OPERATION OF THE ALBA INJECTOR

M.Pont, U.Iriso, R.Muñoz and F.Perez, CELLS-ALBA, Cerdanyola del Vallès, Spain

Abstract

The ALBA injector consists of a 100 MeV linac and a full energy (3 GeV) booster synchrotron and has been in operation since October 2010. The reliability and performance of the linac and booster are examined. Beam measurement results using the installed diagnostic equipment are discussed.

THE ALBA INJECTOR

Linac

The ALBA pre-injector is a 100 MeV linac operating in single as well as in multi-bunch mode. The maximum charge provided in both modes is 4 nC. The bunch train delivered in multi-bunch mode has a length up to 1000 ns. The linac consists of a thermoionic gun, a three stages bunching system and two identical accelerating structures of the S-band type. The linac is driven by two TH2100 pulsed klystrons. The maximum energy reachable at the linac exit is 125 MeV and it is routinely operated at 110 MeV.

The installation and commissioning took place in 2008 and the specifications were exceeded in both single, and multi-bunch modes [1].

Booster

The ALBA booster lattice has a four-fold symmetry with a circumference of 249.6 m consisting of 4 arcs with 4 straight sections of 2.6 m each [2]. The arc structure is made of 8 FODO cells, each with a defocusing gradient bending magnet and a focusing quadrupole. The electron beam is injected at 110 MeV and extracted at 3.0 GeV. The RF power is provided by a five cell Petra-type cavity driven by a 500 MHz, 80 kW IOT [3] also used in the storage ring.

The installation of the Booster was completed in autumn 2009 and the commissioning took place early in 2010 [4]. Table 1 summarises the main parameters of the injector.

Transfer Lines and Pulsed Elements

Transfer lines from the linac to the booster (LT) and from the booster to the storage ring (BT) are 15.85 and 26.00 m long, respectively.

Injection into the booster is done with a single septum and a single kicker for on-axis injection, and a kicker and a septum for extraction. Injection into the storage ring is done with four identical kicker magnets and one septum which are all installed in a straight which has 7.28 m of available space for the injection.

Table 1: Main Parameters of the ALBA Injector

LINAC		
Linac exit energy	110	MeV
Relative energy spread (rms)	0.30%	
Norm. Emittance, both planes	15	mm·mrad
Energy variation pulse to pulse	0.20%	
Jitter	30	ps
BOOSTER		
Injection energy	110	MeV
Extraction energy	3.0	GeV
Circumference	249.6	m
Emittance at injection	150	nm·rad
Emittance at 3 GeV	9	nm·rad
Energy spread at injection (rms)	0.50%	
Energy spread at 3 GeV (rms)	0.10%	
Betatron tunes, Q_x / Q_y	12.42 / 7.38	
Maximum betas β_x / β_y	11.2 / 11.7	m
Maximum dispersion, D_x	0.47	m
RF frequency	500	MHz
Maximum repetition rate	3.125	Hz

LINAC OPERATION

Linac Operation

The operation of the linac has been intermittent since its installation in 2008 until autumn 2010. Afterwards the linac has been in continuous operation. It has been observed that continuous operation periods of the klystrons and of the linac improve the beam parameters stability. In addition, hardware failures are reduced.

A drift of several linac parameters has been observed when starting the system after a shut down period. A warming-up time of about 36 h is required for all linac parameters to be stable inside specifications.

A major repair to the linac was done in spring 2010 when the first accelerating structure was dismantled in order to fix a vacuum leak. After this intervention the vacuum in this accelerating structure is now better than $1\cdot10^{-8}$ mbar. However, the beam transmission between the end of the linac and the end of the LT has been affected by this procedure, decreasing from 100% to 75%. Studies are ongoing to increase the transmission.

Linac Beam Stability

From end of September to end of October 2010 the linac beam settings have been kept constant, favouring comparative studies of linac beam stability. During this operation period the linac delivered a multi-bunch beam of 112 ns length with a repetition rate of 1 Hz. The energy of the beam was 110 MeV and the total charge was either 1.0 or 2.0 nC. The energy variation within this month was of 0.16 % rms. The energy spread measurements gave results always below 0.3 %.

Measurements of the Twiss parameters at linac exit in x and y-directions (α-parameter, β-function and emittance) are all within specifications. Their values and long term stability are shown in Fig. 1. The variation of Twiss parameters was about 35% in x-direction and 25% in y-direction. The measured emittances show a correlation with the charge at the linac end.

The large variations measured of the linac beam parameters were correlated to air temperature fluctuations inside the linac bunker. Temperature fluctuations on the linac bunker of 0.7ºC p-p brought charge oscillations of 0.15 nC and large changes on the Twiss parameters, see Figure 2. Stabilising the temperature down to 0.2ºC p-p has removed the charge oscillations and reduced the variation in the Twiss parameters.

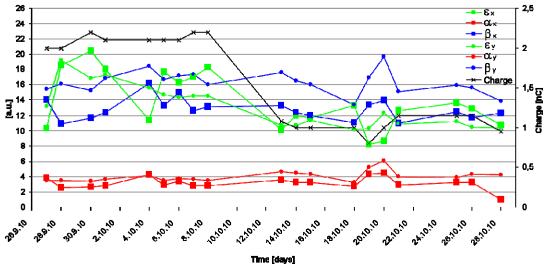

Figure 1: Twiss parameters evolution during 1 month. In red the α-parameters are shown, in blue the β-functions, in green the calculated emittances. The curve in black indicates the total beam charge at the linac exit.

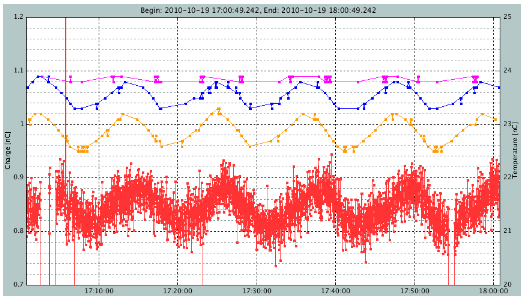

Figure 2: Linac beam charge variations (in red) are correlated to linac bunker temperature oscillations (curves in blue and orange).

BOOSTER OPERATION

Commissioning of the booster took place for two weeks in January 2010 and then for eight weeks in autumn of 2010. In between the installation of the storage ring has been completed since both the booster and the storage ring at ALBA share the same tunnel. In 2011 the booster has already been running in a routine way as injector for the storage ring commissioning. Routine operation uses a multi-bunch beam of 1-2 nC in a 56-112 ns pulse with a repetition rate of 1 Hz.

Single bunch operation has been successfully tried. Differences between single bunch and multi-bunch configurations are largely confined to the linac, taking less than 1 min to switch from one mode to the other.

Trials at the nominal repetition rate of 3.125 Hz have also been successfully carried out. In fact, the booster main power supplies are always running at 3.125 Hz, while the linac, and the pulsed elements can run either at 1 Hz or at 3.125 Hz.

Injection efficiencies are around 50-60% from linac exit to booster injection, and approach 100% from booster to storage ring. There are no losses during energy ramping. The losses at 110 MeV can be attributed to the linac dynamics and to the first turns in the booster. Studies are ongoing to increase this injection efficiency.

Tune during Ramping

The first attempts of ramping were performed with pure sinusoidal curves. Although it was feasible to reach 3 GeV with only pure sinusoidal curves, because of the gradient on the bending magnets and the remanent fields the tunes were doing large excursions. The waveform of the horizontal quadrupole family QH02 and the vertical quadrupole family QV02 were modified until the tunes were kept within ±0.05. Changes were only required at low energies.

Even with the tunes within ±0.05 there is still a strange behaviour at low energy, below 500 MeV (approx. 30 ms). Nevertheless since no current losses are observed during the ramping, see Figure 3, no further effort has been put to reduce this tune variation.

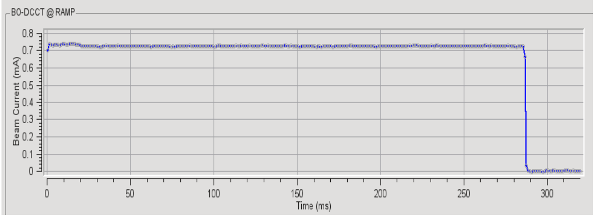

Figure 3: Booster current during ramping up to 3 GeV and back to 110 MeV, horizontal axes shows the time measured in ms and the vertical axes corresponds to the BO current measured in mA.

A good correlation between the measured tunes and the calculated from the output of the power supplies has been found. The present measurement system for the power supplies uses a DAQ-2016 from Adlink 16 bit card with oversampling and filtering. A new card (NI-6820) with 18 bits resolution has been purchased in order to increase the accuracy of the measurements at low currents. The new measurement system is presently under testing.

Figure 4 compares the measured tunes with the calculated ones. The differences found below 40 ms between the measured and the calculated tunes can be attributed to the effect of the remanent fields at these low currents. The noise in the red curve is due to the measurement system for the power supplies.

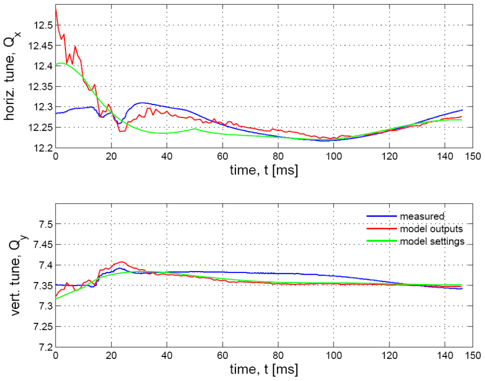

Figure 4: Tune during ramping, blue is the measured tune, green is the calculated tune from the settings sent to the power supplies and red is the calculated tune from the measured output of the power supplies.

Emittance and Beam Size during Ramping

Beam size measurements during ramping are taken using a Synchrotron Radiation Monitor (SRM) [5]. The CCD trigger is changed at every shot to measure the beam size at different times during ramping. The CCD exposure time ranges from 2 ms (to get enough photon flux at injection) to 100 µs (to avoid CCD saturation at extraction).

Horizontal beam size in the booster during ramping decreases during the initial part of the acceleration due to adiabatic and radiation damping, until the influence of the quantum excitation increases the emittance.

Figure 5 shows that the horizontal beam size measurement agrees very well with the theoretical beam size evolution. Both the measured and the theoretical horizontal beam size have a minimum at about 85 ms, when the theoretical horizontal emittance has a minimum. The agreement is not so good in the vertical plane. In absence of quantum excitation, the vertical beam size should decrease during the whole ramp until it gets to a stable value given by the coupling. The measured vertical beam size shows an increase at the end of the ramp (in the last 5 ms or so) which is not yet fully understood and might be due to coupling or spurious vertical dispersion. The theoretical beam size includes the evolution of both emittance and energy spread along the ramp.

The measured emittances at the end of the ramp are (ε_x, ε_y) = (9.9, 7.5) nm·rad. While the horizontal value compares rather well with the design value of 9 nm·rad, the vertical one is larger than expected and it is being presently investigated [6].

A horizontal emittance at full energy of 13.8 nm·rad has been determined using an OTR screen located at the BT transfer line.

Figure 6 compares the image at different times during the energy ramp taken with the SRM (with black background), compared with the image at 3 GeV taken at the BT.

CONCLUSIONS

The ALBA injector has fulfilled the specifications and is routinely running as injector for the ALBA storage ring. Sources of injector instabilities are being identified and corrected, and trials have started for the different modes of operation.

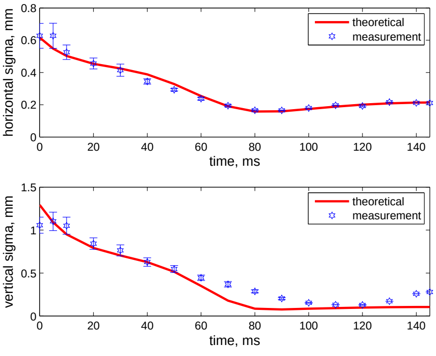

Figure 5: Beam size evolution during ramping. The dots indicate the measurements, the error bar is the rms variation. The solid lines show the expected evolution of the beam sizes.

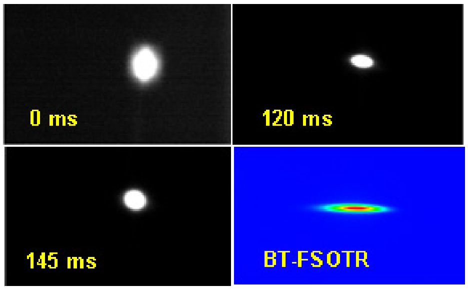

Figure 6: Beam image snapshots during ramp using the Booster SRM (with black background), and beam image at Booster to Storage transfer line (blue background).

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