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OPTIMIZATION OF THE ALBA LINAC OPERATION MODES*

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Abstract

ALBA is a third generation synchrotron light source that consists on a linac, booster and storage ring. The linac is capable of operating in single (SBM) and multi-bunch injection mode (MBM). Since 2016 the Single Bunch Bucket Selection algorithm which runs in SBM, permits to inject on a selected bucket keeping the charge uniformity along the ring below 4%. However when running in SBM a significantly lower transmission along the linac is observed, with respect to the one when running in MBM. Simulation efforts have been deployed in order to build up a reliable model of the ALBA linac which can reproduce the experimental measurements. In this paper we present the new simulation model that renders the experimental observations, and the new optimization procedure developed in simulations and tested in the real machine.

INTRODUCTION

ALBA is the Spanish synchrotron facility working at 3 GeV since May 2012 [1]. The storage ring is fed by the booster which increases the electron beam energy delivered by the ALBA linac from 100 MeV while minimizing its emittance. The linac is responsible to efficiently bunch, focus and accelerate the *e*-bunch emitted by the gun. The linac subsystems are listed below:

- A 90 kV triode gun which derives from a Pierce gun diode geometry.
- Four short solenoid lenses between the gun and the Buncher, namely SL1, SL2, SL3 and SL4.
- A pre-bunching cavity (PB 500) at a sub harmonic frequency of 499.654 MHz.
- A second pre-bunching cavity (PB) at 2997.924 MHz.
- A standing wave cavity (Buncher) plus 2 focusing coils.
- A focusing lens (Glazer).
- Two traveling wave accelerating structures at 2997.924 MHz, namely S1 and S2.
- A triplet between the two accelerating structures.

Figure 1 shows a schematic layout of the ALBA linac. In addition, there are several orbit correctors distributed along the beamline in order to compensate for machine imperfections. Each of the solenoid lenses has a horizontal and vertical corrector in addition to the main focusing coil. Regarding the ALBA linac beam diagnostics [3], there are 6 Fast Current Transformers (FCT) throughout the beamline. At the end of the linac there are 1 beam charge monitor (BCM), 1 Beam Position Monitor (BPM) and 1 screen monitor.

The bunch per charge when operating in single bunch mode (SBM) is typically 0.25 nC while in multi-bunch mode (MBM) varies from 0.001 up to 0.2 nC [2]. The delivered energy spread is ≤ 0.5 % and the normalized transverse emittance is ≤ 30π mm mrad. Additional specifications of the ALBA linac can be found at [4].

MOTIVATION

Although the ALBA linac routinely operates within the specifications mentioned above, the measured beam transmission along the beamline in SBM is significantly lower than the one in MBM. Table 1 shows a typical example of beam current measurement by the FCTs and the corresponding transmission factor (between FCT1 and FCT4) for both modes. The FCT1 is located right after the gun while FCT4 is placed after the Buncher, as shown by Fig. 2. The bunch charge of the measurements presented in Table 1 (SBM) is 0.1 nC, about half of the charge measured at FCT1 (0.18 nC). The measured 50 % transmission in SBM contrasts to the ≈ 90 % obtained in MBM.

Table 1: Induced voltage filtered at 30 MHz at the FCTs and the associated transmission, between FCT1 and FCT4, of both operation modes. Measurements taken on February 4th 2019.

Mode	**FCT1** [mV]	**FCT2** [mV]	**FCT3** [mV]	**FCT4** [mV]	**Trans.** [%]
MBM	14.5	13.0	12.9	12.8	88
SBM	50.0	50.0	34.0	26.5	53

The FCT readings show that the beam losses occur along the bunching section where the beam is not yet relativistic ($\beta \leq 0.3$) and therefore sensitive to space charge effects. This indicates that either the focusing elements, namely SL1, SL2, SL3 and SL4 or the amplitude of the bunching elements, namely PB 500, PB and Buncher, are not optimal to compensate for the increased space charge forces at higher bunch charges, leading to a linac performance in SBM less efficient. The situation in MBM is typically better with charges at the end of the linac ≥ 90 % of the initial charge.

In the following we describe the simulation efforts intended to reproduce the observed measurements when running the linac in SBM and MBM. We present a simulation tuning procedure that optimizes the linac settings in order to minimize the beam losses. Finally the implementation

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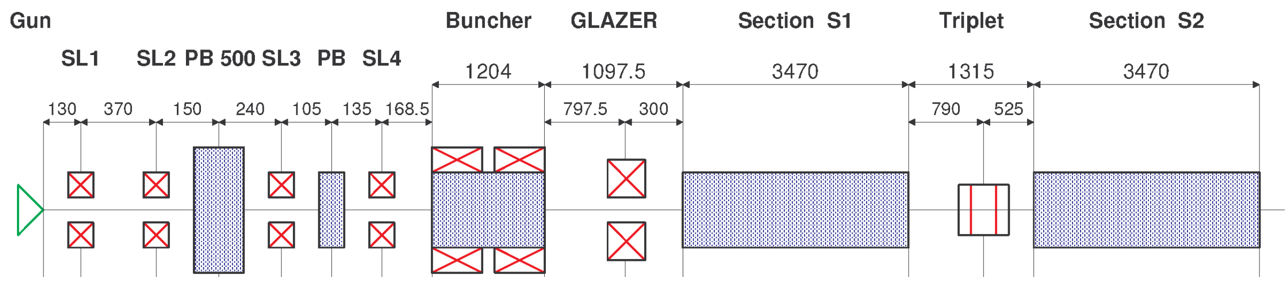

Figure 1: Schematic layout of the ALBA linac. The PB 500, PB, Buncher, S1 and S2 are shown in blue from left to right, respectively. SLs, Buncher coils, Glazer and Triplet are shown by red crosses from left to right respectively. Electron beam goes from left to right.

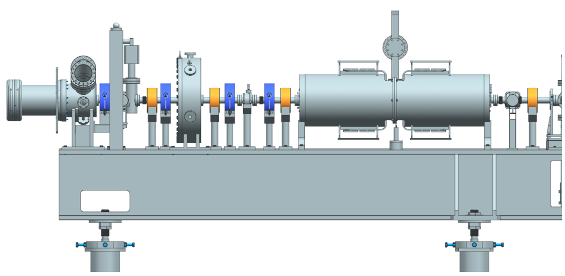

Figure 2: Detailed drawing of the first section of the ALBA linac from the gun to the entrance of the Glazer. The first 4 Fast Current Monitors are marked in orange and the solenoid lenses in blue.

of the new tuning procedure on the real machine and the obtained results are presented.

SIMULATION

Model

A new model of the ALBA linac has been obtained with the aim to better understand the measurements presented in the previous section. The General Particle Tracer (GPT) tracking code [5] is the simulation tool used to build up the model. The choice of this code is based on its capabilities to:

- Describe the beam dynamics without any approximation in energy.
- Include the most relevant collective effects.
- Import existing field-maps of the ALBA linac components.

The existing magnetic and electric field-maps of all the linac components, shown in Fig. 1, are included into the new model, with the exception of the gun and the Triplet, due to the lack of existing field-maps. Instead the Triplet is described by the *quadrupole* build-in element of GPT, while the gun is surpassed by generating the bunch at the exit of the gun, according to the list of parameters shown in Table 2. Upon bunch generation, the 6-D tracking engine transports the bunch from the exit of the gun to end of the linac, under the effects of space charge.

Table 2: Bunch properties at the exit of the gun obtained from [6, 7].

Parameter	Unit	SBM	MBM
Charge per bunch	nC	0.25	0.05
Energy	keV	90	90
Energy spread	%	0.05	0.05
Norm. trans. emittance	mm mrad	4	4
Trans. beam size	mm	2.8	2.2
Bunch length	ns	1	1
Divergence	mrad	5	-4

Optimization Procedure

In order to transport efficiently the electron bunch throughout the linac, the elements responsible for bunching, focusing and accelerating the beam need to optimised. These tasks are completed by 2 optimization algorithms, namely *phases.m* and *lenses.m* written in Octave [8]. These scripts are based on the Nelder-Simplex optimization algorithm [9]. Firstly we run *phases.m* in order to set the phases and amplitudes of the cavities, such as, the obtained final energy and energy spread comply with the linac specifications given in the Introduction. Afterwards *lenses.m* optimizes for the magnetic fields of the SLs, aiming to minimize the beam losses along the linac.

Results

The whole optimization task is carried out in both SBM and MBM. Table 3 shows the obtained optimum values of the SLs for both scenarios, as well as the evaluated transmission when running in SBM but using the settings of the SLs of the MBM, as it is done in the real machine. Indeed the obtained different settings, in terms of SLs and cavity amplitudes, correspond to the different space charge forces that need to be compensated when increasing the bunch charge from MBM to SBM. It is no surprise that the obtained values of the SLs in SBM are between 10 and 25 % larger than the ones for the MBM. Regarding the amplitude of the PBs

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and Buncher cavities, small differences (≤ 5 %) are found between the operating modes.

The obtained simulated transmission when tracking in SBM but with the optimized values of the SLs obtained in MBM is 60 %, as shown by the last row of Table 3. These simulated results besides agreeing with the measurements presented in Fig. 1, suggests that the solenoid lenses need to be optimized when running in SBM.

Table 3: Optimized SLs values and corresponding transmission after executing the optimization algorithms for both operating modes on the ALBA linac model.

Mode	**SL1** [A]	**SL2** [A]	**SL3** [A]	**SL4** [A]	**Trans.** [%]
MBM (Opt)	0.34	0.41	0.55	0.46	91
SBM (Opt)	0.45	0.44	0.58	0.51	78
SBM (as MBM)	0.34	0.41	0.55	0.46	58

MEASUREMENTS

Optimization Procedure

The optimization algorithm *lenses.m* is adapted for optimizing the real ALBA linac. This script uses the SLs as variables and the FCT readings as observables. The figure of merit is set to be the ratio between FCT4 and FCT1. The first optimization attempt was not successful since the transmission was marginally increased. However it is observed a different beam orbit in the vertical plane, when changing from MBM to SBM, see more details in [10]. It is clear that large orbit excursions, due to machine imperfections, could also limit the transmission. Thus a new steering optimization script (*steering.m*) is developed in order to optimize the horizontal and vertical correctors present in each of the SLs. Given both algorithms, a new optimization procedure has been design which consists on firstly optimize the steering coils present in the SLs, and secondly optimize the SLs. The procedure iterates over the algorithms until convergence is achieved.

Results

This new procedure is a key element to increase the transmission when running in SBM. Figure 3 shows the evolution of the FCT readings during the implementation of this new procedure, conducted on April 29th 2019, over roughly 4 hours. The initial and final values of the SLs and FCTs are summarized in Table 4. Comparing the obtained simulated values in SBM presented in Table 1 with the ones from the optimized machine presented in Table 4, we observe differences ≤ 2 % for SL1 and SL3, whereas the values of SL2 and SL4 differ by ≤ 20 % and ≤ 10 %, respectively.

CONCLUSIONS AND OUTLOOK

A new ALBA linac model has been obtained by means of the GPT tracking code. The model has made possible to simulate the beam propagation under different charge conditions. These simulation efforts have resulted in a new optimization procedure that maximizes the beam transmission throughout the ALBA linac in both SBM and MBM. Simulations results have shown that the impact of space charge requires different settings of the solenoid lenses. These has been confirmed in the real machine thanks to the implementation of the new optimization procedure which heavily relies on the simulation work. As a consequence of the focusing and steering optimization we have been able to increase the transmission along the first section of the linac from 62 % to 94 %, leading to unprecedented bunch charge at the end of the linac of 0.3 nC.Next steps are continuing the optimization along the linac and finally confirm that the optimized SBM can be efficiently injected into the booster.

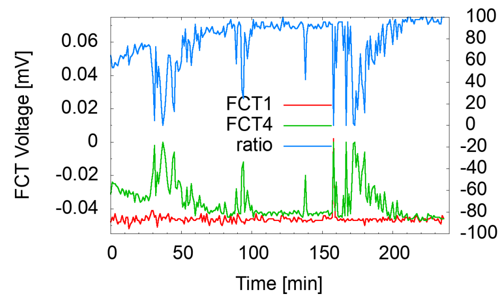

Figure 3: FCT readings (left axis) while optimizing the steering coils and solenoid lenses. Ratio between the FCTs is shown on the right axis.

Table 4: SLs values and FCT measurements before and after applying the new optimization procedure carried out on April 29th 2019 in SBM.

SBM	**SL1** [A]	**SL2** [A]	**SL3** [A]	**SL4** [A]	**Trans.** [%]
Initial	0.50	0.31	0.53	0.48	62
Final	0.45	0.35	0.57	0.47	94
	FCT1 [mv]	**FCT2** [mV]	**FCT3** [mV]	**FCT4** [mV]	**Trans.** [%]
Initial	0.50	0.50	0.34	0.31	62
Final	0.50	0.50	0.48	0.47	94

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