X-RAY AND OPTICAL DIAGNOSTIC BEAMLINES AT THE AUSTRALIAN SYNCHROTRON STORAGE RING

M. J. Boland, A. C. Walsh, G. S. LeBlanc, Y.-R. E. Tan, R. Dowd and M. J. Spencer, Australian Synchrotron, Clayton, Victoria 3168, Australia.

Abstract

Two diagnostic beamlines have been designed and constructed for the Australian Synchrotron Storage Ring [1]. One diagnostic beamline is a simple x-ray pinhole camera system, with a BESSY II style pinhole array [2], designed to measure the beam divergence, size and stability. The second diagnostic beamline uses an optical chicane to extract the visible light from the photon beam and transports it to various instruments. The end-station of the optical diagnostic beamline is equipped with a streak camera, a fast ICCD camera, a CCD camera and a Fill Pattern Monitor to analyse and optimise the electron beam using the visible synchrotron light.

MOTIVATION

The Storage Ring diagnostic beamlines were desiged to serve two essential functions:

1. a continuous on-line measurement of the beam size and stability, and
2. a means to perform dedicated studies of the beam performance.

A simple x-ray pinhole camera system was designed for the first function, while a more versatile and multi-purpose optical diagnostic beamline was designed to fulfil the second function. In general, the x-ray beamline is designed to perform transverse measurements while the optical beamline will mainly perform longitudinal measurements.

X-RAY DIAGNOSTIC BEAMLINE

The X-Ray Diagnostic Beamline (XDB) is an x-ray pinhole camera system and is contained entirely with-in the storage ring tunnel. It does not have a photon shutter and is therefore in continuous operation when the machine is running. The XDB provides a simple but powerful diagnostic tool which will deliver data to the machine group as well as information to the machine status display for the users.

General Layout

Fig. 1. shows the schematic layout of the XDB with a sketch of the expected beam profile measurement. Both diagnostic beamlines have dipole source points. The electron beam parameters for the source points are shown Table 1. for storage ring with the nominal lattice of zero dispersion in the straights and assuming 1% coupling.

Table 1: Electron beam parameters at the source points.

Parameter	ODB	XDB
β_x (m)	0.386	0.386
β_y (m)	32.507	32.464
σ_x (μm)	99	98
σ_x'(μrad)	240	241
σ_y (μm)	72	72
σ_y'(μm)	7	7

The horizontal and vertical beam profile measurement will allow the beam size, divergence, emittance and position to be calculated and displayed in the control system. The nominal emittance is calculated to be 15.8 nm rad.

Pinhole Array

A pinhole array was chosen so both the beam size and divergence can be measure simultaneously. The array spacing is 1 mm along the horizontal direction and 0.5 mm along the vertical direction in order to capture more than five fully resolved images on the YAG screen. The intensity variation in the beam images on either side of the central beam provides a measure of the divergence of the beam (see beam profile in Fig. 1.). The circular pinholes are designed to be 20 μm in diameter, which is

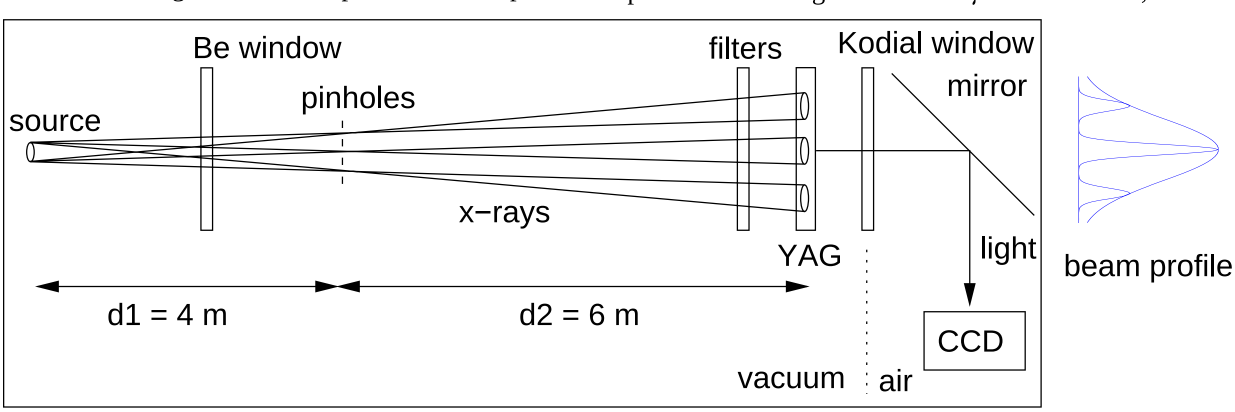

Figure 1: Schematic layout of the X-Ray Diagnostic Beamline viewed from side on.

calculated to be the optimum size for minimising diffraction blurring and minimising resolution by following the calculations in Reference [2]. The geometry of the XDB generates multiple images of the beam with a magnification of

$$M = d_2/d_1 = 6/4 = 1.5.$$

The overall resolution of the XDB is expected to be approximately 10 μm.

Filter Array

A filter array holds up to four foils that can be inserted into the beam by remote control to filter the photon beam. Adding filters reduces the intensity of the x-ray beam at high electron beam currents and improves the resolution of the measurements.

Imaging Cross

The x-ray images made by the pinhole array are projected onto a 100 μm thick YAG crystal positioned perpendicular to the beam. The visible light that fluoresces from the YAG screen is deflected down out of the beam plane and digitised by a Firewire camera (Flea Hi-Res IEEE-1394 camera from Point Grey Research [3]). The camera has a fixed focal length lens and is triggered by the timing system. The control system is capable of providing a continuous stream of size, position and emittance data from the XDB as well as an image for the beam status screen. The Be window at the start of the beamline (see Fig. 1.) prevents any unwanted visible light from reaching the imaging cross.

OPTICAL DIAGNOSTIC BEAMLINE

The Optical Diagnostic Beamline (ODB) has a front-end with an Optical Chicane which extracts the visible part of the synchrotron radiation beam from a dipole and focuses it onto an optical table outside the storage ring tunnel. The ODB will perform a variety of functions, including detailed accelerator physics studies of the stored beam and on-line feedback of the bunch current distribution. The source parameters are almost identical to the XDB (see Table 1.).

General Layout

Fig. 2. shows a schematic of the ODB with the imaging equipment located on an optical table outside the storage ring tunnel. Only visible light enters the beamline equipment enclosure, so it is possible to adjust the equipment on the optical table when the beam is operating.

Optical Chicane

The Optical Chicane extracts the visible part of the synchrotron radiation spectrum using a mirror which grazes the top part of the synchrotron radiation fan (see Fig. 2.). The mirror is a cooled Glidcop block with a polished Al surface and deflects the beam vertically down. The visible light is reflected back to a horizontal direction by the secondary mirror, then passes through a set of horizontal and vertical slits and is focused to form a 1:1 image over the optical table.

The angular acceptance of the ODB is 5.4 mrad in the horizontal and 2.7 mrad in the vertical, resulting in a total beam power in the visible part of the spectrum of approximately 1 mW (calculated using the Spectra code [4]). A thermocouple located below the mirror measures the temperature of the Glidcop and is connected to the equipment protection system which closes a photon shutter if the mirror starts to get too hot.

The secondary mirror, the slits and the lens are all remotely controllable and are used to define the visible beam angle, size and position. The slits are on independent axes so the aperture centre can be scanned in two dimensions.

Optical Table

An optical table with rigid legs was chosen to support the imaging equipment, because the source is *off-table* and a mechanical system with a high natural frequency (>60 Hz) is required for stability. The image is converted on the optical table to a parallel beam so it can easily be split and distributed to the imaging systems where it is refocused to appropriate image sizes for each device.

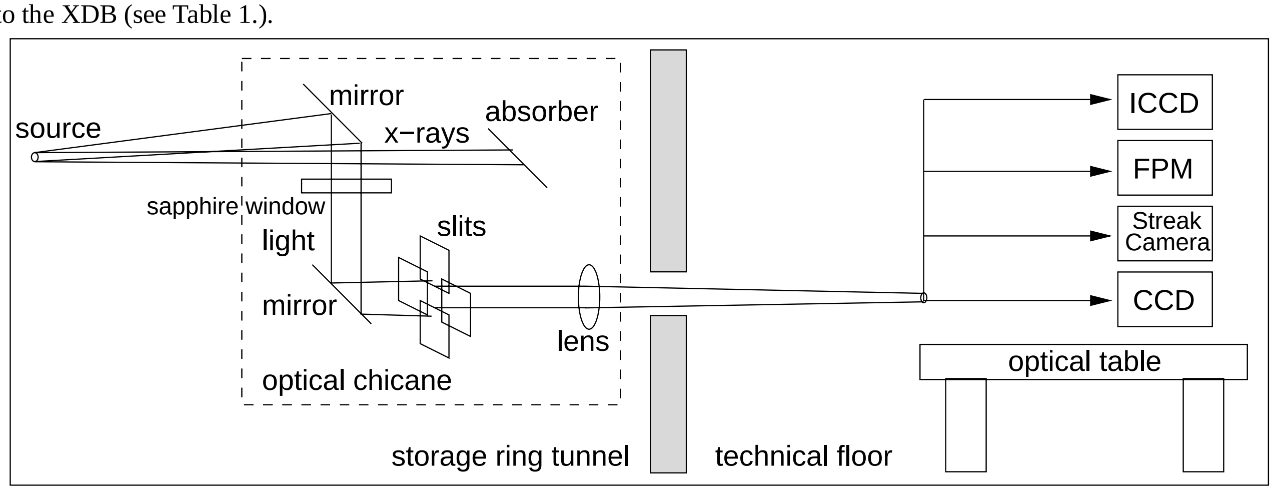

Figure 2: Schematic layout of the Optical Diagnostic Beamline viewed from side on.

Streak Camera

A dual sweep streak camera (OPTOSCOPE model SCMU-ST/BI from Optronis [5]) with one fast, one slow and one synchroscan sweep unit is used to perform temporal/longitudinal measurements on the beam. In the storage ring, the 500 MHz RF-system produces a bunch structure with a temporal width of σ_t = 20 ps and a bunch separation of 2 ns, while the revolution frequency is 1.38 MHz. The synchroscan unit operates at 250 MHz allowing the bunch train to be analysed bunch-by-bunch, even bunches on one sweep and odd bunches on the return sweep. The temporal resolution of the synchroscan unit is less than 2 ps which will allow an individual bunches to be clearly resolved and analysed.

The second sweep units allow the streak camera to be operated in dual sweep mode or in single shot mode with either long (100 ms) or short (200 ps) time frame bunch analysis. Using the slow sweep unit it is possible to look at the long term stability of the beam over several milliseconds. The fast sweep unit triggered by the orbit clock and in one-shot mode can examine a single bunch and take picosecond slices of the beam.

ICCD Camera

An Intensified CCD (ICCD) camera (4Picos from Stanford Computer Optics [6]) is used to make transverse measurements of the beam. The gate width of 0.2 ns allows a head-on image of a single bunch to be capture in order to analyse the shape and stability of the bunch structure of the beam.

Fill Pattern Monitor

The Fill Pattern Monitor (FPM) is used to measure the relative bunch currents in the electron beam for each of the 360 RF-buckets in the storage ring. The visible light from the ODB is sent through a fibre optic delay-and-stretch module to lengthen the pulse before impinging on a fast high-bandwidth photodiode. The output of the diode is digitised with an 8 GS/s 10 bit ADC (model DC282 from Acqiris [7]), which is capable of averaging over thousands of storage ring revolution cycles to improve the statistics. Within 300 ms a 360 element array is written to an EPICS record on an IOC to be made available to the control system. The control system displays the fill pattern in the Control Room and is also used to feedback into the injection timing system.

In top-up mode, which will be implemented in the future, the FPM output will be used to determine which particular bucket should be injected into with the next shot in order to even out the fill pattern around the ring. Within the 1 Hz injection cycle the timing system can be reprogrammed with a new delay based on the FPM output.

In the future a bunch purity measurement system will be implemented using an avalanche photodiode system and a TDC to achieve much higher dynamic range than the FPM.

Firewire Camera

The Firewire camera used on the ODB is identical to the one used on the XDB. It is used as a general purpose camera on the optical table for testing optical configurations, either in triggered mode or to provide a free running video image of the beam.

CONCLUSIONS

The Australian Synchrotron Storage Ring has two powerful diagnostic beamlines to measure both transverse and longitudinal properties of the beam. The data collected from these diagnostics are used for both: a) continuous on-line displays in the control system for operators and users; and b) dedicated and detailed measurements of the beam parameters by the Accelerator Physics Group. The beamlines are ready to be commissioned and used for capturing first light from the storage ring in July 2006.

REFERENCES

[1] J. W. Boldeman and D. Einfeld, Nucl. Instr. and Meth. A **521**, 306 (2004).

[2] W. B. Peatman and K. Halldack, J. Synchrotron Rad. **5**, 639-641 (1998).

[3] Point Grey Research, <http://www.ptgrey.com>.

[4] T. Tanaka and H. Kitamura, J. Synchrotron Rad. **8**, 1221-1228 (2001).

[5] Optronis GmbH, <http://www.optronis.com>.

[6] Stanford Computer Optics Inc., <http://www.stanfordcomputeroptics.com>.

[7] Acqiris, <http://ww.aqciris.com>.