

PRECISE MEASUREMENTS OF THE VERTICAL BEAM SIZE IN THE ANKA STORAGE RING WITH AN IN-AIR X-RAY DETECTOR

A.-S. Müller, I. Birkel, E. Huttel, P. Wesolowski, Karlsruhe Research Center, Germany
 B.K. Scheidt, ESRF, France

Abstract

A major part of the X-rays generated in the ANKA dipole magnets is unused by the experimental beamlines and is, on a number of dipoles, absorbed in a conical shaped Copper absorber. The 8 mm thickness that it presents lets a tiny fraction of the hard X-rays above 70 KeV enter the free air space behind it. The transmitted power of only a few $\mu\text{W}/\text{mrad}$ horizontally is sufficient to be detected, with sub-second measurement time, with a novel In-Air X-ray detector. This extremely compact and low-cost device is situated just behind the absorber. The design, developed and in use at the ESRF [1], is based on a Cadmium Tungstenate (CdWO_4) scintillator converting X-rays into visible light that is collected and focused onto a commercial CCD camera. Since the small vertical divergence of the high energy photons and the distance of the detector from the source point are known, it is possible to derive the vertical electron beam size with a high intrinsic precision. This paper presents results of beam size measurements as a function of various ANKA machine parameters, that illustrates the great diagnostic potential of this type of detector for a 2.5 GeV medium energy light source like ANKA.

INTRODUCTION

Of the emitted synchrotron radiation only a fraction is used by the experimental beamlines. The excess radiation has to be deposited in water cooled absorbers. The material that meets the photons is typically a combination of Fe and Cu. In order to transmit a sufficiently high flux of photons, the absorption length should not be too long. For the case of the ANKA storage ring's electron beam energy of 2.5 GeV, photons with energies above 50 keV can be transmitted through 8 mm copper, the peak of the transmitted flux being at 80 keV. A conical type of absorber, shield-

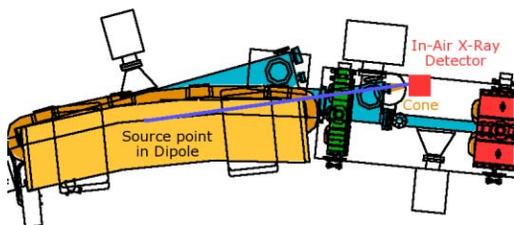


Figure 1: Location of the In-Air X-ray detector behind a conical absorber shielding the mid-bend port.

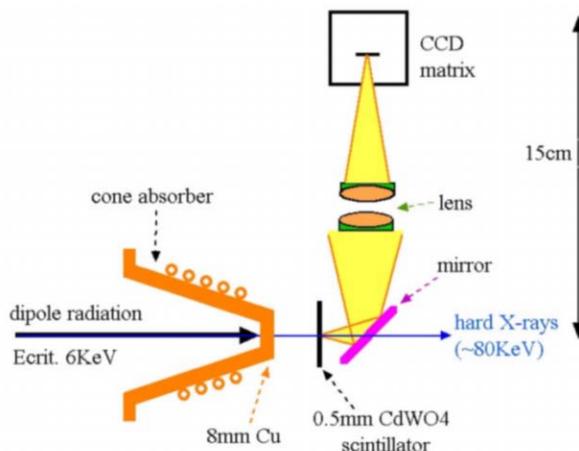


Figure 2: Sketch of the detector setup with the cone absorber in front of the scintillator, an optical focusing system and the camera. The critical energy of the synchrotron radiation at 2.5 GeV beam energy is 6 keV. The energy of the photons emerging the 8 mm copper absorber at the intensity maximum is 80 keV.

ing a mid-bend port (see Fig. 1) ends in a tip of 8 mm of copper. The residual hard X-rays are detected with a novel In-Air X-ray detector outside the machine vacuum system. This is obviously a big advantage in comparison to conventional X-ray detectors, since an intervention can take place at any time without the usually necessary recovery time of the electron beam lifetime.

THE IN-AIR X-RAY DETECTOR

The Fig. 2 shows the detector with the scintillator screen directly behind the conical absorber. The scintillator material is Cadmium Tungstenate (CdWO_4) which is a crystal of $8 \text{ gr}/\text{cm}^3$ density. Its mechanical hardness allows it to be polished to optical quality with a thickness of only 0.5 mm. It is transparent to visible light and has a good light yield for the hard X-rays. The light emitted by the screen is deflected upwards by an aluminium mirror just 7 mm behind to an achromat pair ($f = 50 \text{ mm}$ for both) that collects and focuses an image on the CCD matrix (Wattec-120N). The entire detector is assembled and adjusted optically in laboratory, where the optical resolution is assessed and estimated at below $10 \mu\text{m}$, before installation. The effective aperture of the optics is about 7 mm. The pixel size at the source-point is $7.6 \mu\text{m}$. The schematic does not show the lead shielding of 3 mm thickness around the

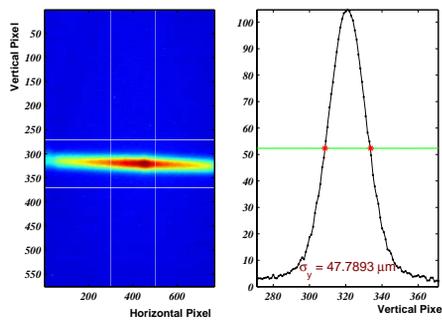


Figure 3: Left: Image taken by the In-Air X-ray detector's CCD camera. The horizontal layout of the synchrotron radiation fan is clearly visible. The horizontal intensity variation reflects the conical shape of the copper absorber. Right: Projection of the maximum intensity region of the camera image onto the vertical axis. The FWHM is shown and the vertical RMS beam size derived from the FWHM is given.

lenses and CCD that efficiently prevents the system from degradation or damage. The measurement time of the Wattec camera can be varied to optimize the image quality for different beam conditions. The analogue output is sent over a roughly 40 m long coaxial cable to a framegrabber (Data-Translation DT-3120) in a PC for digitization and further treatment and analysis of the image of the 760x560 pixels. Figure 3 shows a typical image taken by the In-Air X-ray detector's CCD camera. The horizontal layout of the synchrotron radiation fan is clearly visible. The horizontal intensity variation reflects the conical shape of the copper absorber. The projection onto the vertical axis yields the beam size. The full width half maximum of the image's projection is related to the electron beam parameters by

$$\Delta_{\text{FWHM}} = \sqrt{(2.35 \sigma_y)^2 + l^2 (\theta^2 + (2.35 \sigma'_y)^2)}$$

where $\theta = 80 \mu\text{rad}$ is the divergence of the X-rays in the transmitted range, σ_y and σ'_y the vertical electron beam size and divergence and $l = 1.794 \text{ m}$ the distance of the scintillator from the source point. For the analysis only the region of maximum intensity - denoted by the white

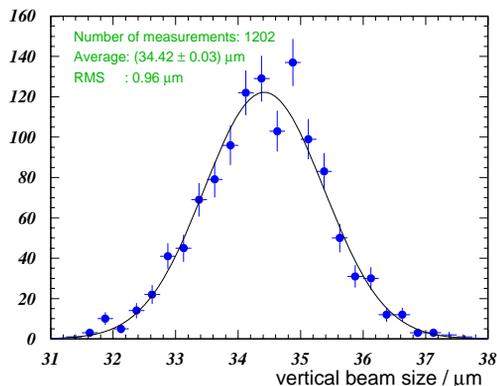


Figure 4: Distribution of measured beam sizes acquired during a scan of about 10 minutes duration. The acquisition time interval varies 160 and 700 ms. The error bars reflect the statistical uncertainty.

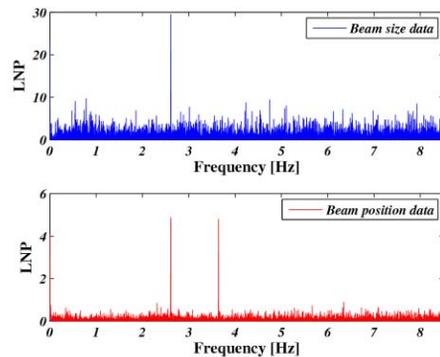


Figure 5: Frequency spectrum (Lomb Normalised Periodogram, LNP [2]) of the beam size (upper plot) and beam position data (lower plot) acquired during a time interval of about 10 minutes. The beam size variation shows a periodicity of 2.6 Hz, the beam position shows in addition a 3.6 Hz component.

boundary lines - is used. The slight inclination of the horizontal fan is due to a small angular misalignment of the system. The precise extraction of the electron beam size requires the knowledge of the source point distance l , the photon divergence θ and the electron beam divergence at the source point, σ'_y . The latter is dictated by the beam optics and therefore needs to be adjusted appropriately. Ideally σ'_y should be determined by a simultaneous beam size measurement at a second location. In the absence of a second detector, a value based on optics calculations is being used. A first idea of the reproducibility of the measured beam size can be obtained from a series of repetitive data acquisitions. The resulting distribution will show variations due to the detector resolution as well as real fluctuations for example due to mechanical vibrations of magnets, girders or the camera support itself. Figure 4 shows an example for the distribution of 1202 measured beam sizes during a run of about 10 minutes duration. The time between two acquisitions varies from 160 to 700 ms and is determined by the transfer rate from the camera to the acquisition system. The RMS width of the distribution is about $1 \mu\text{m}$ which is an upper limit for the intrinsic resolution of the system. The contribution from vibrations is obvious from the frequency analyses [2] of beam size and beam position data shown in Fig. 5 for the same dataset.

BEAM SIZE STUDIES

The ability of the In-Air X-ray detector to perform rapid consecutive measurements was exploited in studies of the change in beam size due to gap scans of insertion devices and scans of the betatron tunes. The main objective of these exploratory studies was to observe the general behaviour of the beam size as a function of different parameters. For an analysis of general trends the absolute size of the beam is of secondary importance, wherefore $\sigma'_y = 0$ was assumed in the following. As a consequence, absolute beam sizes have a systematic uncertainty around 10%.

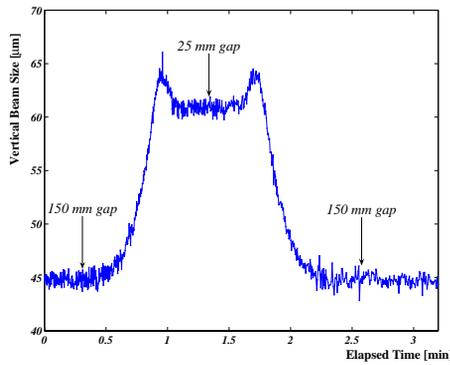


Figure 6: Beam size as a function of time during the closing and opening of the gap of a normal conducting wiggler.

Dependence on Insertion Device Gaps

The beam size as a function of time during the closing and opening of the gap of a normal conducting wiggler is shown in Fig. 6. The significant beam size increase could be caused by a shift of the synchrotron frequency since the current working point is in the vicinity of some strong synchro-betatron resonances (see following section). The decrease in beam size for smaller gap values is due to the betatron tune shift. For properly corrected betatron tunes the beam size continues growing. A scan of the excitation current of the superconducting in-vacuum undulator with 14 mm period length [3] for a gap of 8 mm is displayed in Fig. 7. For the scan performed with a dedicated low- β optics and without tune shift compensation a small increase of beam size is observed for higher magnetic fields.

Scans of Synchro-Betatron Resonances

If the working point approaches a strong coupling resonance, a giant increase in the vertical beam size is expected. Slowly varying the gradient of a defocusing quadrupole family will lead to the crossing of the difference resonance $Q_x = Q_y$. The beam size evolution during such a scan is shown in Fig. 8 where the main resonance as well as the resonances with synchrotron sidebands of the vertical tune are clearly visible. The crossing of the tunes can be seen in Fig. 9 which shows the simultaneously acquired spectrogram.

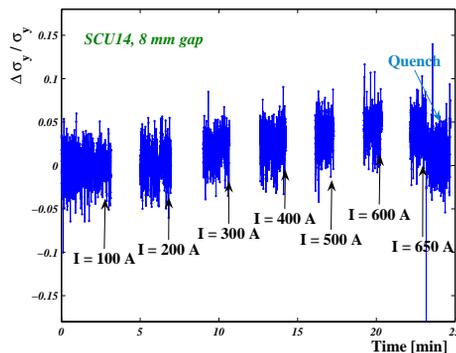


Figure 7: Relative change in beam size for different values of the current in the superconducting undulator [3].

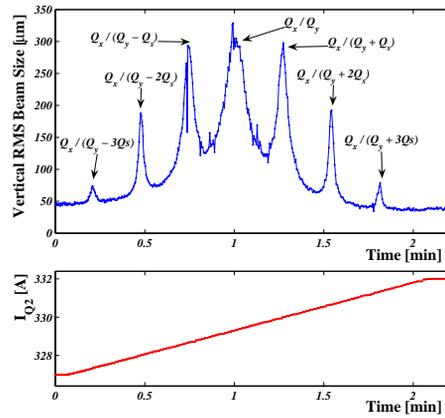


Figure 8: Upper plot: Vertical beam size as a function of time during a resonance crossing. The individual synchrotron sidebands are clearly visible. Lower plot: Current of a defocusing quadrupole family as a function of time.

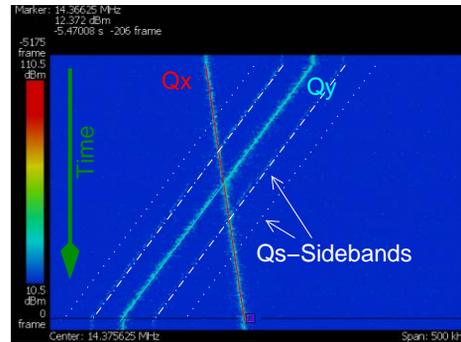


Figure 9: Spectrogram of the betatron tunes during the resonance scan. The spectrogram was measured with a Tektronix RSA3303A real time spectrum analyser.

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