ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB134

LINAC-TO-BOOSTER OPTIMIZATION PROCEDURE TOWARDS HIGH TRANSMISSION FOR THE ALBA INJECTOR

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Abstract

ALBA is a third generation synchrotron light source that consists of 3 accelerators (Linac, Booster and Storage ring) and two transfer lines, Linac-to-Booster (LTB) and Booster-to-Storage (BTS). The ALBA accelerators team has defined a robust procedure that optimizes the beam performance from Linac to Booster in terms of transmission and stability. The implemented beam-based alignment and global orbit correction techniques have been investigated first in simulations and afterwards successfully implemented in the machine.

INTRODUCTION

The ALBA injector consists of a 100 MeV Linac and a full energy Booster. Both accelerators are connected by the Linac-to-Booster transfer line. On-axis injection into the Booster is procured from a single Septum and a single Kicker magnets. In the past years, simulations and experimental efforts have been deployed to maximize the beam transmission from the electron gun up to the Booster entrance. The first studies were focused in optimizing the transmission throughout the Linac regardless of the operation mode [1], but despite the improvements, the effective transmission from the Linac exit up to the Booster entrance was still below 40%. Since higher beam transmission should be plausible, the causes of the poor transmission have been investigated. This paper presents the outcome of these studies and the resulting new optimization procedure, which is currently in use during ALBA operation.

THE ALBA INJECTOR

A lay-out with the main elements of the injector is depicted in Fig. 1. A thermionic electron gun generates electron pulses at a repetition rate of 3 Hz, in these two possible modes [2]:

- Single Bunch Mode: 0.25 nC/bunch at linac exit.
- Multi Bunch Mode: trains of bunches with charge tunable from 0.001 to 0.2 nC/bunch.

At the Booster, the beam is accelerated from 100 MeV up to 3 GeV in 150 ms. Electrons take 832 ns to complete one Booster turn. Four quadrupole triplets define the beam optics: one placed between the two Linac Accelerating Sections (AS) and the other 3 distributed along the LTB.

The beam transmission along the injector (up to the Booster entrance) is extracted from a Beam Charge Monitor (BCM) placed at Linac exit, a BCM placed at the end of the LTB, and from the DC Current Transformer (DCCT) set at Booster ring, from which only the first 1000 turns are considered. Moreover, a series of Beam Position Monitors (BPMs) keep track of the beam orbit, which is adjusted with the horizontal and vertical corrector magnets placed along the beam trajectory.

Additional information regarding the specifications of the ALBA injector can be found at [3] and [4].

Table 1: Beam Transmission Values Before and After the Optimization Process

Transmission	Linac to LTB	LTB to Booster	Total
Before	75%	15-55%	10-40%
After	95%	65-85%	60-80%

MOTIVATION

At the start of this study, at LTB end, 25% of the bunch charge out of the Linac was intercepted, independently of the beam energy or charge. The injection from LTB to Booster had been unstable and maximum transmission levels were below 50%. Table 1 shows the Linac to Booster transmission levels before and after the optimization process, described below.

Along the time, several sources that could lower and/or make the Linac to Booster transmission unstable have been identified. Some of them are being monitored to correct them at the earliest possible, like for example, the stability of the Linac beam energy which is continuously measured at LTB-BPM2 by means of an energy-position calibration [5]. Another known instability source is the Septum pulse voltage which tends to suffer drifts in time and, so an on-line monitoring is being also implemented.

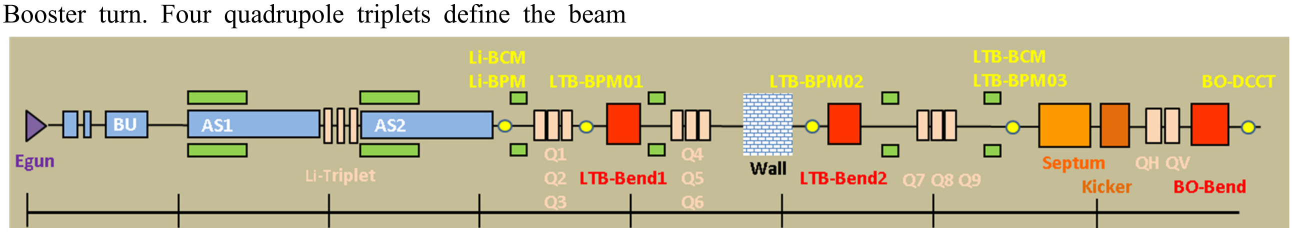

Figure 1: Schematics of the main elements involved in the optimization of the transmission at Linac, LTB and Booster. Notice the Linac cavities (blue), the quadrupoles (pink), the corrector magnets (green), the pulsed elements (orange) and the diagnostics elements (yellow).

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In addition to those, other possible sources of beam transmission instabilities have been investigated: poor orbit, large miss-alignments of the magnets and mismatched conditions among others.

OPTIMIZATION TOOLS

A set of algorithms have been used as *tools* aimed to increase the transmission from Linac to Booster to its maximum value in the shortest time possible. The tools are presented hereunder.

- Quad-BBA: to cure large miss-alignments through the quadrupole triplets. The Beam-Based Alignment (BBA) procedure [6] to align the beam through each triplet has been automatized by a script which automatically shunts the current of one of the quadrupoles of the triplet by 10% for 3 horizontal and vertical orbits. The algorithm extracts the displacement of the beam within the quadrupole and calculates the corrector value needed to bring the beam to the center of the magnet.
- 1-to-1 orbit correction: to cure large orbit excursions throughout the Linac and the LTB. This technique [7] computes the required strength of the h/v correctors that minimizes the h/v beam orbit throughout the beamline. To carry out the calculation the so-called R12 and R34 coefficients are measured in advance. This tool is ideal to keep the orbit inside global orbit tolerances during operation to reduce transmission instabilities produced by orbit displacements.
- Simplex: to seek for optimal injection matching conditions. The Simplex is an optimization algorithm based on the Nelder-Mead algorithm [8]. The figure of merit to be optimized is the transmission into Booster and the variables are the quadrupole magnets. But also other variables have been scanned, like correctors and Linac phases.

The use of the algorithms and their performance during the optimization process is discussed next.

OPTIMIZATION PROCEDURE

Energy Spread and Beam Bunching

As first optimization step, the Linac beam energy is verified to be the nominal, 109.0 MeV, and its energy spread to be minimized and below 0.25%. The dependence of Linac beam parameters on injector transmission was studied using Simplex. Some improvement was observed for the focusing coils values, but it did not converge to a good solution for RF-phases.

However, RF-phases have been found to have a big impact on beam transmission up to the end of the LTB. The Linac to LTB transmission has strongly improved (from 75% to 95%) when using a new Low Level RF signal generator. The new device broadens the RF-phase working range, which improves the longitudinal beam bunching. New RF-phases represents a Linac to Booster transmission improvement of 20%.

Beam Alignment

Exhaustive alignment measurements were performed in order to check the magnets alignment at the LTB using the beam. Firstly, the beam was adjusted by hand setting the correctors to force the orbit to pass within ± 2 mm at all BPMs, i.e., within the range where BPM readings are more linear. Afterwards, Quad-BBA is applied to every quadrupole of each triplet individually, to find the center of the quadrupole with the beam. When aligning a single quadrupole the other pair are switched off. A typical result of the alignment conducted automatically with Quad-BBA is shown in Fig. 2. All LTB triplets have been found to be aligned within 200 μm, which is in a good agreement with alignment tolerances.

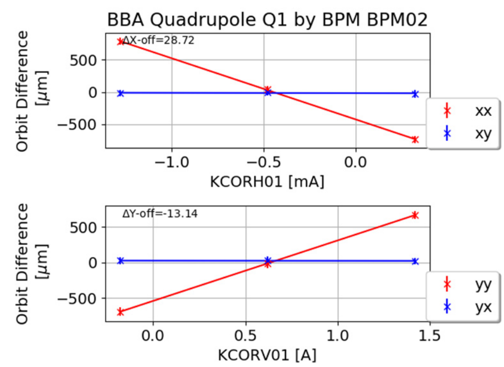

Figure 2: Horizontal (top) and vertical (bottom) magnetic center of quadrupole Q1 of the LTB. xx, xy lines in the top plot, refer to the x, y orbit variations when positioning the beam by the horizontal corrector. yx, yy lines in the bottom plot when changing the vertical corrector.

Once all the quadrupoles were found well aligned, beam alignment measurements along one triplet can be performed scanning only the first quadrupole of each triplet while keeping the rest switched on. Good beam alignment is considered for h/v shifts below 50 microns.

Matching

The beam matching at Booster entrance is obtained by finding the values of the quadrupoles by means of the tracking code MAD-X. The code uses the Twiss measurements at Linac exit and the theoretical Twiss parameters at Booster entrance. The code changes the strengths of the quadrupole magnets along the LTB until a satisfactory matching condition is achieved.

The simulated quadrupole values obtained need to be fine adjusted to further improve the transmission into Booster. This is probably due to calibration mismatches between simulated and real quadrupole currents and also due to uncertainties in the simulated Booster Twiss parameters. In the past, the fine tuning of the LTB quadrupoles was done by hand. To this end, the use of Simplex to fine scan the quadrupoles proved to be an alternative and faster way. The Simplex algorithm takes about 30 minutes to maximize the injection into Booster by optimizing 6 out of the 9 LTB quadrupoles, whose current is scanned by ± 0.2 Amps (10% of its nominal value).

Golden Orbit

The orbit of a well aligned and matched beam along the Linac and LTB is saved as the *golden orbit*. This orbit has been found to increase the Linac to Booster transmission in few percent. However, the golden orbit is not stable over time and its drifts have an impact on transmission. To compensate orbit shifts along the time, the 1-to-1 orbit correction is used during operation. An example of global beam-based alignment correction applied at LTB is shown in Fig. 3, where a transmission dependence on the orbit was measured.

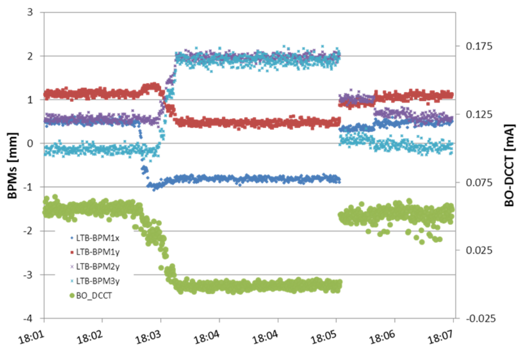

Figure 3: A forced beam misalignment at LTB reduces the beam current injected to Booster (in green). All the Beam Position Monitors (BPMs) readings are successfully brought to golden orbit when iterating over 3 corrections.

Long term beam position monitoring revealed that most orbit displacements at LTB are originated at the Linac stage. Orbit variation dependencies on Linac parameters were studied. It was found that beam position at Linac exit is very sensitive to RF-phases, RF-frequency and pulse charge, as shown in Fig. 4. Small variations of these parameters have a visible effect on beam orbit and, consequently, on transmission.

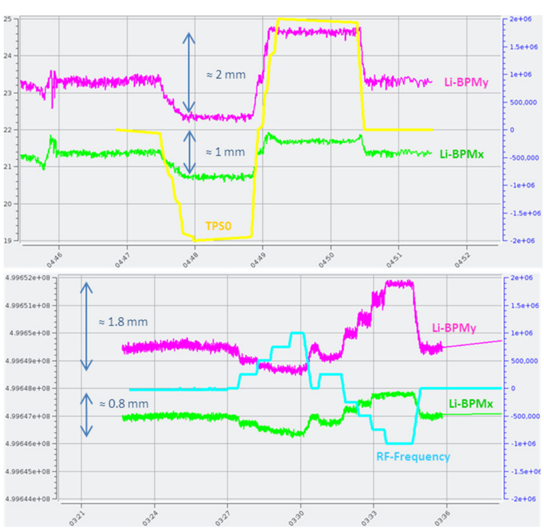

Figure 4: Beam position variations measured at Linac exit at Li-BPM. Above: when varying the 500 MHz pre-buncher phase (TPS0) by ± 3º. Below: when varying the Master Oscillator 500 MHz RF-frequency by ± 2 kHz.

Since most long term orbit drifts occur along the Linac, the 1-to-1 orbit correction algorithm is applied exclusively at Li-BPM and at LTB-BPM1 by adjusting AS1corr and AS2corr with the aim to fix the beam position and beam angle at Linac exit. During operation the so-called *Linac-golden-orbit* is corrected when position displacements higher than 0.5 mm are detected. Orbit stability at Linac exit along RUN2 is shown in Fig. 5.

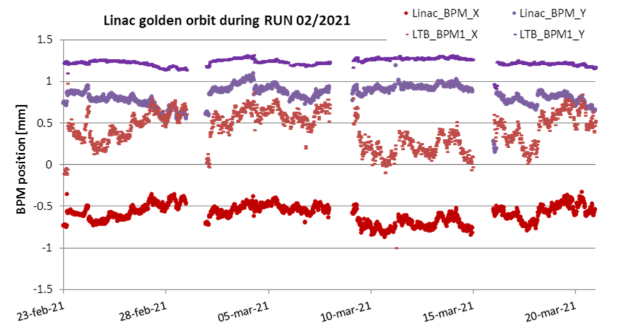

Figure 5: Linac-golden-orbit stability during RUN 2 shows a very good beam position stability. 1-to-1 orbit correction has been applied about twice per week. Orbit oscillations observed are caused by day-night temperature variations.

Injection Optimization

Throughout all the optimization process it is required to adjust, when needed, the Septum, the last LTB corrector as well as Booster magnet offsets. Ultimately, a crosscheck of the Linac beam energy with respect to the Booster energy acceptance window is performed, see Fig. 6.

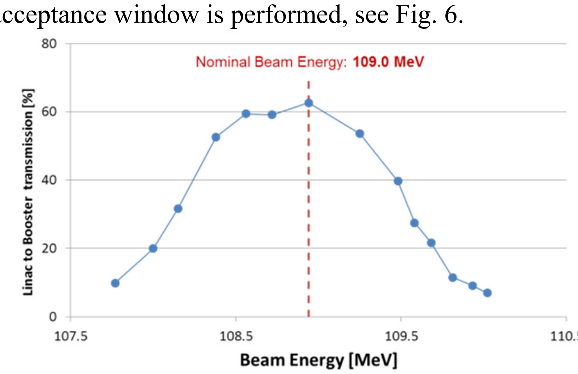

Figure 6: Booster energy acceptance window measurement. Nominal Linac beam energy centered on the window provides higher transmission stability over time.

SUMMARY AND CONCLUSIONS

By means of dedicated algorithms the level and the stability of the Linac to Booster transmission have been successfully improved. Transmission levels up to 90% have been achieved. Secure a good beam bunching at Linac has been found to be essential for the transmission to LTB. In addition, keeping the beam position and angle fixed at Linac exit is a key-point for an optimal and stable transmission of the ALBA injector.

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