ACDIV-2016-14
September 2016

Status and Operation of the ALBA Linac

R. Muñoz Horta, D. Lanaia, F. Pérez

Abstract

The pre-injector of the ALBA light source is a linac that delivers electrons up to a maximum energy of 125 MeV. It consists of a pre-bunching, a bunching and two accelerating sections feed by two 35 MW klystrons. Since July 2014 ALBA is operating in top-up mode, and the linac is delivering 110 MeV electrons in multibunch mode every 20 minutes. Recently, new injection modes have been implemented and successfully tested. For one side, injection into the ALBA booster is now also available with only one of the two klystrons in operation, and the linac delivering a 67 MeV beam. On the other hand, the linac single bunch mode has been integrated to the top-up operation application. By means of an algorithm, single bunch mode operation provides any kind of filling pattern in the ALBA storage ring, with single bunch shots injected to those buckets with lowest current. The performance of the linac beam operated in these different modes is reported.

Accelerator Division
Alba Synchrotron Light Source
c/ de la Llum, 2-26
08290 Cerdanyola del Valles, Spain

STATUS AND OPERATION OF THE ALBA LINAC

R. Muñoz Horta, D. Lanaia, F. Pérez, ALBA Synchrotron, Cerdanyola del Vallès, Spain

Abstract

The pre-injector of the ALBA light source is a linac that delivers electrons up to a maximum energy of 125 MeV. It consists of a pre-bunching, a bunching and two accelerating sections feed by two 35 MW klystrons. Since July 2014 ALBA is operating in top-up mode, and the linac is delivering 110 MeV electrons in multibunch mode every 20 minutes. Recently, new injection modes have been implemented and successfully tested. For one side, injection into the ALBA booster is now also available with only one of the two klystrons in operation, and the linac delivering a 67 MeV beam. On the other hand, the linac single bunch mode has been integrated to the top-up operation application. By means of an algorithm, single bunch mode operation provides any kind of filling pattern in the ALBA storage ring, with single bunch shots injected to those buckets with lowest current. The performance of the linac beam operated in these different modes is reported.

INTRODUCTION

The ALBA Synchrotron is a 3 GeV light source in operation for users since May 2012 [1]. Its injector consists of a linac, shown in Fig. 1, typically set at 110 MeV and a full energy booster working at a repetition rate of 3.125 Hz. The injector runs in top-up mode, which requires a high level of operational reliability. For this reason, the ALBA injector has been provided of the 67 MeV injection mode, with which the injection to the storage ring is possible also when the linac is running with only one of its two klystrons. In addition, recent hardware and software upgrades have allowed the ALBA injector to have an accurate control of the amount and of the position of the electrons injected into the storage ring. The new injection capabilities enlarge the scope of research opportunities at ALBA, such as the performance of time-resolved experiments.

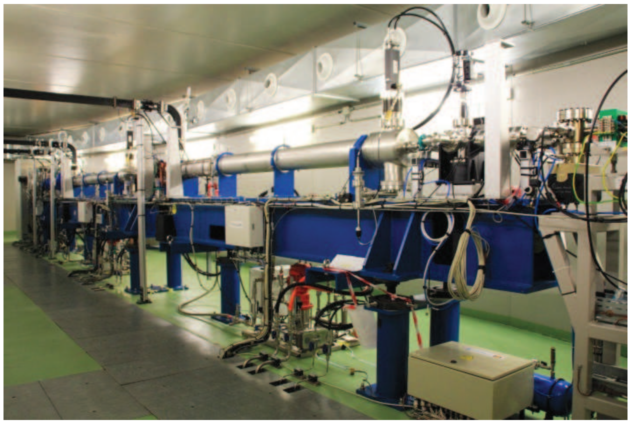

Figure 1: The ALBA linac.

ELECTRON PULSE GENERATION

The beam at the ALBA linac [2] is generated at 90 keV by a thermionic gun. A grid modulates the beam at 500 MHz, creating bunches of 1 ns length which can be extracted in multi or in single bunch modes, see Fig. 2. In multibunch (MBM), trains of bunches separated by 2 ns are produced. In single bunch (SBM), one or several single bunches can be generated separated by an adjustable time interval. The pattern of bunches delivered by the gun can have a maximum length of 400 ns, which is the width of the pulse from the kicker magnet used to inject the beam into the booster.

The maximum charge per single bunch achievable at linac exit is 0.25 nC while minimum measurable charges are in the range of few pC.

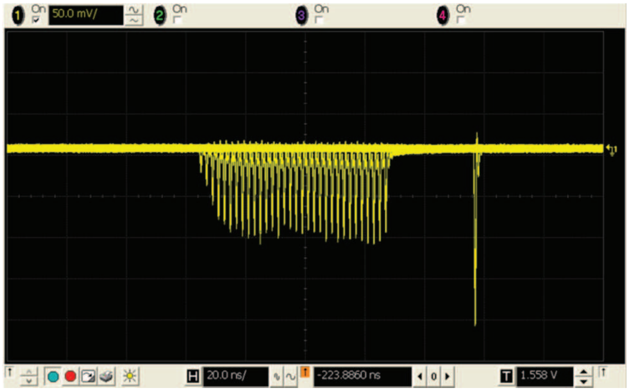

Figure 2: Tain of 32 bunches and one single bunch at FCT right after the electron gun, taken in a two-stage measurement.

After being generated, the electron pulses enter a three stage bunching system consisting of a sub-harmonic prebuncher cavity resonant at 500 MHz (PB1), a 3GHz prebuncher (PB2) and a 22-cell standing wave buncher (BU). At the buncher exit the energy of the beam is of 16 MeV and the bunch length has been reduced by 80%. Two identical travelling wave constant gradient accelerating sections (AS1 and AS2) increase further the energy up to a maximum of 125 MeV. Under normal conditions klystron 1 feeds the bunching section and also the first accelerating structure. Klystron 2 feeds exclusively the second accelerating structure.

LINAC OPERATION

During the first two years of top-up operation the linac performance has been reliable, delivering a stable beam. No failure of the linac system has interrupted the service to users. Most hardware problems use to arise after switching the subsystems off and on. Up to now, the failures that needed a longer reparation time have been related with the electron gun electronics. Besides, fluctuations of the vacuum and instabilities of the high voltage applied

ISBN 978-3-95450-169-4

to the cathode occasionally produce a big change of the electron beam divergence at the emission point, which requires a major adjustment of the linac optics. On the other hand, a hardware upgrade applied on the cooling system has improved the flow stability and has reduced the amount of minor faults due to this subsystem [3].

In top-up mode, the linac deliver trains of 32 bunches of 110 MeV and 0.25 nC of charge at linac exit. The beam is optimized at the start of a run and revised every week. Under normal conditions, the initial settings use to hold good several weeks with minor changes.

Small day-to-day thermal variations are observed on the linac beam energy and shape. They use to be correlated with variations in the amplitude of the 500MHz RF-signal that feeds PB1 and that are delivered by a 800W solid state amplifier, see Fig. 3. These changes are small and are not a problem for injecting into the booster, which has an energy acceptance bigger than 1%.

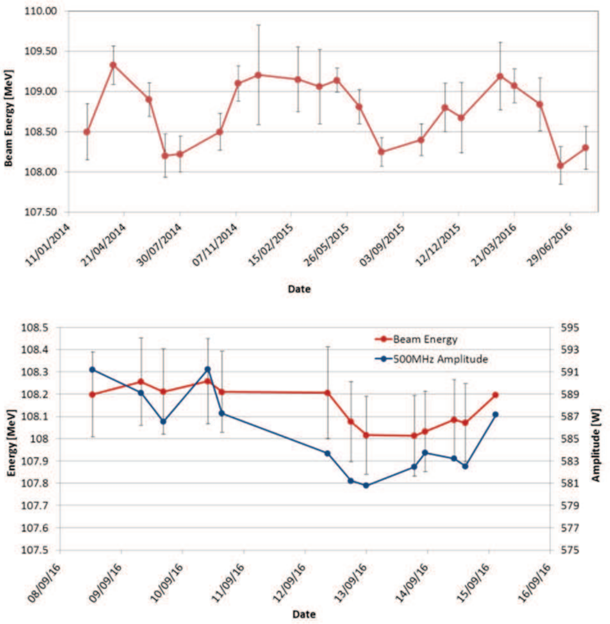

Figure 3: Thermal effects are observed on the linac beam energy. Above: long term temperature variations. Below: day-to-day variations, correlated with the 500MHz amplitude that feeds PB1. Both thermal effects do not affect the injection to booster.

The evolution of the beam energy along the past two years is shown in Fig. 3. Over one year, while keeping the RF power constant, the beam energy varies between 108 and 109.5 MeV. Although these measurements were not taken under identical conditions, one can observe that the beam energy tends to be lower in summer periods. The reason for that are the effects of the seasonal temperature variations on the ALBA building.

The charge transmission at the end of the linac to booster transfer line (LTB) is around 80%. From linac to booster the maximum transmission achieved is 60%. To optimize the beam transmission, the beam is first aligned through the linac and LTB using the beam based alignment technique. Then the linac optics is adjusted to keep the beam divergence at linac exit as low as possible, which helps in having a better matching into LTB.

INJECTION MODES

67 MeV with Single Klystron Working Mode

In 2014 a S-band switching system was installed in the linac waveguide in order to be able to use any of the two klystrons to power the bunching part and the first accelerating section [4]. Using the linac in single klystron working mode, the second accelerating section is not powered. Then the linac delivers typically a 67 MeV beam, which is the energy achieved when using only klystron 1 at nominal power. Measured parameters of the 67 MeV beam are shown in Table 1.

Table 1: Parameters of the Linac Beam at 110 MeV and 67 MeV for MBM and SBM Modes.

	110/MBM	110/SBM	67/MBM
σ_E/E (%)	0.13	0.2	0.14
$\varepsilon_{n,x}$ (µm.rad)	7.4	17.6	8
α_x	0	1.2	0.2
β_x (m)	1.25	3.3	1.63
$\varepsilon_{n,y}$ (µm.rad)	10.9	17	12.2
α_y	0.1	1.1	-0.5
β_y (m)	7.4	3.2	10.5

To achieve the capture of the 67 MeV beam into the booster and its subsequent ramp to 3 GeV has not been straightforward [5]. The simple scaling of the booster magnet settings did not work because at low energies remnant magnetic fields have a big effect on the dipole fields. To overcome it, extra magnetic calibrations and corrections on the magnet waveforms were needed.

The 67 MeV mode of the ALBA injector it is used when one of the two klystrons fails. To switch the injector from the nominal 110 MeV mode to the reduced energy mode typically it takes less than 2 hours. For the linac it implies tuning the klystron power and some of the RF-phases to minimize the energy spread at 67 MeV. On the other hand, since AS2 cavity is off, the beam alignment at the end of the linac has to be adjusted. When using only klystron 2 timing adjustments are also required. The 67 MeV mode is being set shortly after every long shut-down in order to test it and have it available in case it is needed.

The Top-Up Mode

The 500 MHz RF frequency applied in the storage ring cavities divides the ring in 448 buckets, each of 2 ns. The present storage ring filling pattern consists of 10 trains of 32 bunches separated by 12 empty buckets, excepting one spacing that is of 20 buckets. In multibunch mode, the reinjections typically last about 10 seconds and are performed every 20 minutes.

In the present top-up application, which links the injector subsystems with the timing generator, one shot is injected to a determined bucket by controlling the delay that triggers the electron gun. Up to now, this delay had a resolution of 8ns, which therefore, restricted the types of filling patterns working in top-up mode, as for instance the use of a hybrid filling pattern.

Single Bunch Bucket Selection

Top-up injections are also possible using the linac in single bunch mode. However, to be able to inject into two consecutive buckets the control of the timing has been improved. In the new version, the resolution of the delay that triggers the shots has been increased up to 10 ps. In this way, one can select any of the 4 buckets within the 8 ns time slots, and therefore, inject into any bucket.

The upgraded top-up application includes a new mode of injection, the so-called Single Bunch Bucket Selection mode (SBBS). This mode allows controlling independently the amount of current injected at any of the 448 buckets with the aim of keeping a uniform distribution of the filling pattern. For that, the top-up application gets regularly on-line information about the amount of current stored in each bucket of the ring, which is provided by a Time Correlated Single Photon Counting (TCSPC) or a Fast Current Transformer (FCT). An algorithm compares the existing current in each bucket with the one of the defined pattern, decides which buckets will be refilled first and then performs the injections. This process is repeated after injecting few shots and until either the storage ring target current or the number of cycles done reaches a previously defined limit.

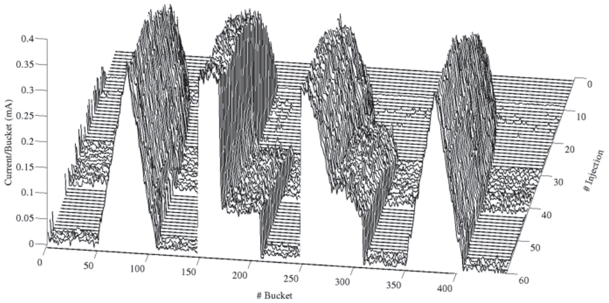

Figure 4: Storage ring filling pattern were ALBA has been written using the SBBS mode.

The SBBS mode has been successfully tested. One proof that any filling pattern can be created is shown in Fig. 4 where the name of ALBA has been written in the Storage Ring. On the other hand, Fig. 5 shows one filling pattern first filled with multibunch shots (it is faster than using SBBS) and later refilled in top-up mode using SBBS. After several injections the distribution of the current within buckets has become uniform and kept constant over time. The distribution uniformity of the charge among the buckets increases when decreasing the charge per shot. However, one has to find a compromise between the charge per shot and the injection speed. At present the time needed to refill the storage ring using one single bunch per shot is about 10 times longer than the time needed using the 32-bunched trains.

To make the SBBS application more robust, further developments will be implemented in the near future, like being able to adjust the linac charge from the algorithm and having the possibility to inject more than one single bunch at the time.

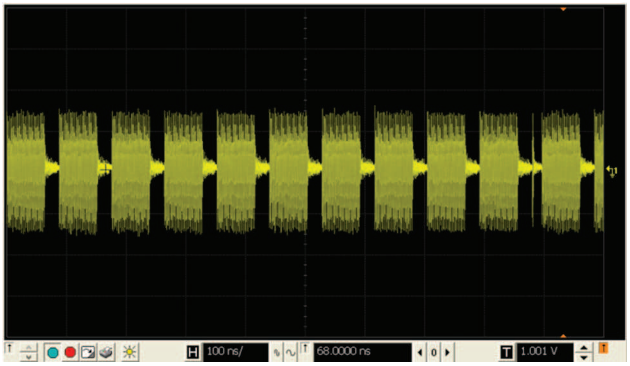

Figure 5: Hybrid mode consisting of 10 trains and one single bunch after some hours of top-up refilling using the SBBS mode.

CONCLUSIONS

In the first two years of top-up operation the ALBA linac has provided a good performance and has delivered a stable beam. New modes of operation have been implemented in order to offer a more robust and versatile service to users. For one side, the single klystron working mode allows injecting to booster from a 67 MeV linac beam. This mode is used when one of the two klystrons fails. On the other side, the Single Bunch Bucket Selection mode allows controlling the amount and position of the electrons injected in the storage ring. The SBBS mode has been successfully tested in the new top-up operation application, which is still under development.

ACKNOWLEDGEMENTS

The upgraded top-up operation application is being developed in collaboration with M.Pont, L.Torino, G.Benedetti and J.Moldes.

REFERENCES

[1] F. Pérez, “1st Year operation of the ALBA Synchrotron Light Source”, in *Proc. IPAC’13*, Shangai, China, 2013.
[2] A.S. Setty *et al.*, “Commissioning of the 100 MeV Preinjector for the ALBA Synchrotron”, in *Proc. PAC’09*, Vancouver, Canada, 2009.
[3] M. Ferrater *et al.*, “Experimental and numerical study of the ALBA linac cooling system”, in *Proc. MEDSI’16*, Barcelona, Spain, 2016.
[4] R. Muñoz Horta *et al.*, “Implementation of Single Klystron Working mode at the ALBA Linac”, in *Proc IPAC’14*, Dresden, Germany, 2014.
[5] G. Benedetti *et al.*, “Commissioning of the ALBA Injector with 67 MeV Single Klystron Linac”, in *Proc. IPAC’16*, Busan, Korea, 2016.