PETRA III DIAGNOSTICS BEAMLINE FOR EMITTANCE MEASUREMENTS

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Abstract

The new 3rd generation hard x-ray synchrotron light source PETRA III at DESY operates at a beam energy of 6 GeV with an extremely small horizontal design emittance of $1\ \mathrm{nm\,rad}$. For a precise emittance online control, a dedicated diagnostics beamline was built up to image the beam profile with synchrotron radiation (SR) from a bending magnet in the x-ray region. The beamline is equipped with two interchangeable x-ray optical systems, a pinhole optic for standard operation and a high resolution compound refractive lens optic. This article describes the setup and reports about first experience with these systems.

INTRODUCTION

PETRA III is the new 3rd generation hard x-ray synchrotron light source at DESY in Hamburg, operating at 6 GeV beam energy [1]. This new facility is the result of a conversion of the existing storage ring PETRA II into a dedicated light source which started middle of 2007. Machine commissioning began in April 2009 and user operation started in 2010. In order to achieve the required brilliance, damping wigglers with a total length of 80 m are installed to reduce the horizontal emittance down to an extremely low value of $1\ \mathrm{nm\,rad}$ with a design emittance coupling of 1%.

To guarantee optimal user performance, a precise online determination of the beam emittance is essential. While the emittance itself is not a directly accessible quantity, the beam size is usually measured from which the corresponding emittances can be calculated based on the knowledge of the beam optic parameters. SR from a bending magnet is a versatile tool for beam size measurements and is widely used at different accelerators [2].

To resolve beam profiles in the order of a few tens of μm, at PETRA imaging is performed at 20 keV photon energy. A dedicated diagnostics beamline was built up to image the beam profile via bending magnet SR using two interchangeable x-ray optical systems: a pinhole optic for standard operation and a high resolution compound refractive lens (CRL) optic. In addition, the SR angular distribution can be exploited at high photon energies. In the following the beamline setup together with first experience during the machine commissioning are comprised.

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BEAMLINE SETUP

The diagnostics beamline is located at the end of the new PETRA experimental hall. With an overall length of about 15 m the whole beamline is situated in the accelerator tunnel. SR with a critical energy of 20.9 keV is produced in the central field of a 1 m long standard dipole. According to the beam optical design parameters the electron beam has an rms size of σ_x = 42.5 μm and σ_y = 18.5 μm at the source point of the beamline.

For the design current of 100 mA the total emitted SR power amounts to 3.5 kW. A water cooled absorber located 5.1 m behind the source point with a rectangular aperture of 1×10 mm^2 reduces the power entering the photon beamline to about 15 W. The x–ray part of the emitted radiation is used to image the beam spot onto a CCD via two interchangeable x-ray optical systems, a pinhole optic and a high resolution CRL optic. They will be described in more detail in the following subsection.

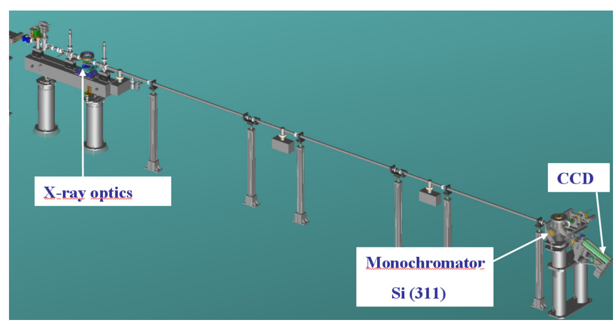

Figure 1: Sketch of the diagnostics beamline starting from the entrance absorber.

Fig. 1 shows a sketch of the diagnostics beamline. The x–ray optics are housed in a small vacuum chamber located 6.1 m behind the source point and mounted onto motorized stages, allowing to exchange the optical systems and to align the optics with respect to the beam axis in three degrees of freedom: two linear translations perpendicular to the beam axis and the rotation around the vertical axis. The whole system is placed onto a beamline girder made of granite together with diagnostic screens for photon beam steering. A valve and a water cooled shutter separate the beamline from the accelerator vacuum system in case of maintenance.

In order to minimize chromatic effects in the CRL imaging, a monochromator selects the first harmonic in Laue geometry from the (311) reflection of a 0.2 mm thick

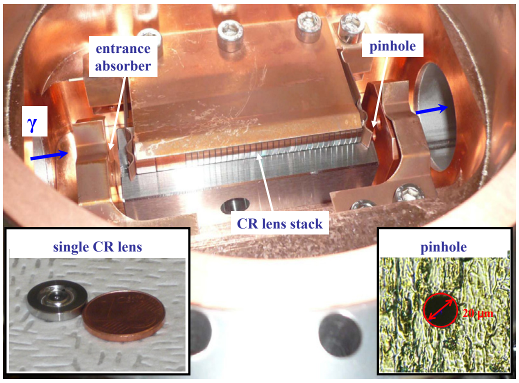

Figure 2: View inside the vacuum chamber for the x–ray optics. The left insert shows a single refractive lens together with a coin of 1 Cent, the right one a photo of the 20 μm pinhole which was laser drilled in a 0.5 mm thick W absorber.

Si crystal at 20 keV. For this purpose the monochromator setup already used at PETRA II was slightly modified [3]. The water cooled crystal is housed in a small vacuum chamber 8.8 m downstream of the x-ray optics. It can be aligned remotely controlled from outside. A linear translation stage moves the crystal along the horizontal axis in and out of the photon beam. A differentially pumped rotary feed through allows the precise adjustment of the nominal Bragg angle Θ_0 = 10.91°, while a rotation around the beam axis is realized via a tilting stage.

The electron beam is imaged either with non–monochromatized SR in straight direction or with monochromatized 20 keV SR deflected under the angle of $2\Theta_0$ out of the orbit plane. During the commissioning phase both detection systems consist of a LYSO scintillator to convert the incoming x–rays into visible light, a 12 bit GigE CCD camera (Prosilica GC 1350) with 4.65 $\times$ 4.65 μm^2 pixel size, and a precision telecentric objective with optical magnification of 2 (Sill S5LPJ2426) to image the scintillation light spot onto the CCD chip. Read-out is performed via the TINE–based video system VSv3 [4]. Taking into account the magnification of the x-ray optical systems by a factor of about 1.55 together with the light optical magnification, each pixel dimension on the CCD corresponds to a size of 1.5 μm in the source plane. The overall light optical resolution was measured to be about 6 μm. In order to improve the optical resolution down to the level of 1–2 μm, an exchange of the camera system behind the monochromator via a high resolution x-ray CCD system (Hamamatsu AA50) is in preparation.

X-ray optical system

Fig. 2 shows a photo of the open housing for the x-ray optics together with the optical systems and absorbers. All components inside the chamber are water cooled. The 10 mm thick entrance absorber made of Cu serves as additional heat load protection of the downstream components. It has three bore holes aligned vertically to allow the passage of SR. By moving the vacuum chamber in vertical direction it is possible to interchange the optics between a CRL system, a 20 μm pinhole, and free passage of the radiation to exploit the SR angular distribution.

The CRL system consists of 31 individual lenses made of Be and manufactured at the IInd Physical Institute, Aachen University (Germany) [5]. Each single lens is centered inside a ring made of hard metal alloy of 1.6 mm thickness. The lenses are stacked behind each other onto a high-precision V–profile shaft to align their optical axes along one common optical axis. Each lens surface has the shape of a concave rotational paraboloid with 200 μm for the design value of the radius of curvature at the apex, and a geometrical aperture of 0.9 mm. In order to adapt the SR spot size to the lens aperture and to minimize the heat load on the lenses an additional conical copper absorber with 0.8 mm free aperture is placed just in front of the lens stack onto the profile shaft. The focal length of the CRL system is 3.72 m with a calculated diffraction limit in the image plane of 0.3 μm (rms).

The pinhole is incorporated in the exit absorber. It consists of a 0.5 mm thick W plate with a bore hole of 20 μm diameter and was manufactured via laser drilling from Oxford Lasers [6]. The insert of Fig. 2 shows a photo of the drilled hole. The pinhole diameter is a result of an optimization similar to the one recently described in Ref. [7]. The point spread function at the SR critical energy was calculated in the image plane based on numerical near field calculations with the code SRW [8], and then convolved with the electron beam profile transformed in the image plane assuming ideal imaging without resolution broadening. The projections of this convolved profile were fitted with a normal distribution, and the pinhole resolution was derived by subtracting in quadrature the beam sizes from the fitted profile widths. The pinhole size of 20 μm opti-

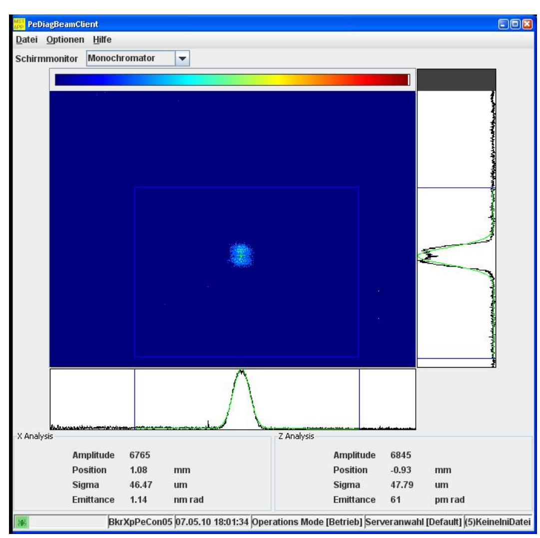

Figure 3: Screen shot of the CRL monitor display for online emittance monitoring.

mized by this method is in good agreement with the analytical expression given in Ref. [9], and the resulting pinhole resolution is $\Delta\sigma_x$ = 20 μm resp. $\Delta\sigma_y$ = 16 μm. In principle a resolution improvement could have been achieved by increasing the magnification of the x–ray pinhole camera. However, due to space limitations it was necessary to set up the complete beamline in the accelerator tunnel, and it was decided to use the CRL system as high resolution monitor.

OPERATIONAL EXPERIENCE

Since beginning of 2010 the diagnostics beamline is permanently in operation with the CRL optic, providing online information about the beam emittances. Fig. 3 shows a screen shot of the monitor display as seen in the accelerator control room. Images are taken with an update rate of 2 Hz. For emittance analysis these images are background corrected, and the projections are fitted with a normal distribution. As can be seen the measured horizontal emittance agrees well with the design value of 1 $\mathrm{nm\,rad}$. For the present setup the error in the emittance determination in estimated to amount ± 0.2 $\mathrm{nm\,rad}$, it will be further reduced with the new detector setup in preparation. However, the measurement of the vertical emittance suffers from an effect which seems to be related with the monochromator crystal: as can be seen from Fig. 3 the beam spot appears twice, slightly shifted in the dispersive vertical direction. This effect is better to see in the vertical projection which exhibits a pronounced minimum. The assumption of the image splitting connected with the monochromator is supported from the fact that it is seen for both x–ray optical systems using monochromatic imaging, but it is not observed with the detector setup in straight direction. Therefore a replacement of the present monochromator crystal is in preparation for the next accelerator shutdown period.

Apart from the distortion in the vertical profile Fig. 4 demonstrates the monitor sensitivity on beam size variations. In this case the dispersion was optimized by changing the accelerator RF. As can be seen from the measured sizes, variations in the sub-μm region are clearly visible.

The commissioning of the pinhole optics started recently. Fig. 5 shows one of the first beam images in direct observation without monochromator. The emittances deduced from that measurement are in good agreement with the design values, taking into account the calculated pinhole resolution in the emittance evaluation.

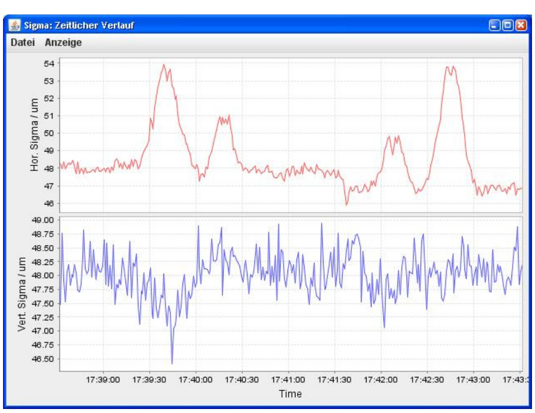

Figure 4: Time evolution of the beam sizes during dispersion correction.

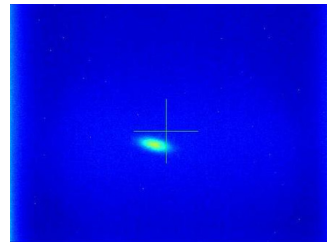

Figure 5: Beam image from the pinhole optic. The beam ellipse is tilted because of uncorrected skew quadrupole settings.

CONCLUSION

This article summarizes the setup and first operational experience with the PETRA III diagnostics beamline for emittance monitoring. It was demonstrated that a beam monitor based on imaging via CRL optics provides sub-μm resolution. Online horizontal beam emittances can be monitored with an error of about 0.2 $\mathrm{nm\,rad}$. Currently a precise online determination of the vertical emittance is affected by the monochromator crystal which will be exchanged in the nearest future.

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