector has been chosen and the bunch parameters have been scaled from the SPARC nominal value (1 nC in a 10 ps long bunch with 1 mm radius), according to the charge and wavelength scaling laws presented in [7].

Layout of the S-C band accelerator

As depicted in Fig.1, the layout consists in a 1.6 cells S-band standing wave gun, followed by a solenoid. The first 3 accelerating sections are S-band travelling wave structures and are embedded in long solenoids. The first section is actually used to operate in the velocity bunching mode, meanwhile the emittance is compensated by the solenoids around the accelerating structures. Finally the Linac 1 and Linac 2 are in the C band technology allowing to reach the energy of 1.2 GeV. A magnetic compression is also foreseen.

The injector operates at 120 MV/m in the gun and the accelerating structures at 25 MV/m, driving the beam to an energy of 171 MeV in the compression mode. The bunch is compressed with the velocity bunching technique allowing to reach a peak current of 200 A, corresponding to a compression ratio of a factor 5.5. The beam is then injected in the following C-band accelerating structures (linac 1) up to 490 MeV to keep the beam out of the space charge dominated regime. The beam is driven along the linac 1 17 degrees out of phase to fulfil the following magnetic compressor requirements: the induced energy spread is 0.3% thus allowing the magnetic chicane (R_{56}=15 mm) to compress the beam to 0.04 mm length, the final current is 417 A, a gentle compression ratio of a factor 2. The downstream accelerating structures (linac 2) drive the beam up to an energy of 1.2 GeV. The rms energy spread previously induced is reduced to 0.1% at the end of the linac 2 by the strong action of the longitudinal wake field in the C-band linac.

In this configuration the whole linac is 45 m long.

Fig. 2 shows the emittance, the rms spot size of the beam and the solenoid magnetic field along the injector. The solenoid at the gun exit has been set to 0.27 T and the solenoids those around the three sections to 0.1 T to compensate the emittance growth during the velocity bunching. An emittance of about 0.56 mm mrad has been obtained giving a $B_{\perp}$ of about 2.6 10^{15} A/m^2.

Finally Fig. 3, Fig. 4 and Fig.5 shows the energy spread, current and length of the bunch respectively along the linac.

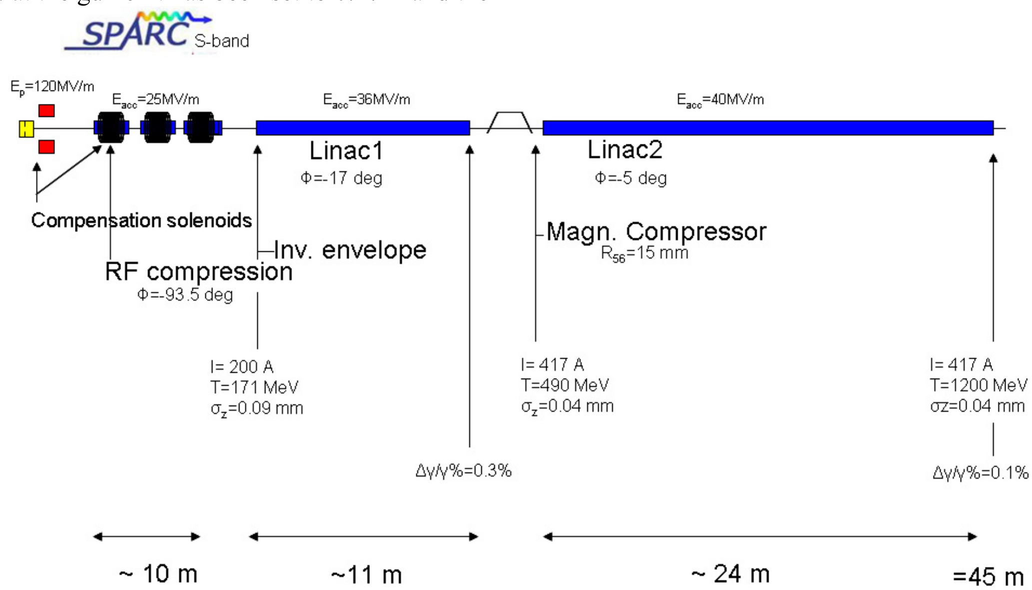

Figure 1: Schematic layout of the Sparc S-band photo-injector and C-band linac to 1.2 GeV.

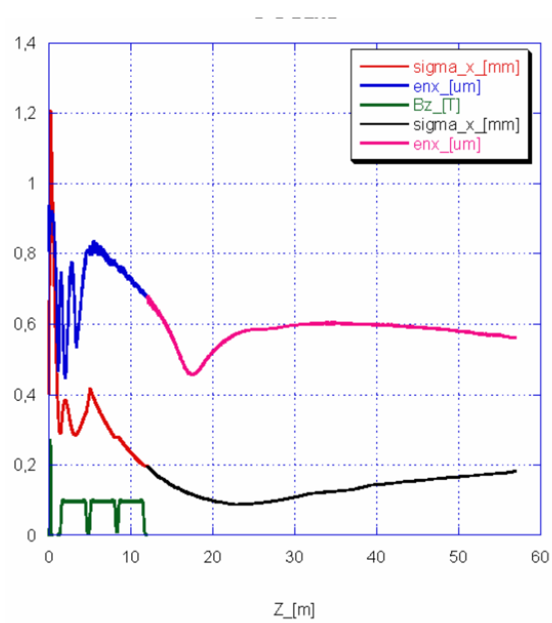

Figure 2: Emittance, rms spot size and the solenoid field along the accelerators up to 1.2 GeV. The different colour along the same line represents the S band (until about 12 m) and the C band

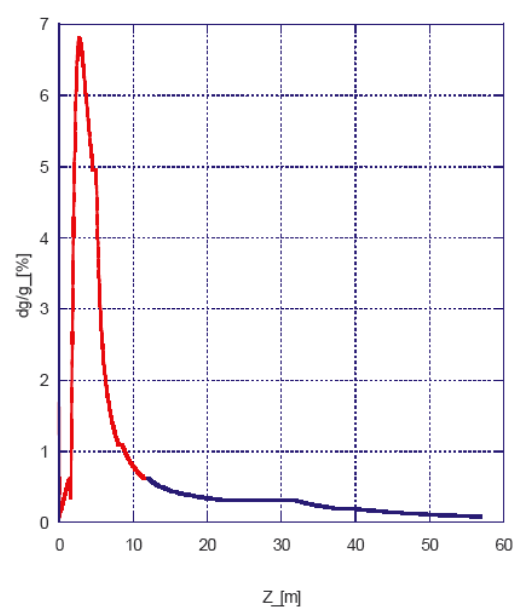

Figure 3: Energy spread along the accelerator.

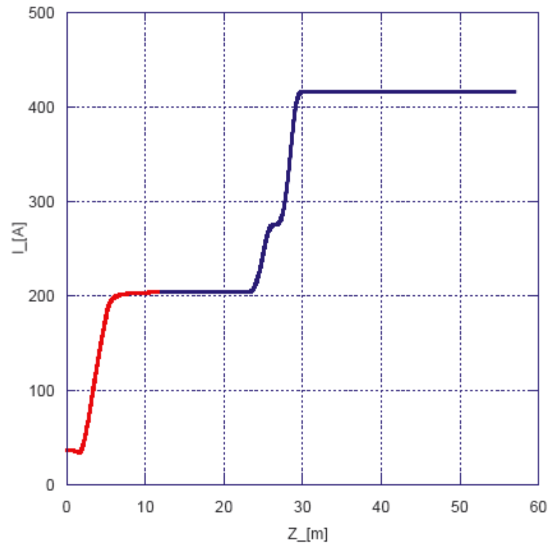

Figure 4: Current along the accelerator.

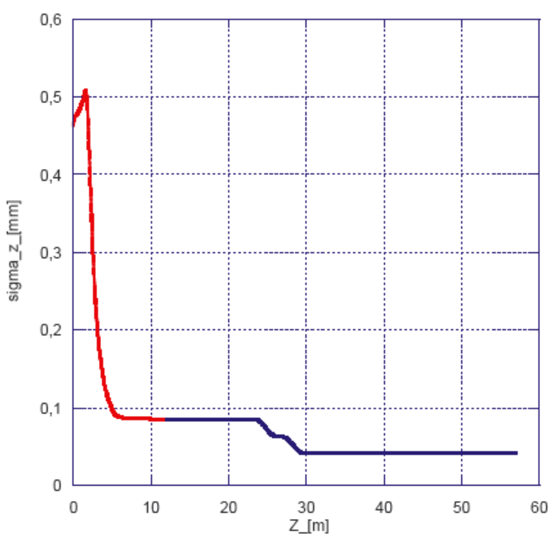

Figure 5: Rms length along the accelerator.

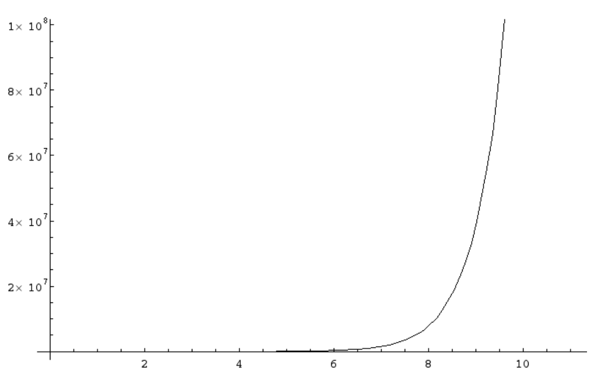

Figure 6: SASE output power along the undulator as predicted by Ming Xie scaling laws at 8 nm wavelength.

CONCLUSIONS

The beam dynamics of a bunch accelerated along an S and C bands hybrid linac has been analyzed showing the possibility to obtain a good matching from an S-band photoinjector including velocity bunching to the following linacs based on C-band technology. The whole study has been done with the Homdyn code, as a preliminary investigation, and the simulations show that very good emittances and relaxed peak current can be obtained giving a brightness up to 10^{15}A/m^2, as well as a compactness of the whole structure. With this parameters Xie scaling laws [10] would predict that a SASE FEL with the SPARC undulators [11] tuned at 8 nm (with K=2) would saturate in 12 m with an output power of 100 MW. There is certainly additional room for an improved optimisation with a different balancing of velocity bunching and magnetic compression ratio, and more detailed studies should be performed with PARMELA and GENESIS codes. The experimental demonstration of the effectiveness of the velocity bunching techniques is currently under way at the SPARC test facility [9].

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