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At ALBA four Beam Position Monitors (BPMs) measure the beam position along the Linac and the Linac-To-Booster transfer line (LTB). The BPM electronics (Libera Spark type) have been recently upgraded in order to be sensitive to single-pass beam detection. As a result, the position resolution measured in LTB BPMs has been increased by a factor 10 with respect to the former electronics. The increased resolution enables us to resolve the energy jitter of the Linac beam, providing an on-line measurement of the Linac energy during regular operation. In this paper a study of the Linac energy jitter is presented as well as its correlation with the jitter sources.

LINAC AND LTB

The injector of the ALBA Synchrotron consists of a 110 MeV electron Linac, a Linac-To-Booster transfer line (LTB) and a full energy Booster that accelerates the beam up to 3 GeV. When running for user operation the injector tops up the Storage Ring current every 20 minutes [1].

The beam at the Linac is generated at 90 keV by a thermionic gun in multi (MBM) or single bunch (SBM). The beam is then sent to a three stage bunching system that increases the beam energy up to 16 MeV. The final acceleration is provided by two identical travelling wave constant gradient accelerating sections, AS1 and AS2. The Linac is driven by two 3 GHz, 5 µs pulsed klystrons that work at a repetition rate of 3 Hz. Klystron 1 (KA1) feeds the bunching system and AS1, whereas klystron 2 (KA2) feeds only AS2. The diagnostics at the Linac exit include one Beam Charge Monitor (Li-BCM) and one BPM (Li-BPM).

The LTB consists of 2 bending magnets (Bend1 and Bend2), 3 triplets of quadrupoles and 4 hor/vert corrector magnets. By means of the switchyard dipole Bend1 the beam can be sent either to the Diagnostics Line (30º) or further down the LTB (8.75º). The LTB is followed by one septum and one kicker magnet. As depicted in Fig. 1, along the LTB there are installed 3 BPMs, 3 YAG screens and 1 BCM.

SPARK BPMS

The electronics that digitizes and processes the electron pulses taken by the BPMs installed in the Linac and LTB have been upgraded from Libera Brilliance to Libera Spark modules by I-Tech [2]. The new electronics improve the definition of the signal window in time, resulting in a reduction of the signal-to-noise ratio of the position signal. Spark electronics were firstly installed and tested at the BPMs of the ALBA Booster-To-Storage transfer line [3]. The resolution of the position calculation was found to be a factor 10 higher with respect to the previous electronics.

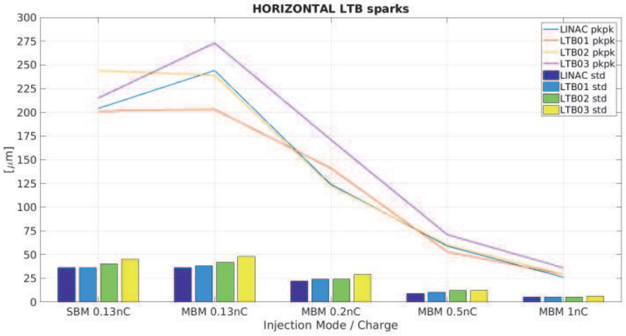

Figure 2: Horizontal position measurement provided by the Spark electronics for the Linac and LTB BPMs at different beam charges. Input signal is forced to zero.

The position error introduced by the Spark electronics has been measured for the Linac and LTB BPMs by adding up the signal recorded by the 4 BPM-buttons. Thus, the expected position reading of the electronics should be zero. For a 0.2 nC beam in MBM mode, which is the Linac charge used during user operation, the error introduced by the electronics in the horizontal position is below 50 microns (200 microns pk-pk) in all BPMs, see Fig. 2. The measurement error decreases down to 10 µm (rms) when the beam charge is increased up to 1nC.

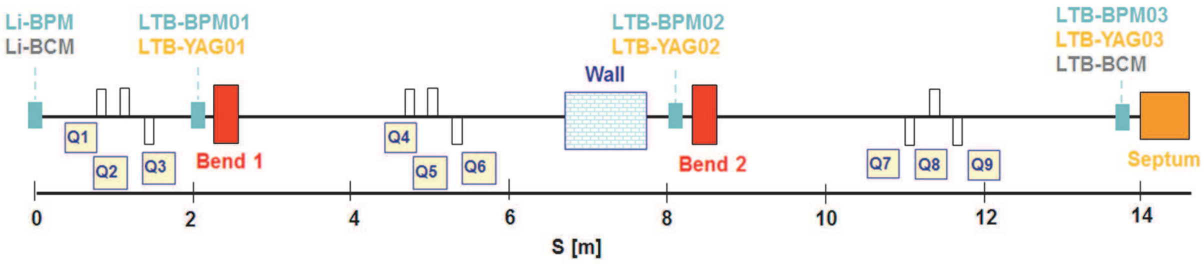

Figure 1: Layout of the Linac-To-Booster transfer line, where the BPMs, YAG screens and BCMs have been indicated.

LINAC BEAM ENERGY

The energy of the beam injected into the booster is typically of 110 MeV. Its energy spread is below 0.3% rms. During one top-up injection the beam has an energy jitter of about 0.1% rms. The energy acceptance to the booster is 1% peak to peak, meaning a beam injection window of about 1.5 MeV.

Air and water temperature instabilities as well as Linac hardware malfunction can produce extra beam energy oscillations which affect the injection into the booster. In order to detect such anomalies, the Linac beam energy should be routinely monitored. This paper describes the implementation of a more sensitive energy measurement by the use of a BPM equipped with Spark electronics and presents the detection of beam energy instabilities and the identification of its sources.

Energy measurement at the Diagnostics Line

The high value of the dispersion function D at the Diagnostics Line allows measuring the Linac beam energy with a resolution of 10 mm/MeV. The measurement is based on the calibration of Bend1. A YAG screen provides the horizontal beam position, x, and the horizontal beam size, σ_x. Energy and energy spread are obtained accordingly from these equations [4]:

$$E(x) = E_0\left(1 + \frac{x}{D}\right) \tag{1}$$

$$\frac{\Delta E}{E} = \sigma_x / D \tag{2}$$

Energy measurement at LTB

The LTB-YAG02 and/or LTB-BPM02 (both placed before Bend2) can be used also to measure the Linac beam energy at LTB, by measuring the horizontal beam position, which is calibrated for different beam energies and for a given LTB lattice [5].

Although being the region with the highest dispersion at LTB, energy measurements in this point have less resolution than in the Diagnostics Line, of only 3.5 mm/MeV. Still, during user operation, energy measurements are simpler and more suitable to be performed at the LTB, during (or in between) the top-up reinjections.

During last years, beam energy measurements were taken with the LTB-YAG02, which measures the beam position with an accuracy of 40 µm rms. Nonetheless, the mechanical system that places the YAG screen at the center of the vacuum chamber introduces a non-negligible error when comparing measurements taken in different times. Due to the risk involved in introducing the YAG screen during user operation, the energy was measured only twice per day, in between top-up reinjections.

Because of their non-destructive diagnostics nature, energy measurements with BPMs are most convenient. However, the measurement with LTB-BPM02 processed by the Libera Brilliance electronics had a too poor position resolution to be used as a energy measurement tool. With the implementation of the Spark electronics the position resolution of the Linac and LTB BPMs readings have increased by a factor of 10, allowing measuring the energy at LTB-BPM02 with 10% better accuracy than the YAG screen measurement. Furthermore, this measurement is permanently provided, with zero risk for the operation. Currently, the derived energy measurement from LTB-BPM2 is being used as a diagnostic tool during routine operation. Figure 3 shows an on-line energy measurement taken with the LTB-BPM02 during one injection in top-up mode. The total rms energy jitter is below 0.1 MeV. A study of the beam energy deviations during operation is reported below.

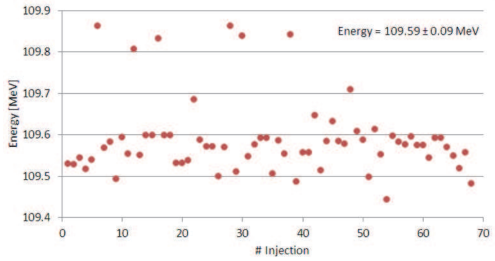

Figure 3: On-line energy measurement with LTB-BPM02 of one injection to Booster in top-up mode.

BEAM STABILITY IN OPERATION

The beam position stability during 48 hours of beam for users is presented in Table 1.

Table 1: x and y Position Variation (rms) in 48 Hours

	LI	LTB			BO
	BPM	BPM01	BPM02	BPM03	BPM
x [µm]	38	62	426	293	88
y [µm]	57	59	99	88	143

Most position variation values (rms) are below 100 µm, excepting the ones of those BPMs set at a higher dispersion region, which have an expected larger rms in x: LTB-BPM2 and LTB-BPM3. BO-BPM, the first BPM at the Booster, has also a higher value in y, due to beam coupling with the x-axis.

Figure 4 shows the readings of these BPMs taken in top-up mode during 48 hours, together with the energy measurement extracted from LTB-BPM02. Each point is the average of all the shots contained in one top-up injection, which lasts about 20 seconds.

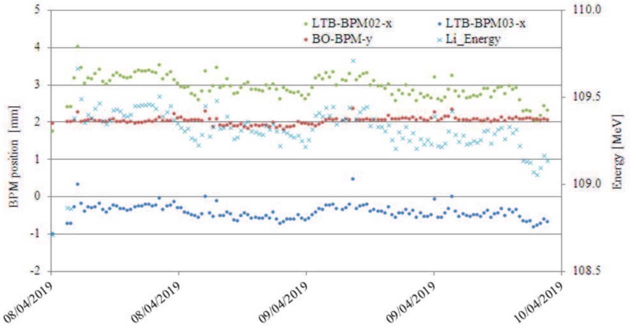

Figure 4: 48 hour data acquisition during top-up operation of LTB-BPM02 (and its extracted energy), LTB-BPM03 and BO-BPM.

Over 48 hours, the average energy of the Linac beam was 109.3 MeV, with a beam energy variation of 0.14 MeV (rms) and 0.85 MeV (pk-to-pk). This jitter includes, among others, the effects due to day/night air and water temperature variations.

LINAC BEAM STABILITY STUDY

To study the sources of the energy jitter and other instabilities that lead to beam position variations, long term measurements have been taken under different conditions using the Spark BPMs.

Energy jitter sources

In Fig. 5, a 15-minute energy measurement (2600 injections) of a MBM beam of 0.2 nC is shown for a nominal beam of 110 MeV and also for a reduced energy beam of about 68 MeV, wherein KA2 was switched off. For the nominal beam the energy variation is 0.08 MeV (rms) and 0.66 MeV (pk-pk), whereas for the reduced energy beam the energy variation is of 0.045 MeV and 0.35 MeV (pk-pk). Therefore, with only one klystron, the energy variation is halved, which suggests both klystrons to be the major sources of the total energy variations of the Linac beam. Nevertheless, in both cases energy variations are below 0.1% (rms) and 1% (pk-pk) which are within specifications.

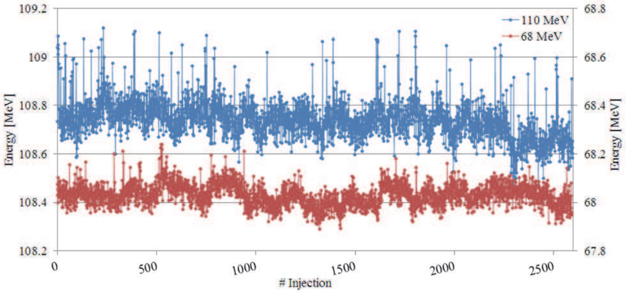

Figure 5: 15-minute beam energy measurement with LTB-BPM02 for 110 MeV (both klystrons on) and 68 MeV (only KA1 on).

Note that in both curves of Fig. 5, but most notably in the 110 MeV one, isolated measurement points (peaks) are set about 0.3 MeV away from the average values. These peaks are more numerous and higher for 110 MeV than for 68 MeV measurements, where both klystrons were running.

The peaks are correlated until to some extent with the klystron modulator parameters, despite that their parameter reading resolution is poor. Figure 6 shows that several energy peak points are clearly correlated with peaks of the KA2 cathode voltage. Variations of the klystron cathode voltage vary the output power delivered by the klystron, which in turn varies the final energy of the Linac electron beam.

Furthermore, klystrons feature a one-minute bumping structure which is visible also in the energy measurements.

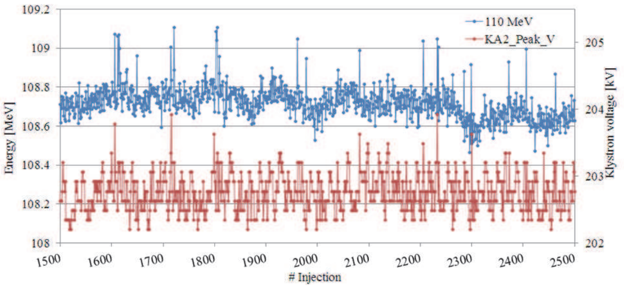

Figure 6: 15-minute energy measurement of a 110 MeV beam versus the voltage applied to the KA2 cathode. A correlation of some of the peaks of both parameters is clearly observed, as well as the time bumped structure.

Beam position and charge

Long term stability measurements taken for different Linac beam charges and modes (SBM or MBM) show that the beam orbit along the Linac and the LTB varies with the charge. This is caused by the wakefields created by the Accelerating Sections when the beam does not cross the cavities on axis. The shift on the trajectory induced by the wakefields depends on the bunch charge. A beam orbit comparison is shown in Fig. 7 for a 0.2 nC bucket (SBM) and a 0.005 nC bucket (MBM).

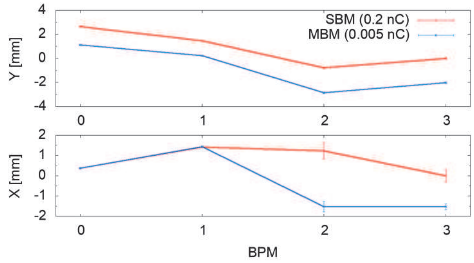

Figure 7: Beam orbit at the Linac exit and along the LTB for a 0.2 nC bunch (SBM) and a 0.005 nC bunch (MBM), where 0: Li-BPM, 1:LTB-BPM01, 2:LTB-BPM02, 3:LTB-BPM03.

SUMMARY

The position accuracy of the Linac and LTB BPMs readouts has been improved a factor of 10 by the use of the Spark electronics. This has enabled the implementation of an on-line Linac beam energy measurement at LTB-BPM02 which serves as a diagnostics tool during user operation in top-up mode. Moreover, it has helped to find out that both klystrons contribute significantly to the beam position jitter.

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