ELECTRON BEAM DIAGNOSTICS FOR THE ALBA LIGHT SOURCE

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Abstract

This paper presents the diagnostics systems that will be used to monitor the electron beam at ALBA, a 3 GeV 3rd generation synchrotron light source. The electron beam is characterized by measuring its transverse position in the beam pipe, beam current, transverse size and longitudinal structure. We provide a complete picture of the systems used to diagnose the electron beam along the ALBA facility, not only in the Storage Ring but also in the injector system (Linac, Booster, and transfer lines).

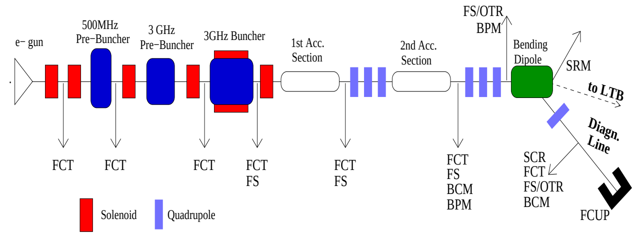

Figure 1: Beam diagnostics components in the Linac.

INTRODUCTION

The ALBA facility consists of a 100 MeV Linac, a Booster that accelerates the beam up to the full energy of 3 GeV, the Storage Ring (SR), and the corresponding transfer lines (Linac To Booster – LTB, and Booster To Storage – BTS). Table 1 lists the main beam parameters for the Linac, Booster (extraction conditions) and SR.

Table 1: Beam parameters in the Linac (single bunch mode), Booster (equilibrium values at 3 GeV) and SR.

	Linac	Booster	SR
energy (GeV)	0.1	3.0	3.0
circumference (m)	...	249.6	268.8
max. current (mA)	5	5	400
bunch spacing (ns)	2 - 128	2	2
rms bunch length (ps)	∼200	60	15
hor. emit. (nm·rad)	150	9.0	4.3
coupling	100 %	10%	1%
dipole field (T)	0.189	0.873	1.42
hor. tune Q_x	...	11.42	18.18
ver. tune Q_y	...	7.38	8.37

We use common instrumentation for light sources thoroughly described in related literature (see for example Ref. [1]). In the following, we describe our choice of the instrumentation that measures the beam parameters listed in Table 1, and thus characterize the beam behaviour along the Linac, Booster, transfer lines and SR.

LINAC

The diagnostics components installed in the ALBA Linac are shown in Fig. 1. The Linac is a turn key system. For the acceptance tests, we shall perform measurements of the beam charge, emittance, energy and energy spread.

Fast Current Transformers (FCT) are installed after each active element. The FCT is a non-interceptive current transformer to measure the beam profile and intensity from the magnetic flux induced in a toroidal core (coil) by a primary winding (the electron beam). As all passive devices, the FCT differentiates the signal, and hence frequencies below a certain threshold are not measured (DC components are lost). These devices are bought *off-the-shelf* from Bergoz and have an upper frequency limit of 2 GHz [2], which is sufficient to measure the beam charge and profile at the Linac exit.

A further crosscheck of the beam charge is performed using the **Beam Charge Monitors (BCM)** [2] and the **Faraday Cup (FCUP)**. The BCMs are *off-the-shelf* units that measure the charge of very fast pulses with high accuracy (resolution is < 1 pC) by means of a capacitively shorted transformer coupled to a fast readout transformer in a common magnetic circuit. The FCUP at the Diagnostics Line is based on the Diamond design [3]. This device is mainly designed as beam stopper, and so it is optimized for charge collection efficiency rather than bandwidth.

The transverse beam spatial distribution is measured using two different screen monitors. The first one includes a movable setup that inserts a **Fluorescent Screens (FS)** in the middle of the vacuum chamber. The screen is made of a fluorescent material (typically YAG:Ce), which produces light upon collision with the electron beam by phosphorence. The second one uses either a FS or an **Optical Transition Radiation (OTR)** monitor (aluminum foil on a polished silicon wafer). While this OTR monitor produces a much lower photon yield, it has the advantage (with respect to the FS) of not saturating because it is a surface effect. This combination of FS and OTR (so abbreviated as **FS/OTR**) is used for the emittance measurements of the Linac Acceptance Tests. At 100 MeV and low currents, the FS provides sufficient photon flux, while for high currents and small beam sizes, we avoid the saturation of the screen using the OTR. The emittance measurements are performed using the well-known technique of the quadrupole scan using the FS/OTR upstream the bending magnet in Fig. 1.

A similar system is thought for the energy and energy

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spread. Both measurements are performed using the bending dipole in Fig. 1 as an energy spectrometer and measuring the beam position and shape with the screen monitor FS/OTR installed in the Diagnostics Line.

BOOSTER

In order to control the injection into the Booster, we locate a FS/OTR downstream the septum to image the beam shape and monitor the beam transport. Furthermore, an FCT allows to control the beam charge that traverses the septum and thus infer the transfer efficiency.

The Booster is equipped with three **Synchrotron Radiation Monitors (SRM)** distributed around the ring. The SRM is a non-destructive method to infer the beam size using the synchrotron radiation produced when the beam traverses a bending magnet. As the FS setups, the light is directed by an optical system of lenses and mirrors towards a CCD camera, where the image is analyzed. This monitor becomes very useful to follow the beam size along the energy ramp, albeit at full energy (3 GeV) the image is affected by diffraction effects and hence a quantitative measurement cannot be provided [4].

The Booster disposes of a **DC Current Transformer (DCCT)**. Similarly to the FCT principle, the DCCT measures the beam intensity based on the magnetic flux induced by the electron beam. However, the DCCT includes a second magnetic modulator that detects the beam DC component using a feedback loop. With the commercially available electronics [2], we expect to achieve sensitivities down to 1 μA/$\sqrt{\text{Hz}}$ (enough for our purposes).

We also instal an **Annular Electrode (AE)**. In this case, an electrode surrounds the inner part of the vacuum chamber, and so when the beam goes through, the electrode detects the complete beam's charge. The advantage of this system is its up to 8 GHz bandwidth [5], permitting bunch length measurements during the energy ramping (yet it is not enough to quantitatively measure the bunch length at top energy).

A total of 44 **Beam Position Monitors (BPM)** are installed around the Booster. The BPM intrinsic resolution is 45.5μm [6] for a beam current of 0.1 mA and a revolution frequency of 1.2 MHz. With 44 horizontal and 28 vertical correctors, simulations show that the orbit correction with this scheme allows an rms residual (at BPMs) below 0.5 mm in both planes [7], and so only 28 BPMs are equipped with the read out electronics.

A proper Booster performance requires the measurement of the betatron tunes. This is carried out using two 50Ω matched **striplines**: the first one excites the beam with an electric kick, the second one is used to obtain the transverse oscillations and thus infer the tune frequency. We have chosen two locations where the phase advance is as close as possible to 90^o in each plane. In an ulterior phase (after the Booster commissioning), and provided that the $\sim$1 mA Booster beam provides enough signal in the button BPMs, any of the 44 BPMs can be used.

Finnally, we have located a FS between the extraction kicker and the extraction septum. This FS is inserted horizontally and is able to intercept the beam orbit at injection (100 MeV) and at extraction (at 3 GeV, when the beam trajectory is kicked towards the BTS).

TRANSFER LINES: LTB AND BTS

The main parameter to care about in the transfer lines is the transmission efficiency. At the LTB, we monitor the beam charge using two BCMs, one installed at the beginning and one at the end of the transfer line. At the BTS, this measurement is performed with two FCTs installed as well at both edges of the BTS.

Both transfer lines dispose of three FS/OTRs, located at the beginning, middle and end of the BTS, which in addition to the SRMs located at the bending dipoles provide beam size and shape information. Together with the button BPMs (4 at each transfer line), this information is used to obtain a proper beam steering along the line and so improve the transfer efficiency.

STORAGE RING

Sections 2 and 3 in the SR are used for beam diagnostics. Figure 2 shows the 3-d sketch of section 2, showing an FS, DCCT, AE, FCT, together with a stripline that will provide the beam excitation for tune measurements. Conceptually identical to the systems installed in the Booster, the main difference is that the DCCT electronics in the SR case dispose of a high resolution module down to 0.5 μA/$\sqrt{\text{Hz}}$ [2] to increase the precision of the beam lifetime measurements.

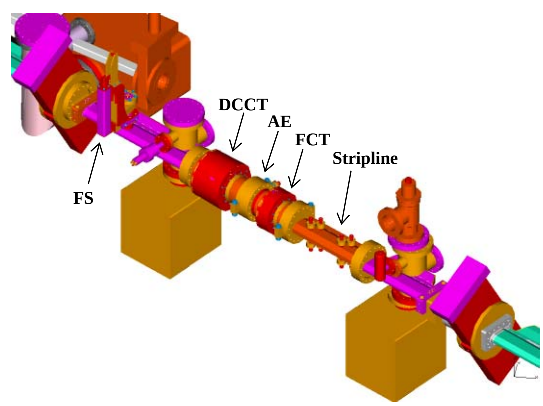

Figure 2: Beam diagnostics components in Sector 2.

Section 3 includes the horizontal and vertical feedback kickers. A feedback kicker consists of two horizontal (or vertical) electrodes of 30 cm length (a bucket length is 60 cm) that are intended to cure possible bunch-by-bunch instabilities using high frequency electric kicks. These kickers will not be installed since day one because their "picky" geometry is in turn a source of beam impedances [8]. We first want to study the SR behaviour without the kickers and, in case instabilities arise, we will install them to cure these instabilities.

Up to 120 BPMs are installed along the 16 cells of the SR. Furthermore, we dispose of 3 extra BPMs that will be used for bunch-by-bunch feedback and tune measurements. Position data from the BPMS are provided for the slow (∼1 Hz) orbit correction, fast (∼10 kHz) orbit correction, and turn by turn data (∼1 MHz). As an option, data acquisition can be changed upon demand. The intrinsic resolution depends on the bandwidth. At 4 kHz, the SR button provides a resolution of 0.11 μm for currents $\geq$ 10 mA [6].

Similarly to the Booster injection, the SR injection straight disposes of three FS to image the beam and optimize the injection efficiency. Moreover, two **scrapers (SCR)** are installed in this location to get rid of the undesired beam halo particles and protect the Insertion Devices from possible damages produced by mis-steered or off-energy beams. The bending dipoles immediately before and after the injection straight are used as diagnostics front ends. One of them uses the X-ray part of the Synchrotron Radiation to monitor the beam emittance, the second uses the Visible part for quantitative bunch length and bunch purity measurements. They are abbreviated as XSR and VSR, respectively.

X-ray Synchrotron Radiation front end (pinhole)

Because of the low SR emittance and the high energy beam, the beam transverse size is typically in the same range as cameras resolution (around 10μm). The simple principle of a pinhole system is widely used in synchrotron light sources to overcome this limitation. Since imaging using the visible range is diffraction limited, the pinhole system has to use the x-ray part of the spectrum of the synchrotron radiation. This is achieved with the Aluminum vacuum window and the Molybdenum filter. The pinhole system design at ALBA provides a magnification factor of 2, which is enough to avoid the screen resolution limitation. Details about the ALBA pinhole are shown in Ref. [4].

Visible Synchrotron Radiation front end

We have designed a front end that uses the visible part of the synchrotron radiation spectrum produced when the beam traverses a bending dipole [9]. This setup is based on the ESRF design [10]. The key system of this Visible Synchrotron Radiation (VSR) front end is a mirror that is inserted vertically. The mirror is placed in such a way that only the visible part of the spectrum is reflected and sent it to an optical hutch, where the light is analyzed by means of a streak camera. The streak camera uses a double sweep to perform quantitative bunch length measurements (with ps resolution) and allows to characterise longitudinal beam instabilities. The mirror is equipped with three thermocouples to avoid possible heat load damage in the mirror and to control its vertical position. In addition, we foresee the use of an Avalanche PhotoDiode that profits the x-ray part of this radiation (the part that is not reflected by the mirror) for bunch purity measurements in a similar design as [11].

SUMMARY

The diagnostics components that will be installed in the ALBA facility are presented. Using these components, we expect to measure (and hence, control) the beam parameters. Table 2 summaryzes the distribution of this components along the ALBA facility. The acronyms have been listed in the text. Further updates and their location around the facility can be followed at [12].

Table 2: Diagnostics distribution along ALBA. The SRM at the SR refer to the XSR and VSR described in the text.

	LI	LTB	BO	BTS	SR
FCUP	1	1	...	...	...
BCM	1	2	...	...	...
FCT	6	3	1	2	1
DCCT	...	...	1	...	1
FS/OTR	3	3	4	4	6
SRM	...	1	3	2	2*
BPM	1	3	44	4	123
Striplines	...	...	2	...	1
SCR	...	3	...	...	2

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