BEAM MEASUREMENTS AT THE ALBA LINAC

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Abstract

The ALBA Linac is a turn-key system able to produce 4 nC electron beams at 100 MeV beams with a normalized emittance below 30π mm*mrad and a beam position stability below 0.1mm. Thorough analysis are carried out to measure the beam emittance, energy and energy spread. This paper discusses the measurement techniques, analysis method, and results obtained during the Linac commissioning with the THALES colleagues.

INTRODUCTION

The ALBA Linac was provided by THALES Communications and installed in spring 2008 at the CELLS site. The installation of the first part of the Linac to Booster (LTB) transfer line and the Diagnostics Line (Lidia) was done simultaneously, under the CELLS responsibility .

The Linac works in Single and Multi Bunch Modes (SBM and MBM), and it was specified to provide beams with charges larger than 1.5 nC (SBM) and 3 nC (MBM) at energies larger than 100 MeV. Other requirements were the 30π mm*mrad normalized rms emittance (or lower), with an energy spread of 0.5% (max). CELLS also set restrictions to beam stability pulse to pulse, all described in Table 1. More detailed descriptions of the Linac are found in Refs. [1, 2], the Linac commissioning and its optimization is found in Ref. [3].

The Acceptance Tests determines whether the Linac delivers the beam within the required specifications, and evaluates its ultimate performance in terms of the beam quality at its exit. This report focuses on the tests and required analysis done to evaluate the Linac performance, with special attention to the beam parameters like emittance, energy and energy spread. Due care is taken as well with respect to the beam stability given by the Linac in terms of position and energy variation pulse-to-pulse.

Table 1: Linac Beam Parameters and Typical Values Measured During the Acceptance Tests

Parameter	Spec	MBM Meas	SBM Meas
charge, nC	$\geq$3, $\geq$1.5	3.96	1.97
pos. stability ptp, mm	$\leq$0.2	<0.1	<0.1
energy, MeV	$\geq$100	108	108
energy var. ptp, %	$\leq$0.25	0.1	0.1
energy spread,%	$\leq$0.5	0.25	0.25
norm. rms ϵ, mm*mrad	$\leq$30π	20π	20π

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DIAGNOSTICS LINE SETUP

The beam measurements are perfomed in the first part of the LTB and Lidia showed in Fig. 1. Both lines are installed inside the Linac bunker and consist of a straigth section with a quadrupole triplet followed by a switchyard dipole to guide the beam to the Booster at 8.75° or to the diagnostics branch and the dumper at 30°.

The line comprises of the following diagnostics devices:

- 2 beam position monitors (BPM), one at the Linac exit and another just after the quadrupole triplet.
- 2 beam charge monitors (BCM), one at the Linac exit and another in the Lidia after the scraper for energy spread measurements.
- 1 horizontal scraper (SCRH) at low horizontal beta and high dispersion location in the Lidia for energy spread measurements.
- 2 screen monitors with both fluorescent (YAG activated by Cerium) and OTR screens installed on the same frame (FSOTR) : one after the quadrupole triplet and another for energy analysis in the Lidia after the scraper.

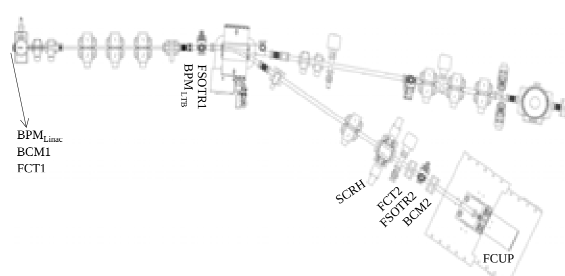

Figure 1: LTB and diagnostics line layout.

BEAM STABILITY

The Linac specifications required a beam stability *within 10% of the beam size*. For a typical round beam with an rms size of 2 mm, this stability translates into 0.2 mm.

Beam position is measured on the two BPMs. Picked-up voltages from the button type feedthroughs are processed by the electronics on a single pass basis. Figure 2 shows the measurement of the beam charge out of the Linac, the beam position on both planes and BPMs, and the current changes on the first quadrupole.

The rms variation on both planes at both BPMs shows that beam position stability is kept below 0.1 mm rms (see

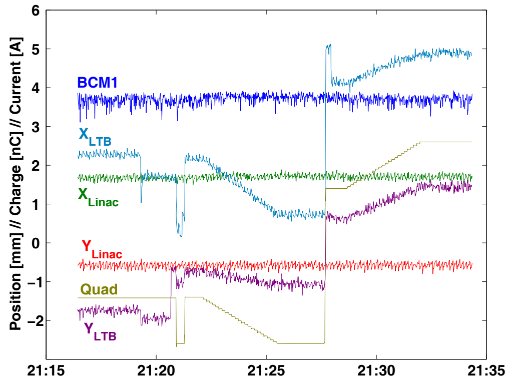

Figure 2: Positions at the Linac and LTB BPMs during the quadrupole scans. The rms stability (inferred from data taken during the first two minutes) is: $\Delta^{\rm rms}_{\rm x,y-Linac} = (65, 71)\mu$m ; $\Delta^{\rm rms}_{\rm x,y-LTB} = (59, 72)\mu$m.

caption in Fig. 2), while the beam charge stays at 3.7 nC. Note that when the quadrupole is scanned (to perform emittance measurements), the LTB BPM shows a drift in both planes. This indicates that the beam was not going through the quadrupole center.

ENERGY AND ENERGY SPREAD MEASUREMENTS

A direct method to infer the beam energy spread is to measure the beam size σ_x downstream the bending magnet using the FSOTR. Using the dispersion function D, this is:

$$\Delta E/E_0 = \sigma_x/D \; . \tag{1}$$

However, large energy spreads can produce images at the Lidia FSOTR wider than the screen itself, which occurred in early phases of the commissioning. In this circumstances, it is convenient to use the dipole, in combination with the scraper and charges measured at the Linac exit and downstream the scraper installed after the dipole.

After crossing a bending magnet, the horizontal position of the centroid x provides the beam energy by

$$E(x) = E_0(1 + x/D) \; , \tag{2}$$

where E_0 is the energy when the centroid travels through the middle of the vacuum chamber, which is determined from the bending magnet calibration.

We measure the energy spectrum using the scraper gap Δx. This is inferred by scanning the position x of a fixed scraper gap:

$$\phi(x) = \frac{Q_2/Q_1}{E(x)\frac{\Delta x}{D}} \; , \tag{3}$$

where Q_2 is the charge measured downstream the scraper (at BCM2), and Q_1 is the charge measured at the Linac exit (at BCM1). The energy and energy spread is then a direct measurement of the peak position and width under the curve described in Eq. 3.

An example of the energy and energy spread measurement following this method is depicted in Fig. 3, showing a long low energy tail of the beam. The typical values for the energy spread are around 0.25% rms.

An equivalent technique is to scan the dipole current, which is then equivalent to scan the parameter E_0 in Eq. 2. In this case, the scraper gap and position are fixed, and the dipole current scan provides a similar curve as in Fig. 3.

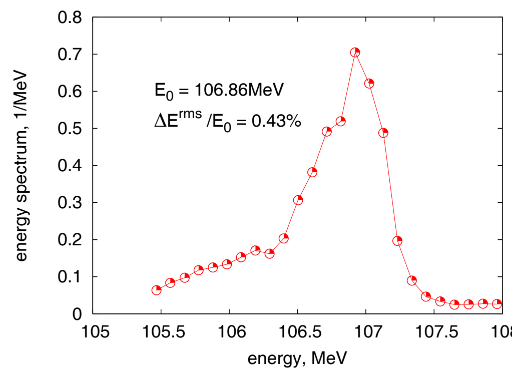

Figure 3: Energy spectrum for a 3.7 nC beam in MBM.

EMITTANCE MEASUREMENTS

The Linac emittance is measured with the quadrupole scan technique [4] using the quadrupole triplet and FSOTR1 (in front of the dipole). The emittance is inferred by observing the beam size variation at the screen due to the change of the strength in the first quadrupole. The distance between the center of the scanned quadrupole and the screen is only 1.2 m (other Linacs use at least twice or three times this drift distance [5]), hence the beam must be very squeezed to produce a waist at the monitor position (beam size up to 0.1 mm rms has been measured), and special care must be taken to avoid saturation of the YAG screen and/or the pixels at the CCD camera.

Data Acquisition

A dedicated application of the control system was developed to perform the quadrupole current scan, acquire the beam images at the screen and calculate the beam sizes. One of the problems given by this online analysis was that in many cases the image analysis software (called Image Beam Analyzer or IBA [6]) was not able to find solutions to the Gaussian fits of the beam spot profiles.

After the commissioning, an IMage Analysis COde (from now on named IMACO) based on Matlab has been developed to process and reanalyse offline all the beam images previously acquired, and to compare the results with the online values given by the IBA.

Image Analysis

The IMACO image processing is performed in three steps: selection of the signal region of interest (ROI), initialization of the Gaussian fit parameters, and computation of the beam size and centroid.

First the ROI selection is entered by the user, thereafter, the horizontal and vertical signal profiles are fitted with a Gaussian distribution of area A, mean x_0 and rms value σ,

$$f(x) = \frac{A}{\sqrt{2\pi}\sigma}\exp(-\frac{(x-x_0)^2}{2\sigma^2}) + h + kx \ , \qquad (4)$$

whith $h + kx$ being a sloped baseline. The Gaussian parameters are initialized from the initial ROI profiles, while the pixels outside the ROI are used to initialize the baseline parameters.

The fit parameters are used to resize a new ROI limited to $\pm 4\sigma$ around the mean x_0. The procedure is iterarated until the rms beam size matches the previous iteration value. Typically this converges in four to five iterations. An example of the horizontal and vertical fit profile of an image taken with the OTR screen is shown in Fig. 4.

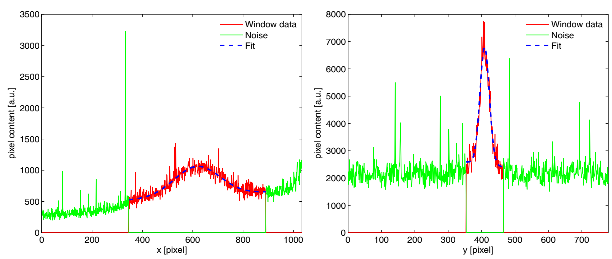

Figure 4: Example of an analyzed horizontal (left) and vertical (right) beam profile. The green line is signal outside the ROI, the red line is the part of the signal used for the analysis and the the blue curve is the Gaussian fit to estimate the rms beam size.

Experimental Results

The Linac emittances in the horizontal and vertical planes have been measured both in SBM and MBM at 107 MeV, with a beam charge respectively of 1.9 nC and 3.8 nC. With these charge densities on the YAG screen, both the screen and the camera response saturated when the beam goes through the waist, and so we used the OTR screen.

The experimental data obtained for one of measurements taken with the OTR screen are shown in Fig. 5. The first quadrupole current is scanned with the other two quadrupoles switched off. The results obtained offline with IMACO and online with IBA are compared. In general, IBA overestimates the beam size, and therefore the emittance, by ∼15%. This is probably because IMACO introduces the sloped term $h+kx$ in its fitting process and iterates the ROI size until a convergion condition is fulfilled, while IBA performs a simple Gaussian fit (no sloped term) with only one iteration.

Normalized rms emittances of about 17π mm*mrad have been achieved in both planes in MBM and SBM.

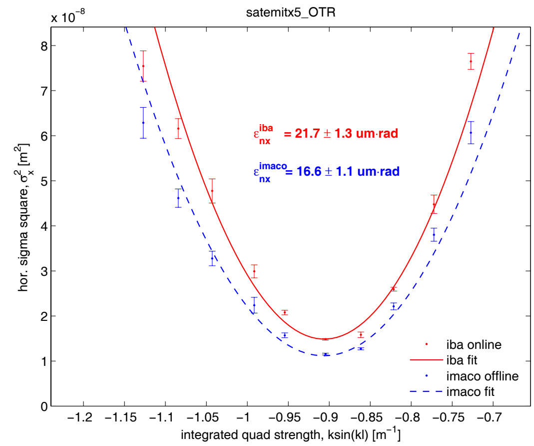

Figure 5: Example of an emittance measurement in the horizontal plane in MBM using the OTR screen (Q=3.8 nC).

SUMMARY

The beam quality provided by the ALBA Linac is evaluated in terms of its energy, energy spread, normalized emittance, and stability pulse to pulse. An image analysis code IMACO has been developed to solve the problems related with the beam image and obtain a reliable measure of the beam size. Typical normalized rms emittances measured for the ALBA Linac are 20π mm*mrad, with an energy spread measurement of about 0.25% rms. The values for the beam position stability, energy, energy spread and emittance are within the required specifications.

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