COMMISSIONING OF BL 7.2, THE NEW DIAGNOSTIC BEAM LINE AT THE ALS*

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Abstract

BL 7.2 is a new beamline at the Advanced Light Source (ALS) of the Lawrence Berkeley National Laboratory (LBNL) dedicated to electron beam diagnostics. The system, which is basically a hard x-ray pinhole camera, was installed in the storage ring in August 2003 and commissioning with the ALS electron beam followed immediately after. In this paper the commissioning results are presented together with the description of the relevant measurements performed for the beamline characterization.

INTRODUCTION

BL 7.2, a second diagnostics beamline at the Advanced Light Source (ALS) [1, 2], was designed with the main goal of measuring the horizontal beam size for emittance and momentum spread measurements, in combination with the other ALS diagnostics beamline BL 3.1. The installation of BL 7.2 was completed in August 2003 and the commissioning started right after. The beamline performance has been experimentally characterized and compared with the design figures. The results were quite satisfactory overall and the beamline is now in routine operation. The only design parameter not yet completely achieved is the one for the system resolution. However, a series of dedicated measurements indicated the origin of the problem, and it will be corrected in the near future.

BEAM LINE DESCRIPTION

A detailed description of BL 7.2 architecture can be found elsewhere [1]; here we present a summary of the main characteristics and describe the new parts of the beamline. Figure 1 shows a 3D layout of BL 7.2. The design is based on two similar beamlines at BESSY II [3] and has been adapted to the ALS characteristics. BL 7.2 includes two photon lines: one basically an in-vacuum hard x-ray pinhole camera, the other a multiple use line with a x-ray beam position monitor and a visible-IR port. This second line, designed for beam longitudinal distribution measurements and for IR radiation experiments, is not yet completely installed. This paper describes the results of the commissioning of the pinhole camera system.

The ALS is a 3rd generation light source operating at 1.9 GeV. The BL7.2 source point is inside the central dipole magnet of the triple bend achromat cell. The rms beam size at the source point is ~ 100 µm horizontally and ~ 10 µm vertically. Table 1 shows the main characteristics of BL 7.2. Instead of a single pinhole, a matrix of pinholes is used, allowing for more flexibility in the measurements, easier alignment and as explained later, accurate calibration of the image size. Downstream of the pinhole array, a filter-attenuator system selects the bandwidth and the flux of the x-ray radiation. Table 2 shows the characteristics of such a system and in the last column, the resolution values associated with the selected filter.

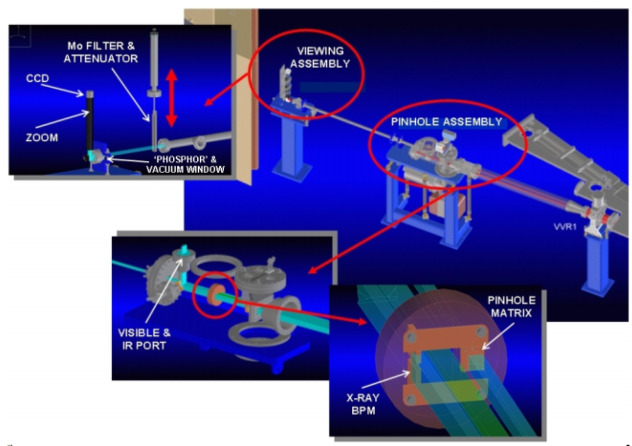

Figure 1: BL 7.2 3D layout.

Table 1: BL 7.2 pinhole system main characteristics

Distance source-pinhole [m]	6.08
Distance pinhole-image [m]	2.04
Pinhole diameter [µm]	20
System maximum magnification	1.31
Phosphor pixel size [µm] (x-ray to visible converter)	~ 1
CCD pixel size [µm]	~ 10
ADC number of bits	8

Table 2: BL 7.2 filter-attenuator design characteristics. Quantities are calculated for 400 mA at 1.9 GeV.

Pos.	Mater.	Thick. [µm]	Flux [ph/s]	Attn. Factor	<E> [keV]	σ_E [keV]	σ_R [µm]
1	Al	10	$1.5\ 10^{11}$	1	8.2	4.0	27.1
2	Mo+Al	5+10	$3.9\ 10^{10}$	3.97	11.0	3.8	24.2
3	Mo+Al	20+10	$1.0\ 10^{10}$	15.3	13.5	3.4	22.8
4	Mo+Al	50+10	$2.6\ 10^{9}$	59.8	15.3	2.7	22.2
5	Mo+Al	90+10	$7.8\ 10^{8}$	196	16.4	2.2	21.9

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After the filter, the x-rays are converted into visible light by a 'phosphor' screen. Finally, the image of the beam on the phosphor is captured by an analog CCD camera equipped with a zoom, which controls the overall system magnification. All remote components are controlled via serial RS 485, including the filter-attenuator selection, the zoom and focus settings and the CCD parameters.

The entire beamline control system and analysis software runs on a single 2.66 GHz Pentium IV under Linux. The images from the monochromatic analog CCD are captured and converted to 640 x 480 pixel images by an 8 bit Matrox Meteor II frame grabber card. The self-developed software for both controls and image analysis is written in C. The graphical user interfaces (GUI) for the respective systems were written using the free source packages Epics and wxWidgets. The computer is part of the ALS local network and the image analysis results, saved as Epics process variables (PV), are easily accessible by external applications and are regularly archived in the ALS database. The image analysis software is continuously running and updating the PVs with calculation results at a frequency rate of about 5 Hz. Main calculations include background subtraction, image tilt angle evaluation and fitting of the image by a 2D analytical gaussian fit. Multiple GUI windows, such as the one shown in Figure 2, can be simultaneously open for monitoring results and setting data analysis parameters. A separate Epics GUI allows control of the RS 485 interfaced components.

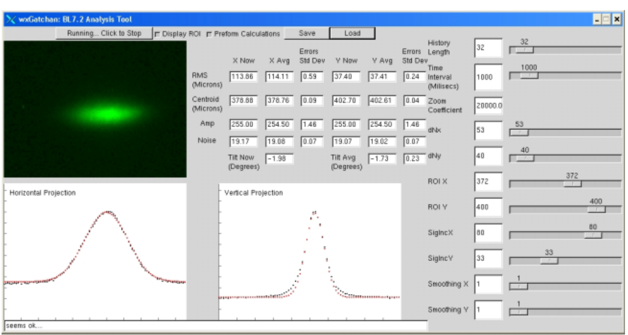

Figure 2: Image analysis graphical user interface during a measurement of the ALS beam.

BEAMLINE CHARACTERIZATION

Several beam and bench measurements have been performed for the beamline characterization. A summary follows.

Initial Results

The very first operation of the beamline was overall smooth and straightforward. Very positive results were the quite uniform and low background level and the extremely rich flux of photons that allows measuring stored currents smaller than 1 mA. On the other hand, two problems were observed and fixed during this phase. In the first case, a poorly filtered power supply for the CCD was generating a bright horizontal band moving vertically along the image. The second problem was more subtle: the Linux driver for the Matrox frame grabber was swapping every other line of the image, creating "comb-like" vertical profiles of the beam.

Bench and Beam Calibration of the Image Size

The calibration of the BL 7.2 image size is straightforward because of the presence of a matrix of pinholes with well known mutual distance. Even in the highest resolution mode, where the zoom is set on its largest focal length, two images of the beam are present on a single CCD frame. The calibration can be performed by simply measuring the number of pixels separating the two image centroids and dividing the result by the known distance. Bench and beam calibration of the image size as a function of the zoom focal length were both performed and agreed well, as shown in Figure 3.

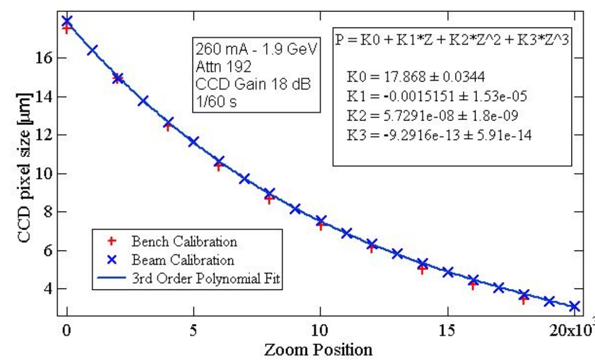

Figure 3: Image pixel size calibration.

Filter-Attenuation System Calibration

The calibration of the attenuation of the Mo-Al filters were performed using beam measurements. Images of the beam with same stored current were analyzed for the different filters. The ratio between the peak values of the measured distributions provides the relative attenuation values. The results are shown in Figure 4.

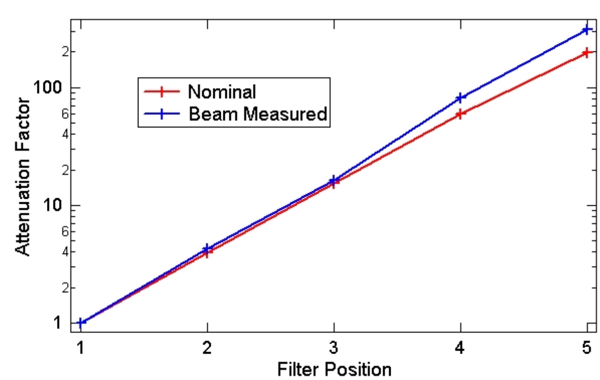

Figure 4: Calibration of the filter-attenuation system.

Resolution Measurement

In electron storage rings where the beam lifetime is dominated by the Toushek effect (Coulomb scattering between the electrons in a bunch), combined measurements of beam size and lifetime allow deriving the resolution of the system being used for measuring the beam size. In such a situation, the beam lifetime τ is given by:

$$\tau^2 = \frac{a}{I_b^2}\left(\sigma_x^2 - \sigma_R^2\right)\left(\sigma_y^2 - \sigma_R^2\right) \qquad (1)$$

where a is a constant, I_b is the current per bunch, σ_x and σ_y are the measured horizontal and vertical rms beam sizes respectively and σ_R is the resolution of the measuring system. In deriving Equation (1) two assumptions were made: i) the resolution is the same in both vertical and horizontal planes and ii) the bunch length is constant at the currents used during the measurement.

By changing the beam size (using skew quadrupoles for example) and simultaneously measuring current, beam lifetime and horizontal and vertical sizes, it is possible to derive the system resolution using equation (1) for fitting the data.

It is important that during this measurement, the overall momentum acceptance of the ring must remain constant. For example, changing the beam size using skew quadrupoles could modify the dynamic aperture of the machine. If the momentum acceptance is dominated by the dynamic aperture term, the accuracy of the resolution measurement could suffer. A simple way to avoid this problem is to reduce the RF power enough that the momentum acceptance is totally defined by the RF bucket size.

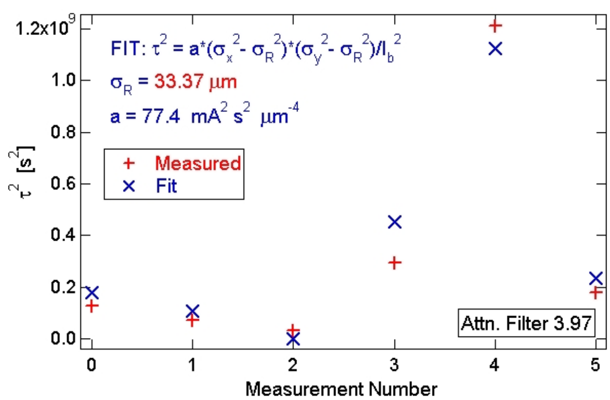

Figure 5: BL 7.2 resolution measurement.

The ALS is a Toushek dominated storage ring and Figure 5 shows an example of this measurement technique applied to BL 7.2 with the filter in the position 2 of Table 2. The measured resolution (~ 33 µm) is significantly larger that the design one (~ 24 µm). Additional measurements showed a similar situation for the other filter positions with the best resolution value measured at ~ 30 µm.

As mentioned in the introduction, BL 7.2 was designed for measuring the ~ 100 µm horizontal beam size during the emittance-energy spread measurement. A resolution of 30 µm adds in quadrature with the actual beam size giving a few percent overestimated measurement. Such a small error is easily removed by de-convolving the resolution effect and will not affect the accuracy of the emittance-momentum spread measurements. On the other hand we wanted to understand the reason for the problem, so we began a series of dedicated measurements and investigations. First, we checked our resolution formulae in [1] by means of the SRW code [4] and no inconsistency was found. Pinhole dilation effects were totally negligible and vibration measurements on different parts of the beamline showed effects smaller than 1 µm. Finally, we measured the diameter of several pinholes on spare pinhole matrixes. Two sets of independent measurements, using an electron microscope and a transmitted light device, showed diameters significantly larger than the design goal. Such differences in the diameters are consistent with the larger resolution values we measured. The holes were drilled in a 150 µm thick tungsten plate by laser ablation. At the present time, we are investigating the possibilities of having a better quality pinhole matrix made by the same technique, or of moving towards a different drilling technology.

CONCLUSIONS AND FUTURE PLANS

The x-ray pinhole camera system of BL 7.2, the new diagnostic beamline at the ALS, has been successfully commissioned and is now in routine operation. All the design parameters were achieved with only the exception of the system resolution, which is larger than expected. The reason for this discrepancy has been understood and the problem will be fixed in the near future. Even with the larger resolution the beamline can accurately perform all the measurements it was designed for.

Plans for the future also include the completion of the second photon line with the x-ray BPM system and the IR-visible port.

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