TUNE MEASUREMENT SYSTEM AT THE ALBA BOOSTER

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Abstract

The ALBA Booster synchrotron is designed to ramp electron beams of 5 mA from 100MeV to 3GeV in a 3Hz cycle. The Booster is equipped with two common $\lambda/4$ striplines for tune excitation and precise beam position measurement. Beam excitation along the cycle requires the amplitude kick to increase in synchronism with the energy ramp. This paper shows the excitation and measurement system at the ALBA Booster, including both mechanical and hardware instrumentation. First results during the 2 weeks of Booster pre-commissioning are shown.

INTRODUCTION

ALBA is a third generation light source whose injection system is composed by a 100MeV Linac followed by a full energy Booster synchrotron, which ramps the electron beams up to 3GeV in a 3Hz cycle. More details about the Booster are given in Table 1 and Ref. [1].

Table 1: Booster design main parameters.

Parameter	Injection	Extraction
energy, E [GeV]	0.1	3.0
hor. emittance, ε_x [nm-rad]	150	9
max. current, I [mA]	5.0	
circumference, C [m]	249.6	
rf freq., f_{rf} [MHz]	499.6	
hor / ver tunes, ν_x/ν_y	12.42 / 7.38	

In order to properly monitorize the betatron tunes along the ramp, two identical $\lambda/4$ stripline BPMs are installed. The first stripline is devoted to excite the beam, while the second one is used to precisely measure the beam position. Their acronyms are SEXC and SMES, respectively.

Horizontal and vertical beam excitation are done with an electrick kick whose amplitude increases in synchronism with the energy ramp. An excessively strong kick will induce beam losses at low energy, while a too weak one will not allow the measurement at full energy [2]. Two weeks of Booster pre-commissioning were scheduled during January 2010 [3]. This paper present as well the first results obtained during this pre-commissioning.

MECHANICAL DESIGN

Two pictures of the Booster stripline are shown in Fig. 1. The same setup is used for excitation and measurements, and so we used $\lambda/4$ electrodes, matched to 50Ω for tune excitation, and shorted for tune measurements (being $\lambda = c/f_{rf}$ the rf wavelength).

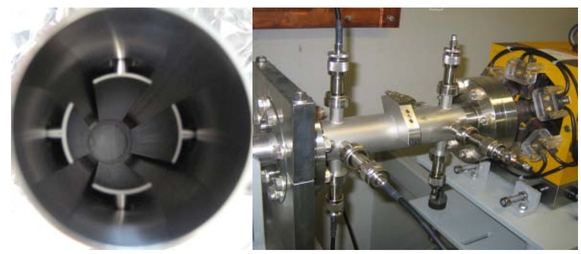

Figure 1: Picture of the stripline transverse geometry (left), and stripline as installed in the ALBA Booster. The electrode covering angle is 60°.

The electrode surface has been maximized as much as possible to increase kick efficiency when used as excitation device, and pick-up detection when used as measurement device. SUPERFISH simulations have been carried out to match the electrodes to 50 Ω. Figure 2 shows the S-parameters measured with the NA, which shows optimum results for both reflection (S11) and electrodes coupling (S12).

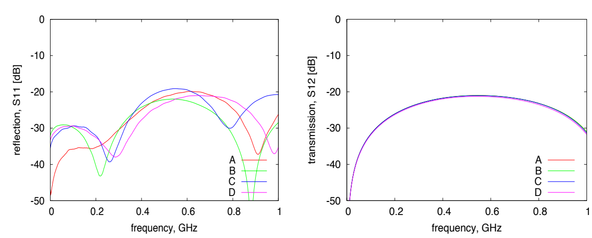

Figure 2: Stripline S-parameters as measured with the Network Analyser (NA): S11 (left) and S12 (right).

TUNE EXCITATION LAYOUT

The shunt impedance Z_{sh} of a kicker made out of two electrodes of length l and spaced with a distance d is [4]

$$Z_{sh} = 2Z_0\left(\frac{2g\beta c}{d\omega}\right)^2 \sin^2\left(\frac{\omega l}{c}\right) , \qquad (1)$$

where Z_0 is the vacuum impedance, ω refers to the kick angular frequency, c is the speed of light, and g is the geometrical factor. Assuming a pessimistic case of a flat electrode of $w = R \times (\pi/3)$ spaced by a distance $d = 2 \times R$ (with R the chamber radius), this is inferred as [4]:

$$g = \tanh \frac{\pi w}{2d} . \qquad (2)$$

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The shunt impedance is $Z_{sh} = 4.23$ kΩ for the frequency range in which we are interested ($\omega \to 0$, since the excitation frequency is much smaller than rf frequency). With a $P = 50$ W, the angular kick is then calculated as

$$\Delta\theta = \frac{e}{E\beta^2}\sqrt{2PZ_{sh}}\,. \tag{3}$$

For an energy $E = 3$ GeV, this is $\Delta\theta = 0.22$ μrad. Although the amplifier IFI-ML50 ensures the linearity to 50 W, it can provide up to 250 W in a non linear regime – for which the kick angle is then ~ 1 μrad.

In order to excite the beam with the same angle all along the ramp, the excitation signal is ramped in synchronism with the energy increase. This is achieved with the setup described in Fig. 3.

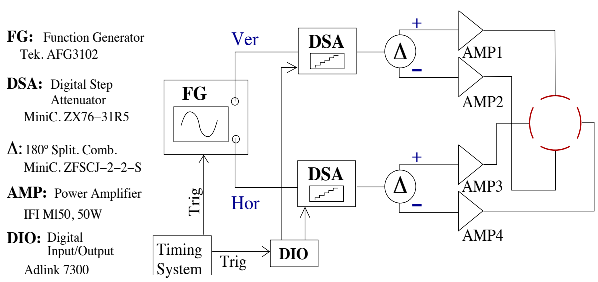

Figure 3: Block diagram of the tune excitation.

The source of the excitation signal is the Function Generator (FG, Tektronix AFG3102), which produces the white noise signal (set with a central frequency plus a frequency range). The signal is then inputed at the Digital Step Attenuator (DSA), which offers an attenuation range up to 31.5dB in 0.5dB steps. The excitation signal is later splitted using a 180° passive splitter-combiner (Δ). The two identical signals (only differing by 180° phase difference) are each amplified by the power amplifier before polarizing the two horizontal (or vertical) SEXC electrodes.

The DSA has a parallel control interface, which allows a fast switching speed up to 1 μs. It is controlled by a fast I/O module with 32 digital channels (Adlink cPCI-7300), which allows to change the DSA attenuation in 64 steps for both hor and ver planes. The timing signal triggers everything in synchronism with the energy ramp. Figure 4 shows the output of the DSA before the 180° SC.

TUNE MEASUREMENT LAYOUT

The signal picked up by an electrode is directly proportional to the electrode's surface, whence the use of a stripline BPM instead of a button BPM. This is specially useful in the early phases of the Booster commissioning (with about 0.1 mA in the machine). In the ALBA Booster, the surface ratio between both electrodes is 15.2.

Figure 5 shows the sum signal of the SMES with respect to that of a button BPM nearby over 16 kturns. The measured ratio between both signals is 6.98±0.16, which is in a good agreement with the expected value (7.6) if we also take into account the 3 dB provided by the splitters. It is worth mentioning that its location was in a high dispersion region and so the betatron tunes had also synchrotron sidebands (this is why the SMES signal in Fig. 5 seems noiser).

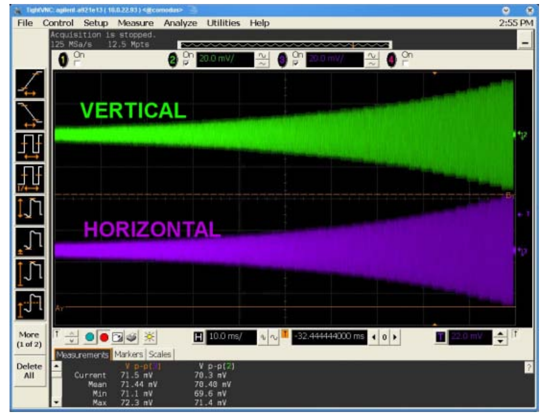

Figure 4: Vertical (green top) and horizontal (violet bottom) tune excitation signals coming from the DSA.

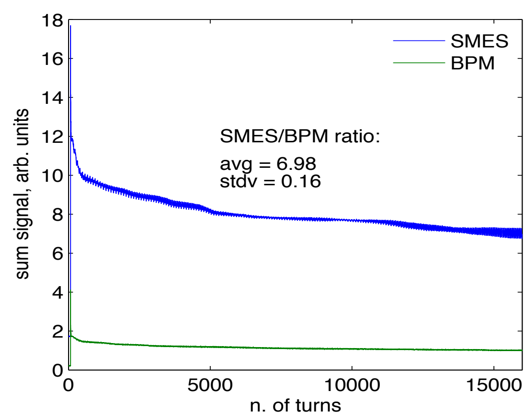

Figure 5: Sum signals of the SMES (blue) compared to the sum signal of a button BPM nearby (green).

The signal coming from the SMES electrodes is splitted in two in order to analyze it through both the BPM read-out electronics (I-Tech Libera Brilliance) and the Real Time Spectrum Analyzer (RTSA, Tektronix RSA3303A). Figure 6 shows the layout of the system that splits the signal coming from the SMES electrodes. Tunes are computed using the FFT from the Libera turn-by-turn position measurements, and the Δ signals proportional to the horizontal and vertical beam offsets.

The Libera electronics have been working on the *Data on Demand* mode in order to capture turn-by-turn data during the ∼190 kturns of the ramp. See more details about the read-out electronics in Ref. [3].

The RTSA is a fast sampling instrument with built-in FFT algorithm and data presentation. The RTSA allows a spectrum measurement every 6.4ms, which corresponds to a total of 25 measurements during the 160 ms ramp. The accuracy of this measurement is $<10^{-3}$ [5].

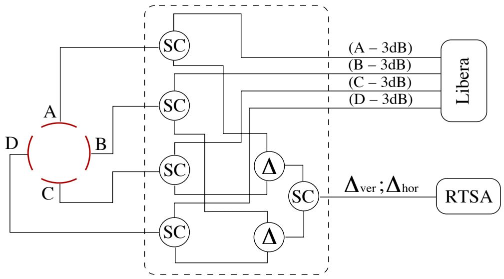

Figure 6: Block diagram of the system that splits the stripline signal for the Libera electronics and the RTSA.

RESULTS

The goal of the Booster pre-commissioning was to check that all subsystems performed according to specifications. We almost reach the full energy in one specific day (we stayed at 2.7 GeV), but in general we stayed below that to get a thorough knowledge of the machine for the next commissioning (July 2010).

Figure 7 shows an example of the tune measurement at injection, using the FFT of the hor turn-by-turn data, averaging over 10 shots. The abovementioned synchrotron sidebands are visible. We can also see that because of the coupling, both ver and hor tunes are visible.

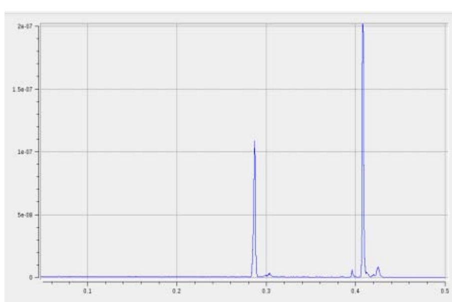

Figure 7: Tune measurement at injection.

The tune excitation application performed according to expectations. However, we would like to carry out more beam studies to perform a fine tuning of our amplifiers and evaluate the effect of the kick amplitude into the beam.

The best tune measurements along the ramp were based on the FFT calculations of the turn-by-turn data provided by the Libera electronics, which is done using the Matlab Middle Layer (MML). With this purpose, a especial GUI has been developed by Beam Dynamics group. Figure 8 shows an example of the tune measurement performed over a ramp from 0.1 to about 1GeV. In this case, the beam was lost after about 70 kturns.

During these two weeks of Booster pre-commissioning, the tune measurement system using the Real Time Spectrum Analyzer (RTSA) could not be set operational. The tune measurement based on the RTSA requires a transformation of the amplitude modulated 500 MHz - signal component as delivered by the beam to the base band. This will

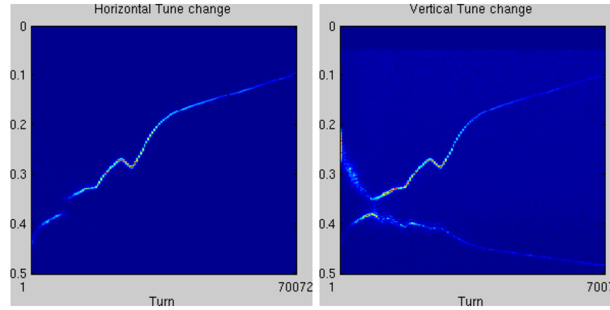

Figure 8: Tune measurement along the ramp in the hor (left) and ver (right) planes.

be done by mixing the stripline signal with the frequency of the master oscillator, or even simpler with a diode. We hope to implement this solution for the next Booster commissioning in order to produce an alternative to the MML.

SUMMARY

The use of the DSA allows to linearly increase the excitation signal with the energy gain, so as to produce the same angular kick throughout the ramp. The kick amplitude can be fixed in a range between 0.25 to 1 μrad.

The use of the SMES in the Booster produces a signal 7 times larger than the button BPMs signal. The signal from this stripline is then analyzed through two methods: FFT analysis of the beam position measurements, and through the RTSA.

The turn-by-turn data collection and FFT-analysis has been the most useful way to determine the tunes during the ramp, and so far, the only method. Further work is needed in order to properly set the tune measurement through the RTSA.

ACKNOWLEDGMENTS

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