STATUS OF THE AUSTRALIAN SYNCHROTRON PROJECT

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Abstract

The Australian Synchrotron, a synchrotron light facility based on a 3-GeV electron storage ring, is currently being commissioned at a site in the Metropolitan District of Melbourne. On July 14, 2006 less than three years after earth moving machines started to prepare the site, beam was captured, accumulated and stored in the storage ring. Storage ring commissioning, and beamline installation and commissioning will continue through March 2007, after which the facility will become operational. In this paper we give a brief overview of the facility and its beamlines, followed by the latest results from accelerator commissioning activities.

FACILITY OVERVIEW

The Australian Synchrotron is located adjacent to Monash University in Clayton, Victoria. It has been built by a project team from Major Projects Victoria (MPV), a part of the Victorian State Government. The funding for the building and accelerators has been provided by the Victorian State Government. The beamlines are being funded by a group of interested parties, including universities, research organisations, other state governments, and New Zealand.

Staffing

The Australian synchrotron is being delivered with a relatively small staff of only 54 people, plus specialist contractors and consultants. Due to the relatively small number of staff, much of the responsibility for the design and project management has been placed on suppliers, with turn-key contracts. Contracts for the following systems included all design, engineering, project management, installation and commissioning:

- Injection system
- Storage ring RF system
- Storage ring vacuum vessels
- Beamline photon delivery systems
- Storage ring girders
- Front ends

Schedule

The original schedule milestones can be seen in Table 1. The project is currently on schedule and transition from the project stage to the start of operations will be in April 2007. All of the major schedule milestones have been achieved within days of the target dates, including the start of accelerator installation in April 2005, the completion of installation in May 2006 and first turns in the storage ring in June 2006.

Table 1: Schedule Milestones.

Design announced.	January 2003
Building contract placed	July 2003
Building complete	February 2005
Staff move into building	March 2005
Installation begins	April 2005
Injection system commissioning begins	October 2005
Storage ring installation complete	May 2006
Storage ring commissioning begins	June 2006
First turns in the storage ring	June 2006
Beamline installation begins	September 2006
Beamline commissioning begins	February 2007
Transition to operations	April 2007

ACCELERATOR SYSTEMS

The Australian Synchrotron accelerator systems are comprised of a 100 MeV linear accelerator, a 3 GeV booster synchrotron, and a 3 GeV storage ring. The entire injection system, from the electron source to the injection septa in the storage ring, was a single, turn-key contract. The storage ring equipment was provided by several different contractors and assembled using the local labour force with supervision from the different component contractors. A schematic of the layout of the accelerator systems is shown in Figure 1.

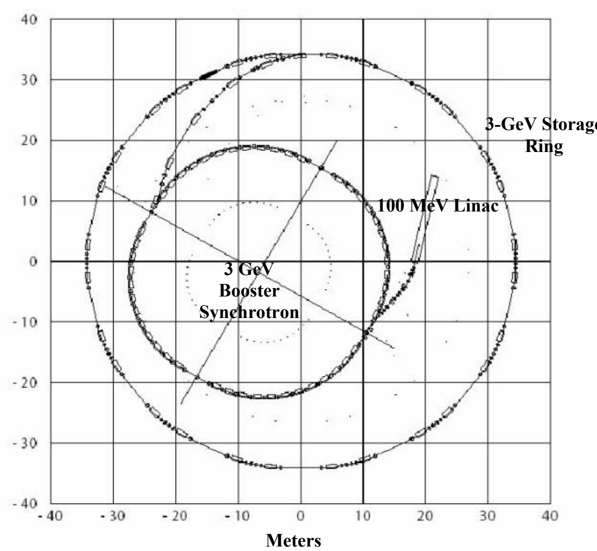

Figure 1: Layout of the accelerator systems.

The Linac

The electron source is a 90 keV thermionic gun that can run in both short pulse mode and long pulse mode. The operating frequency is 3 GHz. The short pulse mode is designed to deliver a single bunch into the 500 MHz structure of the booster. There are two 5 m accelerating structures. The linac specifications can be seen in Table 2.

Table 2: Linac Specifications

Energy	0.1	[GeV]
RF Frequency	2997.92	[MHz]
Sub-harmonic Pre-buncher	499.654	[MHz]
Repetition rate	1-5	[Hz]
Normalised Emittance	<50π	[mm·mrad]
End charge (short/long)	>0.31/>3.1	[nC]

The Booster

The booster is based on a combined function lattice and is made up of four quadrants. Each of these quadrants has 8 vertically focussing dipoles and 7 horizontally focussing dipoles. The sextupole fields needed to get a positive chromaticity in both planes is integrated into the combined function dipoles. There are four quadrupoles for focussing correction as well as four sextupoles for chromaticity correction per quadrant. The booster specifications can be seen in Table 3.

Table 3: Booster Specifications

Energy	0.1 → 3.0	[GeV]
Circumference	130.2	[m]
RF Frequency	499.654	[MHz]
Harmonic Number	217	
Single Bunch Current	>0.5	[mA]
Multi-bunch Train	>5.0	[mA]
Betatron Tune (h/v)	9.2/3.25	
Natural Chrom. (h/v)	-8.8/-11.5	
Energy Spread (3GeV)	0.094	[%]
Horizontal Emittance	33	[nm·rad]

The Storage Ring

The machine functions of one of the 14 sectors of the storage ring are shown in Figure 2.

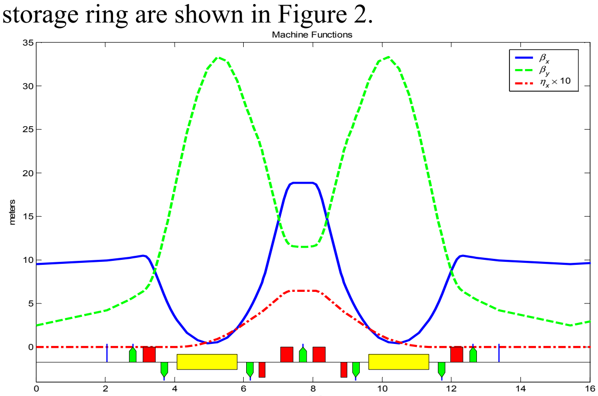

Figure 2: Machine functions for one cell of the ASP storage ring with zero dispersion in the straight sections.

The bending magnets are gradient dipoles with a focusing strength of $k = -0.335\ \mathrm{m}^{-2}$. There are three families of quadrupoles and four families of sextupoles. Horizontal and vertical corrector coils are wound into the sextupole magnets to make the lattice more compact.

The nominal lattice tunes are $\nu_x = 13.3$ and $\nu_y = 5.2$, but the machine can be tuned over a large range by using the outer two of the quadrupole families. The inner quadrupoles are used to distribute the dispersion to allow it to leak into the straight sections. Two of the straight sections are used for RF cavities; one for the injection septum and the remaining eleven will be available for insertion devices. It is possible to install two shorter insertion devices in the straight sections with the RF cavities. The design specifications are shown in Table 4.

Table 4: ASP Storage Ring Specifications.

Energy	3	[GeV]
Circumference	216	[m]
RF Frequency	499.654	[MHz]
Harmonic Number	360	
Peak RF Voltage	3.0	[MV]
Current	200	[mA]
Critical Photon Energy	7.8	[keV]
Betatron Tune (h/v)	13.3/5.2	
Momentum Compaction	0.002	
Natural Chromaticity (h/v)	-28/-27	
Radiation Damping (h/v/l)	3/5/3	[ms]
Energy Spread	0.1	[%]
Radiation Loss Per Turn	932	[keV]
Horizontal Emittance	7-16	[nm·rad]

Controls and Commissioning Tools

The control system for the Australian synchrotron uses EPICS. Different control systems have been delivered by different contractors with varying degrees of control, but in all cases it was specified that they had to be EPICS compatible.

In addition to the EPICS tools available, the Accelerator Toolbox [1] running in the Matlab environment is used. Using the Matlab Channel Access [2], all of the process variables in the control system are available in the Matlab environment making it possible to make measurements while changing settings and then perform calculations on the results. This has been an invaluable resource during the commissioning where a simple Matlab script could be written to automate a number of different measurements.

The Storage Ring Diagnostics

The storage ring is equipped with a host of diagnostics. The beam position monitor system provides first-turn, turn-by-turn, and slow acquisition position information simultaneously. There are seven beam position monitors in each sector.

The other diagnostic equipment is:

- Horizontal and vertical scrapers
- Horizontal and vertical stripline detectors
- A DCCT
- A beam loss monitor system

The beam position monitors and beam loss monitors are distributed around the ring. The rest of the diagnostic equipment is installed in a single straight section.

There are two diagnostic beamlines for machine studies. The first of these is an x-ray pinhole array beamline that is installed inside the storage ring tunnel. It produces images of the beam from a dipole. The beam size and stability can be studied with the beamline. The layout of the beamline can be seen in Figure 3. The second is an optical beamline where the visible light from a dipole is sent through an optical chicane and led into an enclosure where there is a streak camera, an intensified CCD camera, a fill pattern monitor and a firewire camera.

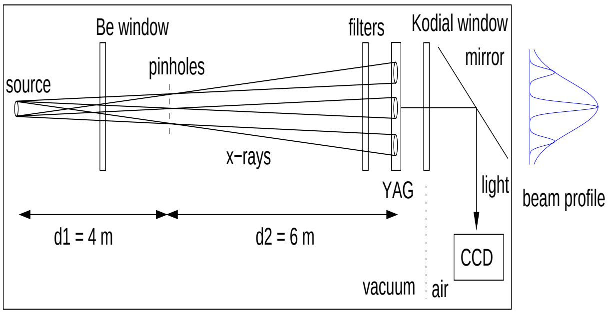

Figure 3: X-ray diagnostic beamline layout.

INITIAL BEAMLINES

The initial suite of nine beamlines is shown in Table 5.

Table 5: The initial suite of beamlines.

Beamline Identifier	Technique	Source
2IR	Infrared Spectroscopy	Bending Magnet
3BM	Protein Crystallography 1	Bending Magnet
3ID	Protein Crystallography 2	In-vacuum undulator
8ID	Imaging & Medical Therapy	Superconducting wiggler
9ID	Microspectroscopy	In-vacuum undulator
10BM	Powder Diffraction	Bending Magnet
12ID	X-ray Absorption Spectroscopy	Wiggler
13ID	Small & Wide Angle X-ray Scattering	In-vacuum undulator
14ID	Soft X-ray Spectroscopy	APPLE II Undulator

Five of these beamlines are expected to be in an advanced state of commissioning in April 2007 with the first user experiments being conducted. These are:

- Infrared Spectroscopy
- Protein Crystallography 1
- Powder Diffraction
- X-ray Absorption Spectroscopy
- Soft X-ray Spectroscopy

The other five beamlines will be built in the coming year, with the final one expected to be finished in the second quarter of 2008.

ACCELERATOR COMMISSIONING

The Injection System

The contract for the injection system included commissioning the systems. It was important for the ASP personnel to be involved in these activities in order to gain the operational knowledge of the systems needed in order to operate and maintain the systems when the commissioning was finished and the contractors left. Members of the accelerator group were present during all of the commissioning shifts and members of the mechanical, electrical, and controls teams also participated.

The linac klystrons were the first systems to be commissioned starting in September 2005. The first electrons from the gun were observed in the first week of October 2005. The first electron beam accelerated through the entire linac was observed in the transfer line in the middle of December 2005.

In February 2006, the first beam was injected into the booster. By the end of March 2006 the booster ramp was being developed and the first beam was accelerated to 3 GeV in the beginning of April 2006. The injection system routinely delivers the specified beam for injection into the storage ring.

The Storage Ring

Due to installation activities in the storage ring tunnel, the commissioning of the booster to storage ring transfer line (BTS) was not included in the injection system program, but was considered the start of the storage ring commissioning program. The first beam in the section of the BTS in the storage ring tunnel was observed on June 1 2006. The first turn in the storage ring was observed on June 8, 2006.

On July 14, 2006 the first beam was stored in the storage ring and the current was stacked to 1 mA. After a few days the storage ring could routinely be injected to 10 mA and all of the diagnostic equipment could be commissioned and the storage ring characterization began. To date, 200 mA has been stored with a lifetime of 6.5 hours after the first of the insertion device chambers has been installed. The first insertion device is installed and has been run with the minimum gap of 14 mm with 100 mA in the storage ring. A second insertion device chamber is installed and the lifetime at 200 mA remained the same as it was previously. The results of the storage ring characterization and performance demonstration will be presented in the next section.

STORAGE RING PERFORMANCE

Injection

The injection system runs at 1 Hz. The injection efficiency from the booster to the storage ring is now ~90%. This results in >2 mA per shot. It takes about 100 seconds to inject from 0 to 200 mA. A strip chart of the injection process can be seen in Figure 4.

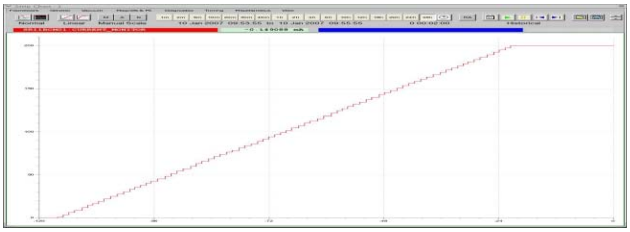

Figure 4: Injection from 0 to 200 mA.

Vacuum Conditioning

The vacuum conditioning has gone well. The lifetime-current product as a function of the integrated dose since the start of commissioning can be seen in Figure 5. The point at which the stored current was spread to ~300 bunches instead of 75 and the installations of the first two insertion device chambers are indicated. To date a total integrated current of 35 Ahrs has been accumulated.

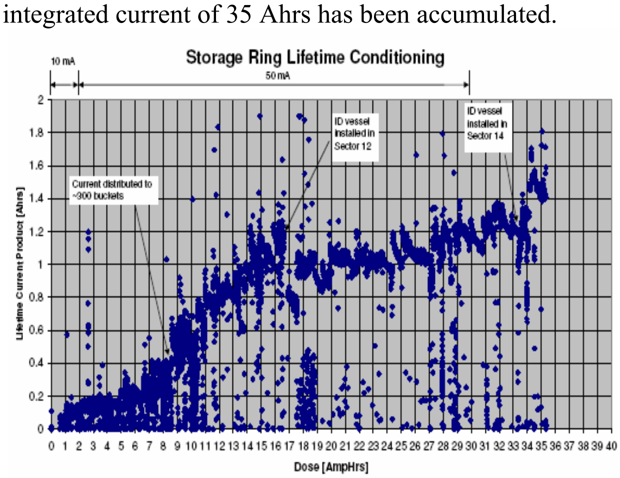

Figure 5: Current-lifetime product as a function of integrated current.

Orbit Correction

Beam based alignment has shown that the mechanical and electrical offsets of the beam position monitors were of the order of a few mm. The rms noise on the position signals is ~0.2 µm. The orbit has been corrected to an RMS deviation from zero of ~16 µm. Figure 6 shows the beam position offsets from the beam based alignment.

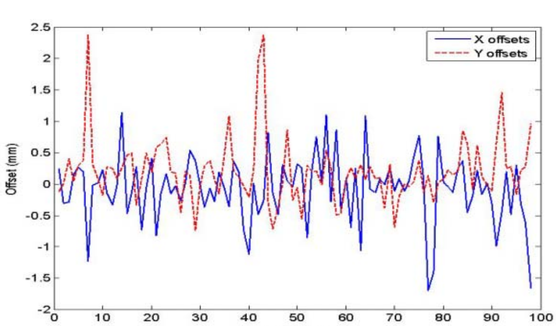

Figure 6: Measured BPM offsets.

Storage Ring Optics

LOCO [3] is used to get calibrated models of the storage ring. These models are then used to calculate corrections and changes to the optics. The first measured response matrix can be seen in Figure 7. There were some BPMS that had some coupling that was not correct as can be seen in the coupling quadrants of the matrix.

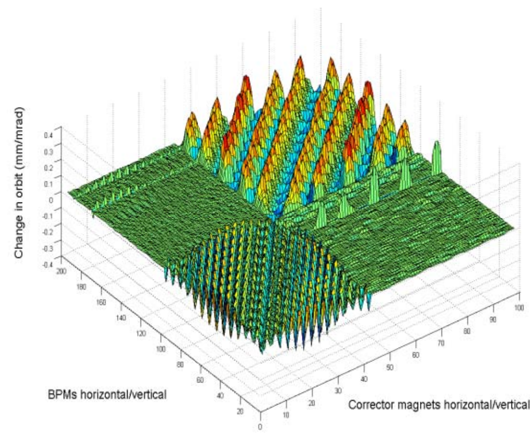

Figure 7: The first measured response matrix

Once the BPM signals were fixed the response matrix was used to correct the initial betatron beating. Figure 8 shows the measured and model vertical beta functions prior to correction. The corrections were applied and Figure 9 shows the results of a new LOCO run where the betatron beating has been corrected.

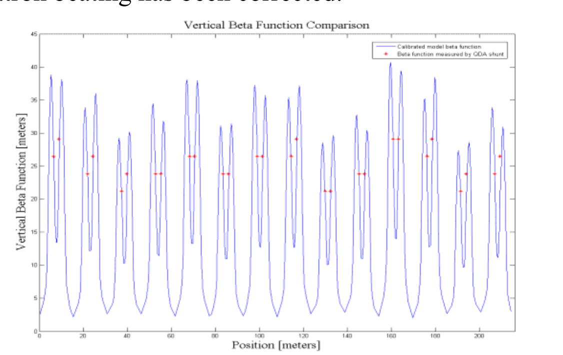

Figure 8: Measured and model vertical beta functions.

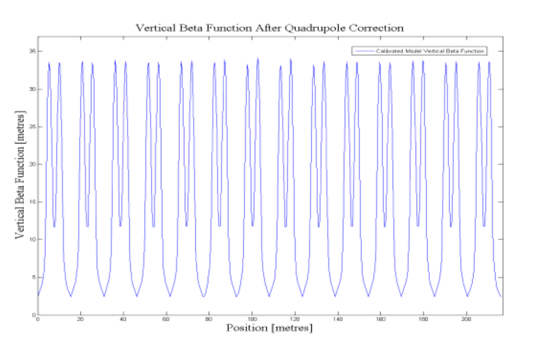

Figure 9: Corrected vertical beta functions.

Distributed Dispersion Optics

The commissioning lattice had zero dispersion in the straight sections. The final operating lattice will have a finite dispersion in the straight sections of ~0.1 m. A calibrated model from LOCO was used to set the dispersion. The measured dispersion functions before and after the changes are shown in Figure 10 and Figure 11. As can be seen, there was a BPM in sector 3 that was not functioning at the time of the measurement.

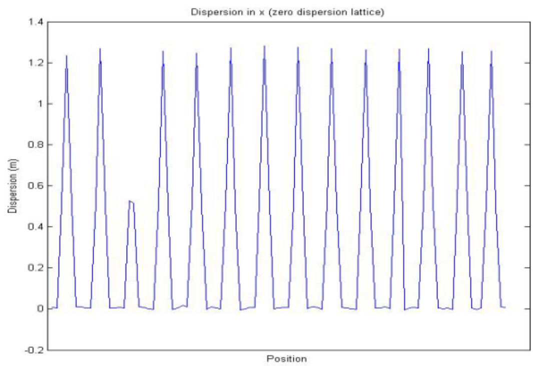

Figure10: Zero dispersion in the straight sections.

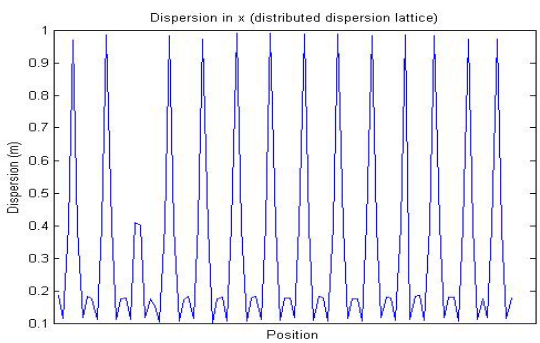

Figure 11: Distributed dispersion in the straight sections.

Emittance

The emittance has been measured using the x-ray diagnostic beamline. Using the beta functions from the model obtained using LOCO on the response matrix gives a horizontal emittance of 18.7 nm rad and a vertical emittance of 0.09 nm rad. Figure 12 shows the images from the pinhole array.

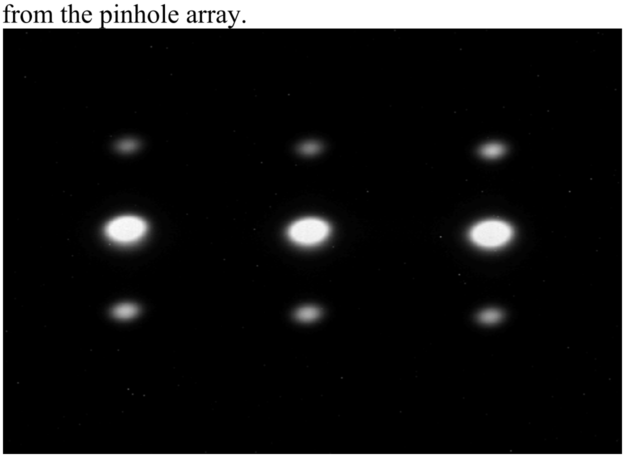

Figure 12: X-ray diagnostic beamline pinhole array image.

Bunch Length

Studies of the bunch length are under way. The streak camera on the optical diagnostic beamline is used to measure the length of a single bunch with increasing current. Figure 13 is an image showing a single bunch on two successive turns.

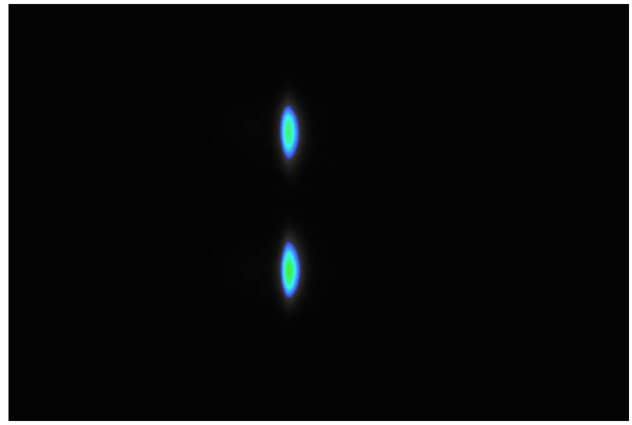

Figure 13: Streak camera image of a single bunch.

CONCLUSIONS

The Australian Synchrotron Project has been very successful. While there is still work to be done before becoming an operational facility, the small team of dedicated staff have done an excellent job of writing the specifications, working with the contractors and integrating all of the systems. This has led to a smooth commissioning according to the project schedule.

REFERENCES

[1] A. Terebilo, "Accelerator Modelling With Matlab Accelerator Toolbox", PAC 2001, p. 3203.

[2] G. Portmann, J, Corbett, A. Terebilo, "An Accelerator Control Middle Layer Using Matlab", PAC 2005, p. 4009.

[3] J. Safranek, G. Portmann, A. Terebilo, C. Steier, "Matlab-Based LOCO", EPAC 2002, p. 1184