# COMMISSIONING OF THE 100 MEV PREINJECTOR FOR THE ALBA SYNCHROTRON

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*Abstract*

A turn key 100 MeV linac was provided by THALES Communications in order to inject electrons into the booster synchrotron of ALBA [1]. The linac was commissioned in October 2008. This paper reminds the main features of the linac [2] and gives results obtained during the commissioning tests. The energy and emittance measurements have been done on the transfer line designed and installed by CELLS. Specified and measured beam parameters will be compared.

## INTRODUCTION

ALBA, the new Spanish SR facility, has had the 100 MeV pre-injector installed and tested. The operational specifications of the linac are to be found in ref. [3]. The pre-injector is designed to work according to two operation modes: a Single Bunch Mode (8 pulses of 1 ns - 2.0 nC total), and a Multi Bunch Mode (40 to 1000 ns - 4 nC). For the two injection modes, the energy, energy spread, current, charge and emittance have been measured.

Table 1 gives a summary of the commissioning measurements. Final acceptance took place on the 17th of October 2008.

## SHORT DESCRIPTION OF THE LINAC

The low energy part of the pre-injector is made up of a 90 kV triode gun, followed by a 500 MHz sub harmonic prebuncher, a 3 GHz prebuncher and a standing wave bunching section. Four short shielded magnetic lenses ensure the focusing between the gun and the buncher.

Fig. 1 shows the two prebunching cavities with the shielded lenses.

Two 3.2 m long, $2\pi/3$ travelling wave accelerating structures increase the energy of the beam from 15 MeV at the exit of the buncher up to 100 MeV. The structures are used without external focusing, except for a triplet between them and a Glazer lens after the buncher.

The whole machine is powered by two 80 MW modulators that drive two 35 MW TH2100 klystrons. The RF output of the first klystron is split into two waveguides: the first one feeds the first accelerating section, the other one feeds the bunching components.

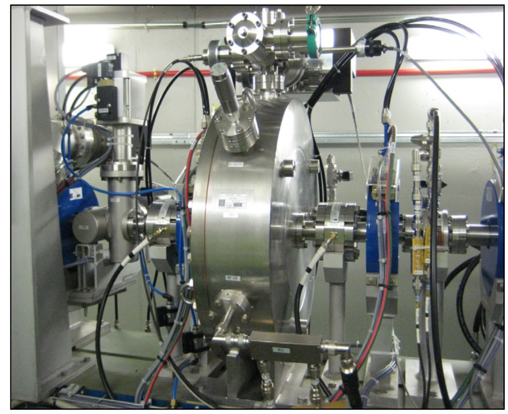

Figure 1: Prebunching cavities and shielded lenses.

## MEASUREMENTS

### *Diagnostics*

Six FCT (Fast Current Transformers), one beam charge monitor and three fluorescent screens are available along the linac.

The main linac parameters, energy, energy spread, charge and transverse emittance were measured using the diagnostics available along the transfer line between the linac and the booster ring.

The main components of this line were one FCT, two FS/OTR monitors, two BPM, one beam charge monitor, an energy analysing slit, a bending magnet, a Faraday cup and an emittance monitor at the end of the straight branch.

### *Beam Optimisation Method*

The first beam on the 2nd of July 2008 was carried out without feeding the 500 MHz prebuncher. Then the sub harmonic cavity was characterized and the beam compression was checked [2]. The optimisation process was first carried out without feeding the second section. A small charge beam (112 ns – 0.55 nC), was emitted in order to minimize the beam loading effect. At the linac exit the measured energy beam was 70 MeV.

First stage: 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

Table 1: Commissioning Measurements in Single and Multi-Bunch Modes

| | **MBM** | | **SBM 8 pulses** | |
|---|---|---|---|---|
| | **Specified** | **Measured** | **Specified** | **Measured** |
| **Pulse length (ns)** | 40 to 1000 | 112 | 1 (FWHM) | 0.4 |
| **Charge (nC)** | ≥ 3 | 4 | ≥ 1.5 | 2 |
| **Energy (MeV)** | ≥ 100 | 107 | ≥ 100 | 107 |
| **Pulse to pulse energy variation** | ≤ 0.25% | 0.06% | ≤ 0.25% | 0.08% |
| **Relative energy spread (rms)** | ≤ 0.5% | 0.23% | ≤ 0.5% | 0.28% |
| **Norm. Emittance 1σ mm mrad** | ≤ 30 | < 25 | ≤ 30 | < 25 |
| **Pulse to pulse time jitter (rms)** | ≤ 100 ps | 25 ps | ≤ 100 ps | 25 ps |

with a precision of 1 degree at 3 GHz, i.e. a precision smaller than 1 picosecond.

Second stage: 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 14 degrees between beam and RF field along the whole first structure, i.e. a mean value of 7 degrees. In fact, with this method a 6 degrees phase shift was measured for a 1 degree temperature change of the cooling water.

The first stage gave, at the first section exit, a beam phase extension equal to 18 degrees i.e. 17 ps. The beam phase extension at the linac exit was estimated to around 14 degrees i.e. 13 ps. The accelerating structures met the calculated values, 52 MeV for 18 MW.

The energy gain of the buncher was equal to 15 MeV with an input power of 5.5 MW and the first section gave 55 MeV for 20 MW. An input power of 9 MW in the second section, gave a 107 MeV beam at the linac exit.

### *Prebunching Cavities*

Measurements of the beam at 70 MeV was made with and without the prebunching cavities for the Multi Bunch Mode. The measured values met the simulated ones. The results are summarized in table 2.

Table 2: Simulations and Measurements (%)

| | Buncher exit | | AS1 exit | |
|---|---|---|---|---|
| Beam mode | Simul. | Meas. | Simul. | Meas. |
| 0.5 & 3 GHz | 98 | 96 | 68 | 66 |
| 3 GHz | 84 | 83 | 67 | 58* |
| 0.5 GHz | 77-87** | 80 | 47 | 47 |
| No cavities | 59*** | 64 | - | 37 |

* Measurement was done without the phase adjustment of the 3 GHZ prebuncher.

** Simulations show oscillations of some electrons being apart from the main bunch. The main bunch and the first satellite contain 77% and 5% of the gun current.

*** Simulation has been done without space charge and without magnetic field.

The 500 MHz prebunching cavity allows for only one pulse at 3 GHz, instead of three, from the 1 ns pulse. The energy spread is then reduced. Table 3 gives the summarized results at 70 MeV.

Table 3: Charge and Energy Spread Measurements

| | BCM1(nC) | ΔE/E% |
|---|---|---|
| Without cavities | 0.25 | 0.6 |
| 500 MHz | 0.30 | 0.6 |
| 3 GHz | 0.45 | **0.9** |
| 500 MHz & 3 GHz | 0.55 | 0.6 |

### *Current Transmission*

Fig. 2 shows the FCT signals for the MBM mode at the gun exit, the 500 MHz cavity exit, the 3 GHz cavity exit and at the buncher exit. The commissioning has been done with two pulses lengths: 112 ns and 240 ns (shown here).

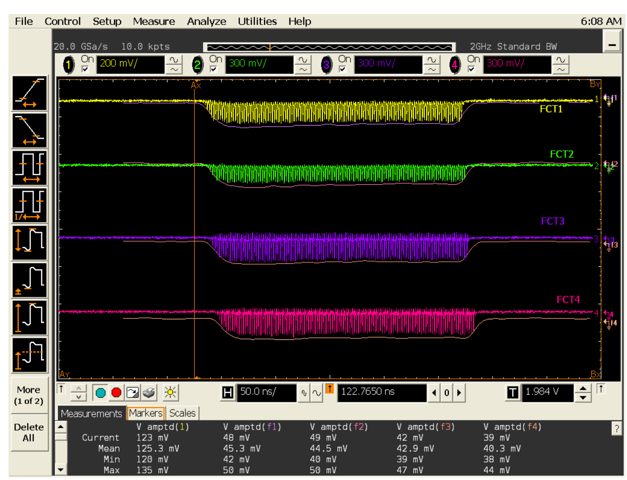


Figure 2: FCT signals for the MBM mode.

Fig. 3 shows the FCT signals for the 8 pulses of the SBM mode. The delay between 2 pulses was set to 50 ns.

No enlargement of the energy spread was observed when switching from 1 to 8 pulses. The enlargement is observed only for a 6 ns interval between pulses. This interval is the minimum travelling time for the RF from cavity n to cavity (n+1) at the beginning of the accelerating structure (18 ns at the exit of the structure).


Figure 3: FCT signals for the SBM mode.

### *Beam Loading Compensation and Energy Spread*

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 proper conditions of power, charge and pulse length, the beam loading effect can be considerably reduced.

The energy spread measurement was performed using the bending magnet together with the two charge monitors. The analysing slit was set at 0.4% resolution.

Fig. 4 show the energy spread without and with beam loading compensation, for a charge of 4 nC.

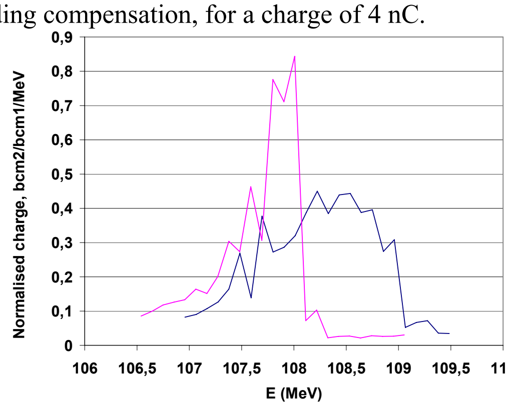


Figure 4: Energy spread for both cases.

The FWHM energy spread has been reduced from 1.55 MeV to 0.5 MeV, i.e. divided by 3.

### *Emittance*

A detailed description can be found in ref. [4]. The emittance measurements were performed by varying the strength of a quadrupole and measuring the resulting variation of the beam size at a downstream Cerium doped YAG screen or with an OTR screen.

The distance between the scanned quadrupole and the screen monitor is only 1.2 m. Nevertheless the emittance and the associated beam parameters were obtained with a good fit.

Fig. 5 shows a horizontal emittance measurement for a 112 ns Multi Bunch pulse. The measurements indicate an emittance below 20 mm.mrad.

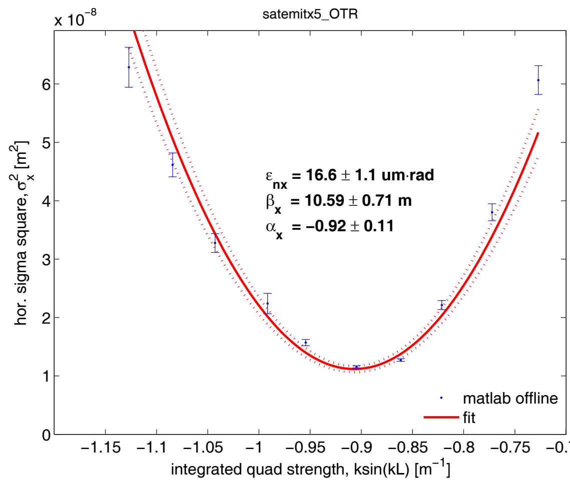


Figure 5: MBM horizontal emittance measurement.

## CONCLUSION

The ALBA pre-injector was successfully installed and commissioned during the past year. The measured linac parameters fitted well with the beam dynamic simulations.

Emittance growth was kept moderate, despite the strong beam compression achieved with the two prebunching cavities at energy around 90 keV. This was obtained by a careful design of the gun, avoiding over-focusing the outcoming beam, and by a fine adjustment of the magnetic field between the gun and the buncher.

The expected low energy spread was achieved, thanks to the small phase extension at the buncher exit and to the use of the beam loading compensation.

The measured energy spread and emittance bettered the specified values and even better results are expected as a result of further optimisation.

## REFERENCES

[1] D. Einfeld, "Progress of ALBA", EPAC08, Genoa, Italy, June 2008.

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[4] U. Iriso, G. Benedetti, A. Olmos, "Beam measurements at the ALBA linac", this conference.