A NEW BUNCHER FOR THE ESRF LINAC INJECTOR

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Abstract

The electron linac was designed to be able to deliver more than 2.5 Amps in less than 2 ns at 200 MeV within an energy spread of 1% for positrons production at ESRF [1]. The 200 MeV electron linac was commissioned in 1991. A new gun, a cleaner, a pre-buncher cavity and 4 shielded lenses were tested and installed on the injector in 2008 [2]. Then, a new Buncher for the ESRF electron linac injector was manufactured and commissioned in 2015. Meanwhile, some new settings were performed to reduce the energy spread for both cases: the long pulse mode and the short pulse mode. The simulations and measurements will be presented.

INTRODUCTION

The linac subsystems are listed below:

- A 90 kV triode gun.
- Four short focusing shielded lenses between the gun and the buncher.
- An electrostatic chopper.
- A pre-bunching cavity.
- A standing wave buncher.
- Two travelling wave 6 m accelerating structures.
- A Glazer lens between the buncher and the first accelerating structure.
- A quadrupoles triplet between the two accelerating structures.

There are two operation modes:

- A short one for 180 mA and 1 ns.
- A long one for 5 mA and 1 µs.

The gun replacement in 2008 was done to improve the cathode lifetime. The pre-buncher cavity was added to suppress the multipactor effect of the old one. And finally new diagnostics were added: FCTs, target, camera and a modern electronic modulator.

The decision to replace the buncher was taken by the regretted former synchrotron director Pascal Elleaume. The buncher was identified as a masterpiece that may induces a stop of the machine in case of failure.

DESIGN AND SIMULATIONS RESULTS

The Buncher

The previous buncher required a RF power of 4.7 MW. The first cavity of the buncher was using a moderate field level acting like a pre-buncher cavity.

The new buncher is from a design of the SOLEIL injector [3]. The input RF power is around 5.5 MW. The idea of this high energy buncher was to avoid the use of solenoids on the travelling wave accelerating structures.

The injection space, between the gun and the buncher, is now similar to the SOLEIL one. At the ESRF linac, the two accelerating structures are surrounded by solenoids providing a 0.15 Tesla focusing field.

The buncher is a 1.1 meter long standing wave structure at the $\pi/2$ 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 5.5 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.

Without the pre-bunching cavity the electron capture is reduced to 25 %. Calculation for the 120 mA (respectively 450 mA) mode give 64 % (respectively 56 %) of the gun current inside a 13 degrees phase extension at the buncher exit.

For a 120 mA mode, 64% of the electrons lie inside ± 0.64% energy spread and for 59% the energy band width is reduced to ± 0.48%.

Figure 1 shows the energy histogram at the buncher exit for 120 mA mode.

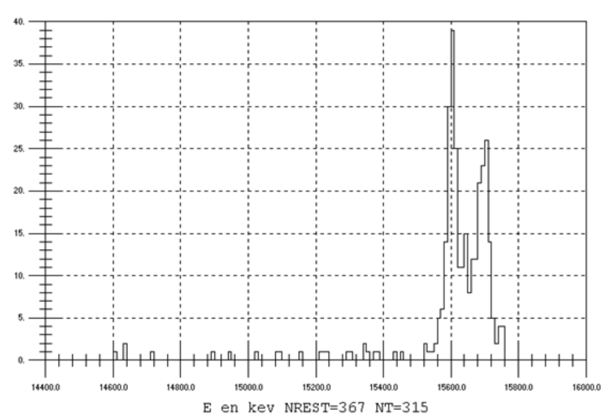

Figure1: Energy histogram at buncher exit for 120 mA.

The Accelerating Section

The 6 meters accelerating structures are a travelling wave $2\pi/3$ mode sections designed with a constant gradient. The iris diameter varies from 26 mm to 16 mm,

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giving a group velocity c/v_g from 31 to 149 over 180 cells including the couplers cavities ones.

The filling time is 1.49 µs and the power attenuation is equal to 9.4 dB.

A peak electric field of 27.7 MV/m on axis (42.7 MV/m on copper) provided with a 35 MW RF feed, allows an energy increase of 108 MeV.

The radial focusing is ensured by solenoids surrounding the accelerating structures. The magnetic field is equal to around 0.15 Tesla.

Beam Loading Compensation

Generally, the first electrons of a long pulse have the greatest energy gain while crossing an accelerating section as the stored energy left for the last electrons is reduced. This is what we call the beam loading effect.

The beam loading compensation is achieved by sending the beam during the filling time of the second accelerating structure. In fact, the first electrons cross the last part of the section without the nominal stored energy in it. The last electrons cross a full stored energy section. In certain conditions of power, charge and pulse length, the beam loading effect can be considerably reduced.

The energy shift along the macro bunch pulse due to the beam loading effect is around 2.2 MeV between the energy with no current and a 25 mA mode at 108 MeV, i.e. an energy spread of ± 1.0%.

Figure 2 shows the energy gain along the structure for those two modes.

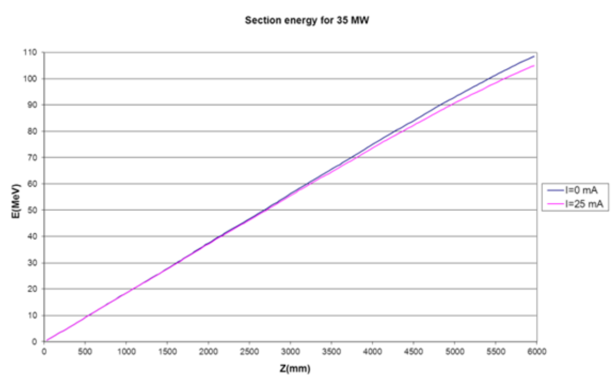

Figure 2: Energy for I = 0 mA and I = 25 mA at 35 MW.

To compensate the beam loading effect we need to have a higher beam current than the 5 mA of the long pulse. In our case, the beam loading effect is equal to 1.32 MeV. The energy beam spread can be then reduced to 1.07 MeV. In fact, there is no need to compensate the beam loading effect.

For a beam pulse of 80 mA – 250 ns, the beam loading effect is equal to 8.7 MeV. It can be then reduced to 0.4 MeV by sending the beam in the second accelerating structure 0.5 µs before the total 1.5 µs filling time.

BEAM MEASUREMENTS

Beam Optimisation Method

A beam with a phase extension of 20 degrees centred on the "wave crest" generates an energy spread band of 1.5%. This beam shifted by 40 degrees, with respect to the wave crest, induces an energy spread of 25.8%. This allows, with a bending magnet and two structures (buncher and analysing section), to give the phase extension and the temporal structure of the beam with a precision of 1 degree at 3 GHz, i.e. a precision smaller than 1 picosecond.

A frequency variation of the travelling wave section induces a phase shift with respect to the wave crest. A 50 kHz variation, i.e. a 1 degree temperature change of the cooling water of the section, induces a phase shift of 27 degrees between beam and RF field along the whole first structure, i.e. a mean value of 13.5 degrees.

If the section is warmed up, the frequency will be reduced with respect to the buncher frequency and the beam will get a phase advance while travelling across the section. If the section is cooled, the beam will be delayed.

In our case, it was easier to change the frequency and the temperature of the buncher.

Results

At the end of the linac after the dipole magnet, the energy slits have an open gap of 20 mm while injecting the beam in the booster. The central beam trajectory has a 1.556 meters radius and the magnetic field is equal to 60.318 Gauss/amps.

The beam measurements were done with an 8 mm gap. The frequency variation or the temperature change allows us to find the lowest FWHM energy spread.

In the beginning, for a full energy around 188 MeV, the FWHM energy spread was around 4.2 MeV.

With only one accelerating structure (second modulator off), the energy was reduced to about 101 MeV with a FWHM of 5 MeV. This is due to the fact that with two accelerating structures and a wrong temperature setting, we can compensate the energy spread with the RF phase between the two structures.

Then by changing the frequency and the temperature of the buncher, we reduced the 5.0 MeV of the one structure mode to around 4.0 MeV.

Figure 3 shows the current behind the 8 mm gap slits versus the energy for two temperature of the buncher and for one accelerating structure (second modulator off).

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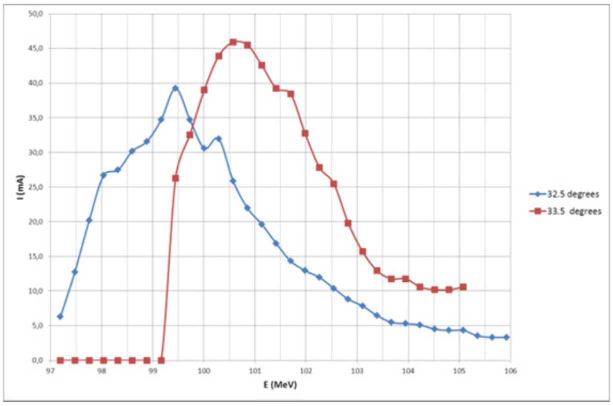

Figure 3: Current versus energy for two temperatures.

Figure 4 shows the current behind the 8 mm gap slits versus the energy for three temperatures of the buncher and for the whole linac.

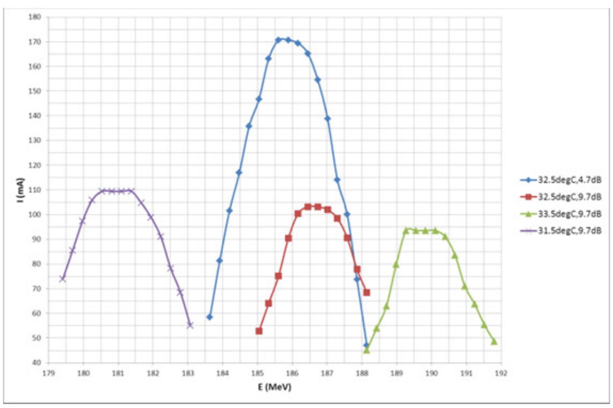

Figure 4: current versus energy at the linac exit for three temperatures.

The difference between the two settings at 32.5 degrees is that the red curve is obtained without feeding the pre-bunching cavity. Without the cavity, the maximum current is reduced by 39%.

Between the 33.5 degrees and the 32.5 degrees, the measured energy shift is equal to 11.7 degrees for a 13.5 degrees calculated. In the same way, between 31.5 degrees and 32.5 degrees, the measured energy shift is then equal to 14.2 degrees.

Figure 5 shows the current behind the 8 mm gap slits versus the energy for three different RF phase settings of accelerating structure number two and for the whole linac.

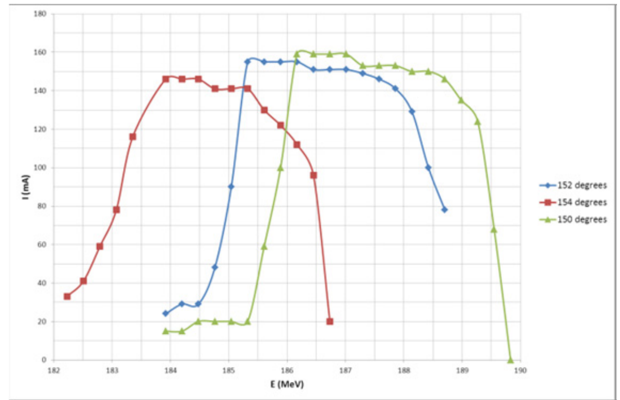

Figure 5: current versus energy at the linac exit for three RF phases of structure two.

For this final setting at 184 MeV for 32.5 degrees and a frequency of 2998.120 MHz, the FWHM energy spread was reduced to 3.4 MeV and a total energy spread of 4.8 MeV was achieved.

CONCLUSION

The buncher, having his own cooling water new system, can be easily tuned. In fact its temperature is then adjusted by minimizing the reflected power, as the buncher with the standing wave, is a narrow band structure.

The 6 meters accelerating sections, using travelling waves, are large band structures, can only be tuned with the beam on. In fact, we can then measure the phase shift induced by the frequency variation on the energy spread.

In the future, we intend to move the pre-bunching cavity cooling from the accelerating structures cooling to the buncher cooling.

The changes made in 2008 and 2015 allow us to upgrade the ESRF linac that was initially designed for the production of positrons with a higher gun current.

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