BEAM DYNAMICS OF THE 100 MEV PREINJECTOR FOR THE SPANISH SYNCHROTRON ALBA

A. Setty, THALES Communications, 160 Bld de Valmy 92700 Colombes, France

Abstract

A turn key 100 MeV linac is under construction, in order to inject electrons into the booster synchrotron of ALBA [1]. The linac will deliver electron beams according to two operation modes: a single bunch mode (1 to 16 pulses - 0.25nC each) and a multi-bunch mode (112ns - 4nC). We have calculated the beam dynamics, using our in house code, PRODYN [2], from the gun to the end of the linac. The beam behaviour, such as the radial control, the bunching process, the energy spread and emittance are analysed.

INTRODUCTION

The electron dynamics are complicated. Their energies vary from zero to more than one MeV in a length comparable to the pre-bucket dimension. Velocities are different at the same abscissa. On-axis oscillations occur. Space-charge effect can locally be large. RF field phase and amplitude laws must be shaped precisely. Such non-linear bunching and acceleration process requires a step-by-step simulation made in a time domain. All efforts have been made to implement this and to upgrade it continuously as a highly interactive, fully three-dimensional tool for design purposes.

PRODYN includes backward as well as forward movements and relativistic space-charge effects.

The provided elements are: RF accelerating cell, drift, magnetic lens, quadripole, dipole and bending magnet. The accelerating cell may include a magnetic lens and a dipole. Sub-harmonic frequencies can be used. This code has been last used for the beam dynamics of HELIOS, the SOLEIL synchrotron linac [3].

GENERAL DESCRIPTION OF THE LINAC

Fig. 1 shows a schematic layout of the 100 MeV linac. The subsystems are listed below:

- A 90 kV triode gun which derives from a Pierce gun diode geometry.
- Four short focusing shielded lenses between the gun and the buncher.
- A pre-bunching cavity at a sub harmonic frequency of 499.654 MHz.
- A pre-bunching cavity at 2997.924 MHz.
- A standing wave buncher.
- Two travelling wave accelerating structures.
- A Glazer lens between the buncher and the first section.
- A triplet between the two accelerating structures.

The main specifications of the linac are presented in table 1.

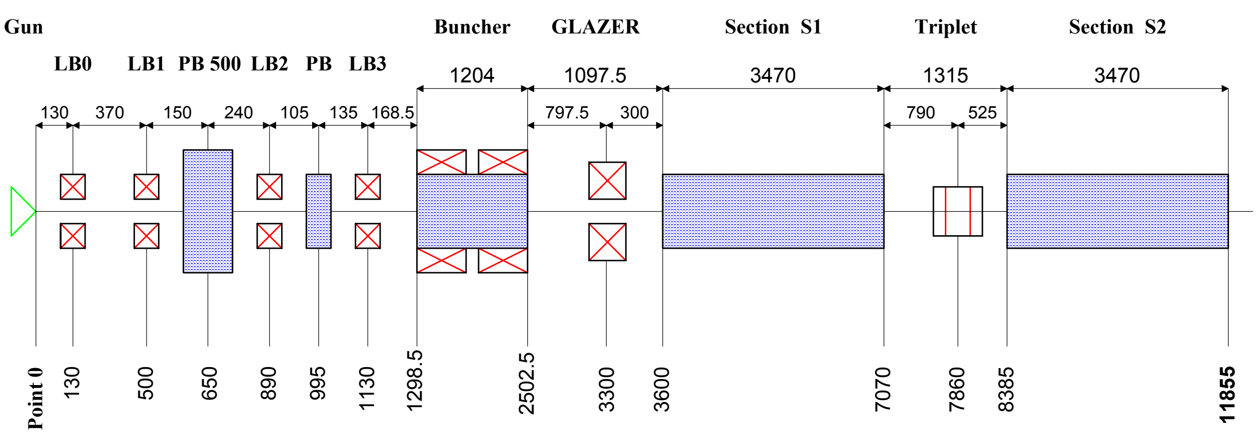

Figure 1: Schematic layout of the 100 MeV linac (unit in mm)

Table 1: Linac Specifications

RF frequency	2997.924 MHz
Energy	≥ 100 MeV
Energy spread	< 0.50% rms
Repetition rate	3 to 5 Hz
Normalised emittance $\pi\beta\gamma\sigma\sigma'$	≤ 30π mm. mrad
Single Bunch Mode	1 to 16 pulses per train
Gun pulse width	1 ns
Time between pulses	8 to 256 ns
Output charge per pulse	0.25 nC
Multi Bunch Mode	
Gun pulse duration	112 to 600 ns
Maximum charge per train	4 nC

According to the two different running modes, two current levels are needed at the gun output: 240 mA for the multi bunch mode and 420 mA for the single bunch mode.

SIMULATION RESULTS

The Gun and the Pre-Bunchers

Except for the chopper, which has been replaced by a sub-harmonic cavity, the injection line from the gun to the buncher included is the beginning of the HELIOS linac of SOLEIL [3]. This decision was taken following the successful installation and commissioning at the end of 2005 [4] and the advantage of having a sub harmonic booster frequency with no need for a chopper.

The proposed gun is a Pierce type geometry using an EIMAC Y-845 cathode with a 0.5 cm^2 emissive area. This gun has been simulated with the EGUN code [5].

For both operation modes, the outgoing beam is practically parallel in order to limit the space charge effects and therefore to reduce the final emittance. The four short shielded lenses between the gun and the buncher ensure the beam focusing at low energy.

The sub-harmonic pre-bunching cavity at 499.654 MHz is a pill box cavity derived from the ELETTRA preinjector [6]. The cavity is cylindrical, with a diameter of 460 mm and a length of 140 mm. The drift between the pre-buncher and the buncher is 650 mm long. The beam modulation is about ± 25 kV. The one nanosecond pulse (180 degrees at 499.654 MHz) is bunched with a phase extension of 40 degrees at 499.654 MHz, or 240 degrees at 2997.924 MHz.

The pre-bunching cavity allows for only one pulse at 3 GHz, instead of three, from the one nanosecond pulse. This enables a halving of the energy spread in Single Bunch mode.

The beam modulation of the pre-bunching cavity is about ± 10 kV with a 90 W RF feed. The drift between the pre-buncher and the buncher is 30 cm long.

With the two pre-bunching cavities, 86% of the 1ns input pulse falls within a 64 degrees phase extension at the buncher entry and for 75% of the gun current the phase extension is reduced to 43 degrees (i.e. 7 degrees at 499.654 MHz). Fig. 2 shows the phase-energy diagram at the buncher entry.

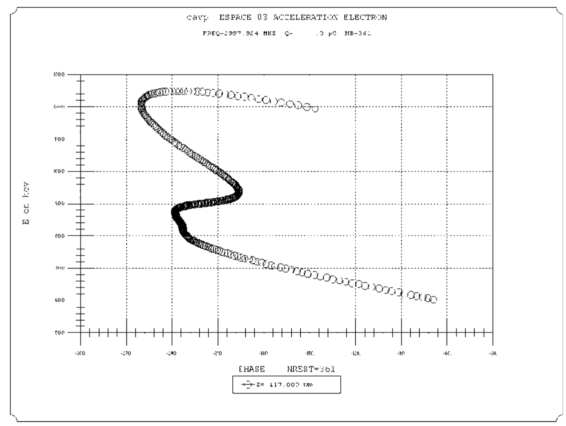

Figure 2: Phase-energy diagram at the buncher entry.

The Buncher

The buncher is a 1.1 meter long standing wave structure at the π/2 mode. The beam aperture diameter is ø 27 mm. The first two of the 22 cells have a reduced beta for the bunching process (ß = 0.78 and 0.90).

A 5 MW RF input power increases the energy up to 15.7 MeV with an average electric field on axis of 18.7 MV/m (peak field of 27 MV/m). The beam focusing is ensured by two shielded solenoids surrounding the buncher structure and providing a maximum magnetic field of 0.2 Tesla.

The choice of this high energy buncher avoids the use of solenoids on the first accelerating structure. For both modes, around 95 % of the gun current is found at the buncher exit. Without the sub harmonic cavity, the buncher transmission decreases to 80 %.

Table 2 gives the beam properties, at the buncher exit, with respect to the gun current at 15.7 MeV.

Table 2: Beam Properties at the buncher exit

Gun Current	0 mA	240 mA	420 mA
Transmission in:			
ΔE =400 keV	87 %	74 %	69 %
ΔE = 300 keV	85 %	69 %	63 %
Δφ = 20 degrees	89 %	73 %	72 %
Δφ = 16 degrees	85 %	67 %	65 %

The Accelerating Sections

The main accelerating structures are identical to those made for the ELETTRA preinjector [6].

They are travelling wave $2\pi/3$ mode sections designed with a constant gradient. The iris diameter varies from 22.4 mm to 16 mm, giving a group velocity c/v_g from 51 to 149 over 96 cells including the couplers cavities ones.

The filling time is 0.88 μs and the power attenuation is equal to 5.6 dB.

A peak electric field of 23.4 MV/m on axis (36.1 MV/m on copper) provided with an 18 MW RF feed, allows an energy increase of 52 MeV per section and a final energy of 119 MeV at the end of the linac.

The sections are used without external focusing, except for a triplet between them and a Glazer lens between the buncher and the first section.

The linac phase adjustments insure radial focusing in the first unit. Energy spectrum broadening is corrected with the particle of lowest energy put at the "wave crest" of the second unit with some radial defocusing.

Figures 3 and 4 show, at the linac end, respectively the X-X' plane emittance for the 240 mA and the energy histogram for the 420 mA.

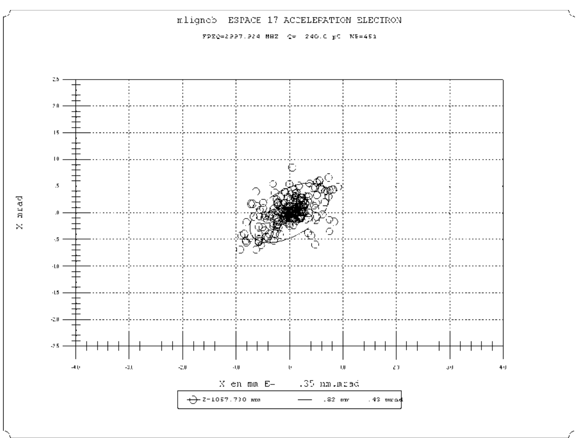

Figure 3: Emittance at the linac end for the 240 mA mode.

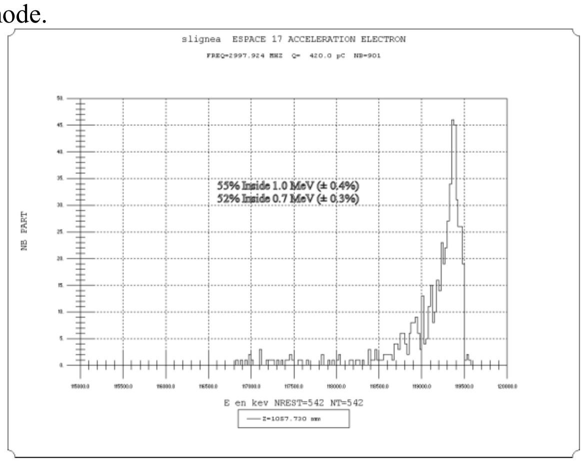

Figure 4: Energy histogram at the linac exit for the 420 mA mode.

The following table gives the beam properties at the linac end for both operation modes at 240 mA and 420 mA.

Injection mode	MBM–240mA	SBM–420mA
Final average energy	119 MeV	119 MeV
Total transmission	67 %	60 %
Transmission in:		
$\Delta\varphi$ = 15 degrees	61 %	57 %
$\Delta\varphi$ = 11 degrees		52 %
ΔE=2 MeV (±0.84%)	61 %	
ΔE=1 MeV (±0.42%)	50 %	55 %
ΔE=.7 MeV (±0.3%)		52 %
Beam radius (mm) for 95 %	2.2	2.9
$\pi\beta\gamma\sigma\sigma'$ (mm.mrad) average value for 68%	22 π	29 π

Simulation have been carried out with a variation of all the setting parameters around the operating values in order to study their influence on the beam and to verify that the linac adjustment can be achieved smoothly.

The beam loading compensation was also explored. It is achieved by sending the beam during the filling time of the second accelerating structure [4].

CONCLUSION

Beam dynamics for the two operation modes at 240 mA and 420 mA, meet the specified values.

The expected low energy spread is achievable thanks to the small phase extension, at the buncher exit, due to the use of the two pre-bunching cavities.

We were able to reduce the specified emittance values, by a factor of almost 1.7, due to the measured emittance on HELIOS the SOLEIL preinjector linac [4].

REFERENCES

[1] D. Einfeld, "Status of the ALBA project", EPAC 06, Scotland, Edinburgh, June 2006.

[2] D. Tronc and A. Setty, "Electrons RF auto-focusing and capture in bunchers", Linear Accelerator Conference 1988, Virginia.

[3] A. Setty, "Electrons beam dynamics of the 100MeV preinjector HELIOS for the SOLEIL synchrotron", EPAC'04, Switzerland, Lucerne, July 2004.

[4] A. Setty et al, "Commissioning of the 100 MeV preinjector HELIOS for the SOLEIL synchrotron", EPAC 06, Scotland, Edinburgh, June 2006.

[5] W. B. Herrmannsfeldt, "EGUN An electron optics and gun design program", SLAC report 331, 1988.

[6] C. Bourat et al, "The 100 MeV preinjector for the Trieste synchrotron", PAC89, Chicago, March 20-23 1989