A SECOND BEAM-DIAGNOSTIC BEAMLINE FOR THE ADVANCED LIGHT SOURCE*

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Abstract

A second beamline, BL 7.2, completely dedicated to beam diagnostics is being installed at the Advanced Light Source (ALS). The design has been optimized for the measurement of the momentum spread and emittance of the stored beam in combination with the existing diagnostic beamline, BL 3.1. A detailed analysis of the experimental error has allowed the definition of the system parameters. The obtained requirements found a good matching with a simple and reliable system based on the detection of X-ray synchrotron radiation (SR) through a pinhole system. The actual beamline, which also includes a port for visible and infrared SR as well as an X-ray beam position monitor (BPM), is mainly based on the design of two similar diagnostic beamlines at BESSY II. This approach allowed a significant saving in time, cost and engineering effort. The design criteria, including a summary of the experimental error analysis, as well as a brief description of the beamline are presented.

INTRODUCTION

Diagnostic beamlines using synchrotron radiation (SR) are a powerful tool for measuring storage ring parameters. In our case, we were particularly interested in measuring emittance and momentum spread of the ALS electron beam. The new beamline, BL 7.2, while allowing several different measurements, has been optimized for the measurement of these two quantities in combination with the existing diagnostic beam line, BL 3.1. In this paper we present a summary of the experimental error analysis that allowed defining the new system specifications, the pinhole system that we select as a best requirement matching and a general description of BL 7.3 features. The new beamline is presently under installation and will be commissioned in August this year.

THE MOMENTUM SPREAD-EMITTANCE MEASUREMENT

For a beam at equilibrium the transverse beam size is given by the combination of the emittance and momentum spread terms. For the horizontal rms size we can write:

$$x_{rms} = \left(\beta_x \, \varepsilon \frac{1}{1+\kappa} + \left(\eta_x \frac{\sigma_p}{p} \right)^2 \right)^{1/2} \qquad (1)$$

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where β_x and η_x are the horizontal beta function and dispersion at the point of observation, ε is the natural emittance, κ is the emittance ratio and σ_p /p is the rms relative momentum spread. If horizontal beam size measurements in two different points of the machine are performed and the optical functions at the observation points are known, it is straightforward by using equation (1) to extract the values of the horizontal emittance and of the momentum spread:

$$\varepsilon_x = \frac{\varepsilon}{1+\kappa} = \frac{x_{rms1}^2 \eta_{x2}^2 - x_{rms2}^2 \eta_{x1}^2}{\beta_{x1}\eta_{x2}^2 - \beta_{x2}\eta_{x1}^2} \qquad (2)$$

$$(\delta\, p)^2 = \left(\frac{\sigma_p}{p} \right)^2 = \frac{x_{rms2}^2 \beta_{x1} - x_{rms1}^2 \beta_{x2}}{\beta_{x1}\eta_{x2}^2 - \beta_{x2}\eta_{x1}^2} \qquad (3)$$

Here and throughout the paper the index $i = 1$ refers to the new BL 7.2 and $i = 2$ to the existing BL 3.1.

Experimental Error Analysis

In order to define the specifications for the new beamline a complete analysis of the experimental error has been performed [1]. As example, we report here the expression obtained by propagating the error on equation (3):

$$\begin{aligned} \frac{\sigma_{\partial p}^2}{\partial p^2} = {} & \mathrm{M}_{\partial p1} \frac{\sigma_{M1}^2}{M_1^2} + \mathrm{M}_{\partial p2} \frac{\sigma_{M2}^2}{M_2^2} + P_{\partial p1} \frac{\sigma_{px1}^2}{p_{x1}^2} + P_{\partial p2} \frac{\sigma_{px2}^2}{p_{x2}^2} + \\ & + R_{\partial p1} \frac{\sigma_{x_{R1}}^2}{x_{R1}^2} R_{\partial p2} \frac{\sigma_{x_{R2}}^2}{x_{R2}^2} + \Gamma_{\partial p1} \frac{\sigma_{g1}^2}{\bar{g}_1^{\,2}} + \Gamma_{\partial p2} \frac{\sigma_{g2}^2}{\bar{g}_2^{\,2}} + \\ & + B_{\partial p1} \frac{\sigma_{\beta_{x1}}^2}{\beta_{x1}^2} + B_{\partial p2} \frac{\sigma_{\beta_{x2}}^2}{\beta_{x2}^2} + B_{\partial p12} \frac{\sigma_{\beta_{x1}\beta_{x2}}}{\beta_{x1}\beta_{x2}} + \Pi_{\partial p} \frac{\sigma_p^2}{p^2} \end{aligned} \qquad (4)$$

Equation (4) shows the dependence of the experimental error on the errors of the single parameter of the actual measurement system: M_i is the total magnification of the i-th system, p_{xi} is the pixel size (CCD or phosphor), x_{Ri} is the system resolution and the quantity g_i defined as the 'digital amplitude' is the numerical amplitude of the signal at the ADC frame grabber at the end of the acquisition chain. For a Gaussian distribution [1]:

$$\frac{\sigma_{gi}^2}{\bar{g}_i^{\,2}} = \frac{\ln\left[D_i \left(2^{bi} - 1 \right) \right]}{3\pi \, D_i^2 \left(2^{bi} - 1 \right)^2} \qquad (5)$$

where b_i is the number of bits of the ADC and $0 \leq D \leq 1$ is the 'dynamics factor', a numerical quantity indicating the percentage of the system dynamics used in the measurement. The coefficients of the error terms in equation (4) are functions of the source point and measurement system parameters. For example:

$$R_{\delta p2} = \left(\frac{x_{R2}^2}{x_{rms2}^2} \right)^2 H_{X22} \qquad (6)$$

with

$$H_{X22} = \frac{\beta_{x1}^2 x_{rms2}^4}{\left(\beta_{x1} x_{rms2}^2 - \beta_{x2} x_{rms1}^2\right)^2} \qquad (7)$$

Equation (4) and the similar expression for the emittance have been systematically evaluated for the ALS case (Table 1) as a function of all the measurement system parameters. Figure 1 shows some examples.

Table 1: ALS Parameters

ALS Parameter	BL 7.2	BL 3.1
βx [m]	0.9	0.35
ηx [m]	0.07	0.03
xrms [µm]	105	57.1
Energy [GeV]	1.9	
Current [mA]	400	
Critical Energy [keV]	3.07	
Natural Emittance [nm]	6.9	
Natural Energy Spread	0.001	

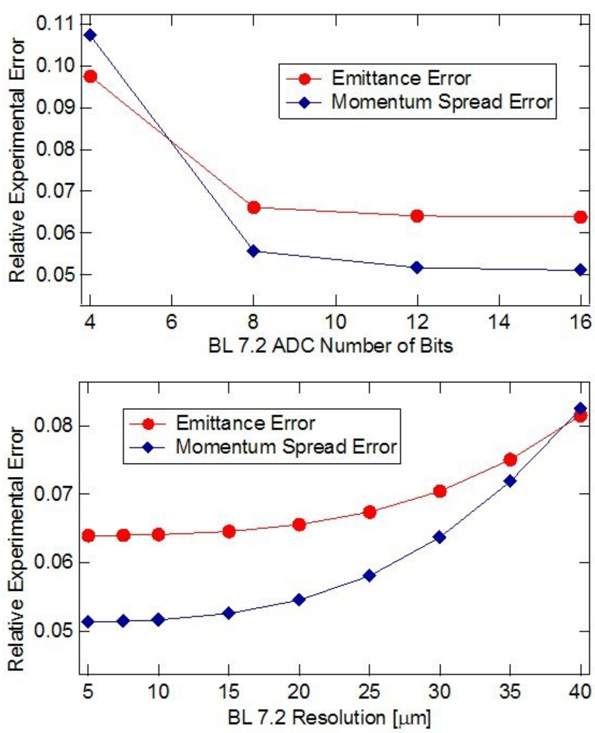

Figure 1: Experimental error as function of the BL 7.2 ADC number of bits (top) and resolution (bottom).

The complete error analysis brought to the specifications for the new system shown in Table 2.

Table 2: BL 7.2 Specifications

Parameter Specification	Value
Resolution [µm]	≤ 25
Pixel size [µm]	≤ 10
Total magnification	≥ 1
ADC number of bits	≥ 8
Dynamics factor	≥ 0.5

The resolution requirement finds a good matching with a very simple and reliable system based on the detection of X-ray synchrotron radiation through a pinhole system.

THE PINHOLE SYSTEM

The pinhole shown in Figure 2 is the simplest system for performing profile measurements.

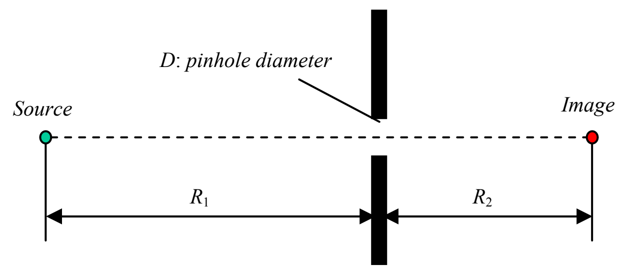

Figure 2: Pinhole System Schematics.

The magnification of the system is R_2/R_1 while the total resolution is given by [2]:

$$x_R = \sqrt{\frac{4}{25} R_1^2 \frac{\lambda^2}{D^2} + \frac{1}{16}\left(1 + \frac{R_1}{R_2}\right)^2 D^2} \qquad (8)$$

where λ is the wavelength of the radiation used for the measurement and the other quantities are defined in Figure 2. The first term in the right hand side of equation (8) is due to diffraction while the second is due to the geometry of the system. For the optimum pinhole diameter:

$$D_{OPT} = \sqrt{\frac{8}{5} \frac{R_1 R_2}{R_1 + R_2} \lambda} \qquad (9)$$

the two contributing terms become equal and the resolution assumes its minimum:

$$x_{R\ \min} = \sqrt{\frac{1}{5} R_1 \left(1 + \frac{R_1}{R_2}\right) \lambda} \qquad (10)$$

BEAM LINE 7.2 DESCRIPTION

BL 7.2 was mainly based on the design of similar diagnostic beamlines at BESSY II [3] allowing a significant saving in time, cost and engineering effort. With reference to Figure 2, a variable thickness Molybdenum filter has been inserted between the pinhole and the image plane with the double role of band-pass filter for the proper selection of the radiation wavelength and as a variable attenuator. Downstream the filter at the image plane, a phosphor screen allows the conversion from X-rays to visible light. The image is then collected and digitized by a system composed by a remotely controlled zoom, a CCD camera and a frame grabber. Table 3 summarizes BL 7.2 parameters while Table 4 shows the characteristics of the five positions filter-attenuator used in the system.

Table 3: BL 7.2 Characteristics

BL 7.2 Parameter	Value
R1 [m]	6.08
R2 [m]	2.04
Pinhole Diameter [μm]	20
CCD Pixel size [μm]	8.6
Total maximum magnification	1.31
ADC number of bits	8
Dynamics factor	≥ 0.5

Table 4: BL 7.2 Filter-Attenuator Characteristics

Pos.	Mater.	Thick. [μm]	Flux [ph/s]	Attn. Factor	<E> [keV]	σ_E [keV]	x_R [μm]
1	Al	10	$2.3\ 10^{11}$	1	8.5	3.6	26.7
2	Mo	5	$6.3\ 10^{10}$	3.7	10.8	3.7	24.3
3	Mo	20	$1.5\ 10^{10}$	15.3	13.3	3.3	22.9
4	Mo	50	$3.9\ 10^{9}$	59.0	15.1	2.7	22.3
5	Mo	90	$1.2\ 10^{9}$	192	16.3	2.2	21.9

The fourth column of Table 4 shows the flux of photons impinging the phosphor downstream the filter at the nominal ALS current. The intensity is large enough to allow low error profile measurements with stored currents much smaller than the nominal maintaining at the same time a reasonable integration time. The sixth and seventh columns of the table show respectively the average energy and the rms energy spread of the filtered photons. The last column indicates the system resolution obtainable with the different filters.

Table 5 summarizes the performances of the system for different measurements. It must be remarked that the minimum value for the emittance and momentum spread experimental error is mainly defined by the optical functions at the two source points and cannot be significantly reduced by a further adjustment of the BL 7.2 parameters.

Preliminary resolution studies considering the polarization of the synchrotron radiation [4] have shown a better resolution for the pinhole system than the one calculated by using expression (8). In fact, due to the nature of the SR the photons passing through the small pinhole are naturally polarized in the machine plane. The diffraction figure for such a polarization is smaller than for the case of non-polarized light with beneficial impact on the resolution. A more precise characterization of such effect is under way.

Table 5: BL 7.2 Calculated Performances

Measurement Type	Experimental Error (rms value)
Momentum Spread	5.6 %
Horizontal Emittance	6.6 %
Horizontal Beam Size	1.3 %
Horizontal Dispersion	1.2 %
Horizontal Distribution Centroid	1.1 %

In the actual design, BL 7.2 has a matrix of 21 rows and 11 columns of pinholes instead of a single pinhole. As described in reference [3], this configuration allows the measurement of other quantities such as emission and aperture angles of the SR at the source. The remotely controlled zoom lens permits passing from the high resolution mode, where only the central pinhole is visible, to the low resolution one where the whole pinhole matrix can be viewed.

Another feature of BL 7.2 is the presence of an X-ray beam position monitor for the measurement of the electron beam orbit position and angle at BL 7.2 source point. The system, which is of the same kind of the ones in successful operation at BESSY II, is based on the differential measurement of the electron secondary emission induced on two metallic blades by the SR [3].

Finally, a special BL 7.2 port dedicated to visible and infrared SR can be used for several different electron beam measurements including longitudinal distribution profile and motion, transversal motion and coherent effects in the SR at the infrared and far-infrared wavelength.

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