SYNCHROTRON RADIATION MONITORS AT ALBA

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Abstract

Synchrotron Radiation Monitors (SRM) are one of the most useful, non destructive tools, to easily obtain information of three important parameters for a synchrotron user: beam position, beam dimensions and beam stability. These monitors diagnose beam performance using the radiation produced when the beam traverses a bending magnet. An extensive usage of SRM, based on the visible part of the spectrum, is planned in the ALBA synchrotron: Linac, Booster, Transfer Lines and the Storage Ring. The latter will be equipped as well with a SRM based on the x-ray part of the spectrum, using the PinHole technique in order to accurately measure the low beam size and emittance. This paper describes the different SRM designs for the ALBA light source.

INTRODUCTION

The ALBA facility includes an injector consiting of a turn-key 100 MeV Linac and an intermediate Booster that accelerates the beam up to the full energy – 3 GeV. This system allows top-up injection mode into the Storage Ring (SR). Transfer lines drive the beam from the Linac to the Booster (LTB), and from the Booster to the Storage (BTS). Beam diagnostics systems are required for the initial machine commissioning, and, in routine operation, they are intended to improve machine performance.

We call Synchrotron Radiation Monitors (SRM) to those beam diagnostics systems that take the light coming from a magnetic element (in our case, a bending magnet) and use it to obtain a transverse image of the electron beam. This image is then analyzed to infer the horizontal and vertical beam size. The beam transverse sizes depend on the lattice parameters. Typical values for these sizes through the accelerator system at CELLS are listed in Table 1.

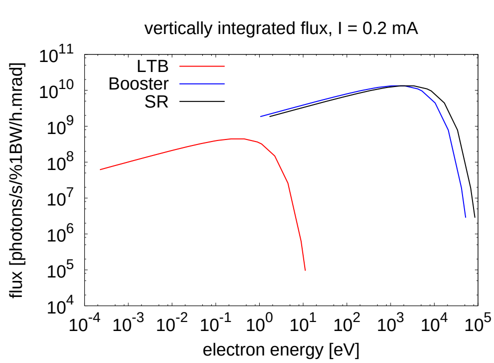

Figure 1: Fluxes along in the injector and SR for a beam current of 2mA.

In the ALBA injector, these monitors use the visible part of the synchrotron radiation, whence the name Visible Synchrotron Radiation (VSR) monitors. For the storage ring ALBA, this monitor uses the X-ray part of the synchrotron radiation, and we use XSR as its acronym. We also use a VSR in the SR for qualitative diagnostics. Figure 1 shows the fluxes produced when an electron beam crosses a bending dipole in the LTB, Booster, and SR. In the following, we review the effects affecting the monitors performance, and give a conceptual design for the VSR and XSR in ALBA.

Table 1: Injector and SR parameters at the ALBA.

Parameter	Linac Extract.	Booster Extract.	SR
energy, E [GeV]	0.1	3.0	3.0
magnetic field, B [T]	0.1686	0.873	1.42
bending angle, θ [^{o}]	8.75	5 & 10	11.25
hor. emittance, ϵ_x [nm-rad]	150	9	4.3
critical energy, ϵ_C [eV]	1.12	5225	8500
coupling	100%	10%	1%
hor. rms size, σ_x [mm]	< 1.8	< 0.3	0.062
ver. rms size, σ_y [mm]	< 1.8	< 0.10	0.03

VISIBLE SYNCHROTRON RADIATION MONITORS – VSR

Table 2 lists the distribution of SRM along the ALBA facility (Transfer lines, Booster, and SR). The basic conceptual design for the SRM along the injector is shown in Fig. 2.

Table 2: SRM at the ALBA synchrotron.

	LTB	Booster	BTS	SR
VSR	2	3	2	1
XSR	-	-	-	1

The photon beam produced by the synchrotron radiation when the electron beam traverses the bending dipole is extracted through a window, which can be made of sapphire to enhance the transparency in the visible range. The mirror (in air) is added to direct the light 90^o down, so that the optical equipment is not exposed to the beam radiation. The slit, or diaphragm, provides an aperture limitation to decrease the detrimental effects of the depth of field (see below). Finally, a lens focuses the image to the CCD camera. An alternative method is to place the mirror inside the vacuum chamber (before the sapphire window), but we much prefer the configuration described here to avoid complex cooling systems in the mirror.

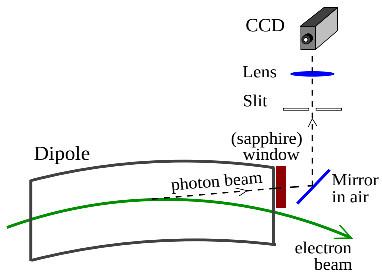

Figure 2: VSR schematic layout in an injector dipole. The mirror reflects the light 90^o down or up.

The image is affected by optical effects that have to be taken into account. The *curvature limit* makes the intrinsic beam profile to be further augmented by the horizontal broadening due to the curvature within the dipole. But the most image limiting effect is the *depth of field*, which accounts for the curvature limit and the distances in the optical system: a point source produces a point image if the point source is at focus, but its adjacent points are out of focus. If we call d_1 the distance from the source point to the lens, and d_2 the distance from the lens to the image (CCD screen), the apparent length is [1]

$$\sigma_{\rm dof} = \rho(\theta^2/2)d_2/d_1 \ , \tag{1}$$

where ρ is the curvature radius in the bending magnet, and θ is the fan width. This limit is not relevant if the detector uses the x-ray part of the spectrum. The aperture restriction in the horizontal plane (slit shown in Fig. 2) limits θ to minimize this effect. However, in practical situations this aperture restriction is often not needed because the optical system only focuses the centered image, and thus the adjacent points do not disturb the final image [2].

The lens will introduce some chromatic effects. To account for these effects using the visible part of the spectrum, we plan to use a double achromatic lens. Note that the depth of field does not affect the image in the vertical plane because curvature only occurs in the horizontal plane.

X-RAY SYNCHROTRON RADIATION MONITORS – XSR

In the SR, because of low emittances and high energy beams, the beam transverse size is typically in the same range as cameras resolution (around 10 μm). 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.

In a pinhole system, the image of a beam with general transverse size σ_u (the subindex u denotes either the horizontal or vertical direction) is amplified in a pinhole system by:

$$\sigma_{\rm image} = \sigma_u L_2/L_1 \ , \tag{2}$$

where L_1 is the distance from the object position (beam inside the dipole) to the pinhole position, and L_2 is the distance from the pinhole (sheet) to the screen where the image is formed. The screen resolution limitation is avoided if the magnification, i.e. the ratio L_2/L_1 is large enough.

System geometry

The pinhole width w must be chosen in a trade-off between blurring and diffraction effects. The rms image "noise" produced by the blurring effects is,

$$\sigma_{\rm bl} = \frac{w(L_1+L_2)}{\sqrt{12}L_1} \ , \tag{3}$$

while the diffraction effects produce an rms signal of

$$\sigma_{\rm dif} = \left(\frac{\sqrt{12}}{4\pi}\right)\frac{\lambda L_2}{w} \ , \tag{4}$$

where λ is the wavelength of the light. This noise is minimized when the diffraction contribution equalizes the blurring effects (see Fig. 3). This plot shows the diffraction and blurring effects considering a $\lambda = 12$ nm (corresponding to the peak emission for Molybdenum), which sets the optimum pinhole width to $w_{\rm opt} \sim 20\mu m$.

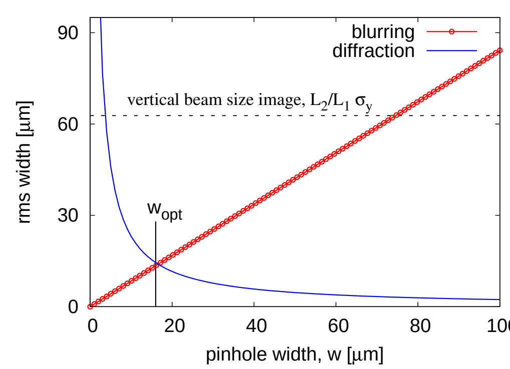

Figure 3: Blurring and diffraction effects as a function of the pinhole width, w. The dotted line shows the rms vertical beam size considering $L_2/L_1 = 2$.

From Eq. 2, it follows that small values of L_1 and large values of L_2 are desired. This condition is limited by the available space between the SR dipole, shielding wall, and the required instrumentation to easy alignment, vacuum and safety issues. The final distribution is sketched in Fig. 4. A detailed description of the components in the beam line can be found in Ref. [3]. Taking into account the space for these components, the lengths for the XSR are $L_1 = 6$ m and $L_2 = 12$ m.

We decide to place the filters in front of the pinhole sheet to decrease the heat load into the pinhole sheet. This avoids the design of an *ad-hoc* system to cool down the pinhole sheet. The filters are required to 1) control the photon flux (to avoid screen saturation), and 2) produce a monochromatic light to avoid possible chromatic effects. The present

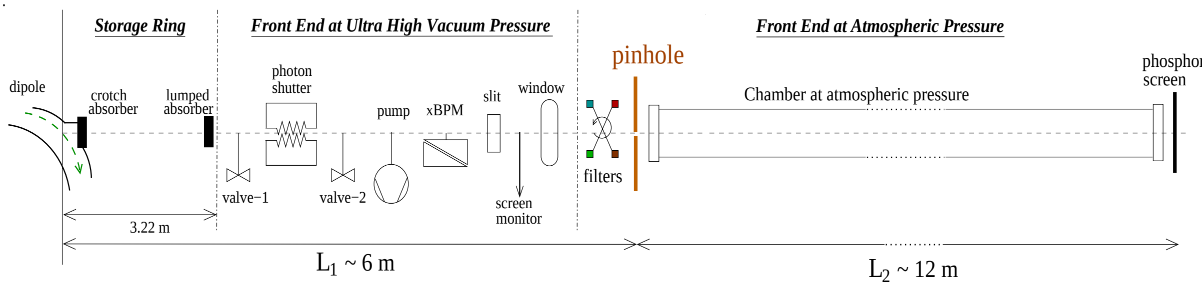

Figure 4: Sketch with the required components to be installed in the XSR [3]. Distances are not to scale.

material choice is Molybdenum, whose emission peak is at 17 keV ($\lambda = 12$ nm).

Finnally, after 12 m of drift space, the image is formed in a phosphor screen and an optical system (similar to the VSR) transports the image from the phosphor screen to the CCD camera.

Heat load

The heat load in the XSR components produced by synchrotron radiation must be carefully considered to avoid possible detrimental effects. The power received by each component when the electron beam traverses a SR bending magnet at nominal conditions (3 GeV energy and 400 mA current) is shown in Table 3. Most components can be bought "off-the-shelf" with the appropriate cooling system (photon shutter, slit, etc).

Table 3: Heat load at the XSR components. The power at the pinhole (downstream the filters) is less than 35 mW.

component	photon shutter	slit	screen monitor	vacuum window	filters
power [W]	195	130	65	45	20

However, due attention must be paid to the vacuum window. This has to withstand both the heat load and the pressure difference, and simultaneously, it must have enough x-ray transparency. The most stringent difficulty to efficiently cool the window down does not stem from the total power (45 W, see Table 3), but from the power density (up to 4.9 W/mm^2 [4]). A Finite Elements analysis has been performed to study the temperature and stress at the vacuum window [5]. The temperature distribution is shown in Fig. 5. The cooling system must avoid possible thermal deformations, which either by themselves or in conjunction with the pressure stress could fatally affect the window. The trade-off solution is a 1 mm thickness of Aluminum with water and air cooling [4, 5].

The power received by filters amounts to 20 W, thus the design of a cooling system for this component is not ruled out. However, the filters act as well as a radiation shielding for the pinhole sheet, which will receive less than 35 mW.

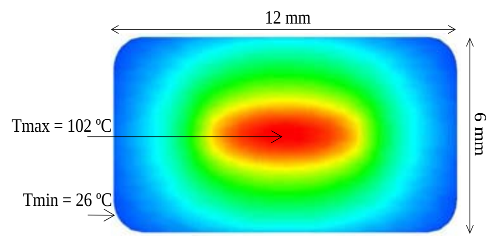

Figure 5: Temperature distribution in the XSR vacuum window. Courtesy of B. Calcagno [5].

SUMMARY

The effects to take into account when designing SRMs using the spectrum produced by an electron beam as it crosses a bending magnet are reviewed. We propose to install enough SRMs to be able to follow the beam size evolution from the Linac exit until the beam is stored in the SR. Designs to improve performance of VSR and XSR are presented. For both designs, but especially for the XSR, the components location have been chosen to reduce the heat load produced by the synchrotron radiation.

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