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CONCEPTUAL DESIGN OF A FUTURE AUSTRALIAN LIGHT SOURCE

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Abstract

ANSTO currently operates the Australian Synchrotron, a 3 GeV, 3rd generation light source that begun user operations in 2007. The Australian synchrotron is now halfway through its expected life span and we have begun planning the next light source facility that will eventually replace it. This paper describes the conceptual design of an entirely new light source facility for Australia, which makes use of the latest advances in compact acceleration technology and 4th generation lattices.

INTRODUCTION

The Australian Synchrotron light source was commissioned in 2006 and begun operations in 2007. It was designed and delivered to be a world-class synchrotron radiation facility that could meet the needs of 95% of the Australian user community. Since then it has performed with world-leading reliability, has achieved record coupling control [1] and is currently undergoing an expansion of its beamline suite to continue to service the Australian user community. The Australian Synchrotron is halfway into its expected 30 year lifetime and it is now the appropriate time to consider how best to service the Australian Synchrotron user community beyond the 15 year horizon.

OVERVIEW OF EXISTING FACILITY

The Australian Synchrotron Light Source is a 3rd Generation Light source facility (Figure 1. It operates a 200 mA, 3 GeV electron beam producing synchrotron radiation for a suite of beamlines. It has 14 fold symmetry and currently services 10 beamlines, with another 8 being currently built.

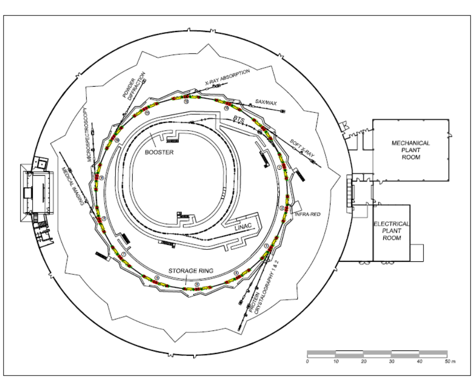

Figure 1: Layout of the Australian Synchrotron light source.

It uses a full energy injector system comprising of a 100 MeV linac and 3 GeV booster synchrotron to inject beam into its storage ring. The full energy injector allows for 'top-up' mode operation of the storage ring, which requires frequent, small injections of beam to keep the storage ring current within a few percent of maximum at all times. The Australian Synchrotron's accelerator systems were installed and commissioned between 2005 and 2006, with first light in July 2006. It entered into full user operations in July 2007. Since then, it has delivered approximately 5000 hours of user beam per year and maintained a world-leading reliability of $\sim 99\%$.

UPGRADE VS NEW FACILITY

The Going into the Future, a new or upgraded facility will still need to provide for 95% of Australia's diverse user community as it will be the only light source facility within thousands of kilometres. This necessitates a design in which a wide range of X-ray energies can be utilised, ensuring a broad range of synchrotron based techniques are catered for. It also makes a reduction of dark time during any upgrades a priority.

A study into an upgraded lattice utilising the existing 216 metre storage ring [2] which we have labelled AS-U. This lattice was severely constrained by the available space, resulting in a design that would have considerable design challenges while still delivering an emittace that would place it at the tail end of what is achievable by 4th generation light sources. Therefore we have embarked on a design study of a new facility, allowing for a larger ring, new injector and possibility of an associated FEL facility.

NEW LIGHT SOURCE DESIGN

One of the main constraints in upgrading the existing Australian Synchrotron was the small circumference of the storage ring (216m) which limited achievable emittance and pushed up the RF requirements. Lowering the beam energy to alleviate this is not compatible with user requirements for good flux at high photon energies. Therefore we are now considering a larger ring design on a new or 'greenfield' site. One of the features of ultra-low emittance lattices is that they have smaller dynamic apertures, requiring injection of low emittance beams, ideally from a linear accelerator, for efficient capture. With the increasing use of higher gradient accelerating technologies and in line with current local research programs in compact accelerator technology, we have decided to use an X-band linear accelerator as a full energy injector for the new storage ring. The new facility will therefore be close in layout to MAX IV Light source arrangement, with the linac injecting into the storage ring from the outside of the ring (Figure 2). Using CLIC X-band RF technology with accelerating gradients of around 70 MV/m will allows

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for full 3 GeV acceleration with a linac of approximately 100m or less.

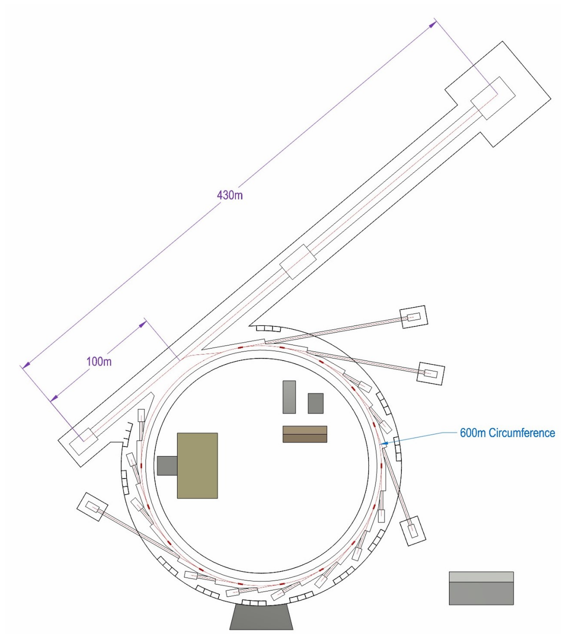

Figure 2: Possible Layout of a new Australian light source, with FEL option shown.

Injector

The Injector linac will closely follow the design of the linac used in the CompactLight design study [3], which ANSTO contributed to. The H2020 CompactLight project used CERN X-band accelerating technology developed for CLIC to create a X-ray free electron laser design that is more compact and with lower operating costs than current FELs. Using a design based on CompacLight will allow for an associated FEL facility to be built, either initially, or as a future upgrade. The first ~ 100m of this linac will be sufficient to provide 3 GeV electrons for the storage ring and future design work will explore both a short 3 GeV injector linac and the injector + FEL option. The injection scheme into the storage ring will utilise off-axis injection via a nonlinear kicker magnet (NLK), which is used to alter the trajectory of the injected particles into the acceptance of the storage ring without perturbing the stored beam. This method of injection has been adopted several other facilities successfully and the Australian Synchrotron is currently developing such a magnet for future use in the existing light source.

Storage Ring Lattice

A 600 m, 24 sector Storage Ring was designed based on the longitudinal gradient and reverse bend lattice concept [4]. Each unit cell is a 7-Bend acromat with geometry is shown in Figure 3. A ring symmetry of 24 sectors was selected because it allowed significantly long straight lengths (6 m per sector) and allowed a long sector length of 25 m, to accommodate the unit cell, while maintaining an even and high numbered periodicity. 24 sectors will allow for sufficient numbers of 4^{th} generation beam-lines for the local user community. The lattice parameters are shown in Table 1.

Figure 3: Magnet geometry for one sector of the ring-around-the-ring 600 m lattice. Dark Blue: Longitudinal gradient dipole. Light Blue: reverse bend. Green/yellow: Quadrupole families. Red: Sextupoles.

Table 1: Main Parameters of the AS2 Lattice, the Existing AS Lattice and the Previously Studied Upgrade Lattice (AS-U)

Par.	AS	AS-U	AS2
ϵ_x	10348.8 pm	308 pm	17 pm
Circ.	216 m	216 m	600 m
Energy	3 GeV	3 GeV	3 GeV
α_c	0.0021	-0.00135	-2.85e-6
U_0	0.93 MeV	1.95 MeV	0.577 MeV
δ_E	0.103 %	0.162 %	0.0874 %
Natural σ_z	29.37 ps	9.19 ps	0.96 ps
Coupling	1 %	5 %	5 %

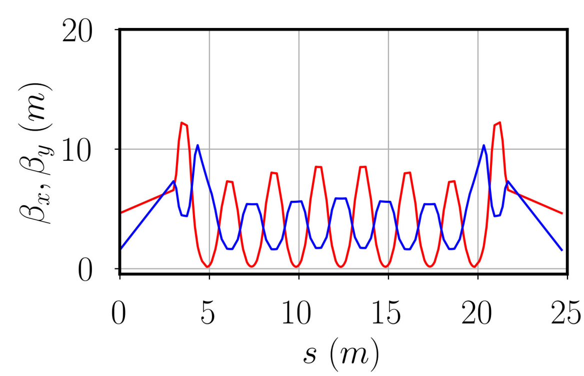

Figure 4: Betatron β_x (red) and β_y (blue) optical functions for one sector.

As it can be seen from Table 1, we are able to achieve an ultra low emittance of 17 pm·rad with a 600m, 24 sector Storage Ring. This preliminary lattice design requires more optimisation to ensure a large dynamic aperture and other considerations so we would expect the final emittance to increase somewhat. However an emittance of around 50 pm·rad can be reasonably expected.

1. We are able to obtain an extremely ultra-low emittance of 17 pm (compared to our current 216 m lattice emittance of 10349 pm and the 216 AS-U lattice design of 308 pm).

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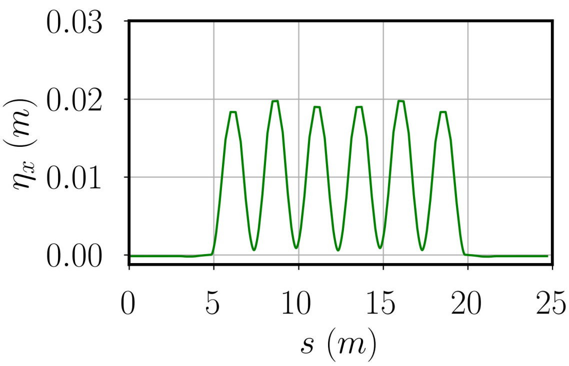

Figure 5: Dispersion η_x function for one sector.

2. Our RAR design has low Energy Loss Per Turn of 0.58 MeV which relaxes the requirements for RF to compensate for this loss of energy.

3. This lattice design has a very low peak η_x (see Figures 4 and 5). Large peak η_x (> 0.08 m) severely limits the maximum momentum acceptance (MA) possible. Based on other similar designs by SLS-2 and ALS-U we do not expect the MA to be a issue at such a large circumference.

4. The 600 m lattice design is not constrained to a small momentum acceptance - this is important for beam lifetime as even with a large RF acceptance, a large momentum acceptance is needed for an acceptable beam lifetime.

5. The large number of sectors insures future proofing for any space needed for 5th generation upgrades.

The preliminary design presented in this chapter requires further optimisation to ensure the optimal magnetic strength configurations have been selected.

RF Systems

Our default position will be to continue to use 500 MHz as the storage ring RF frequency, due to the maturity of the technology and its widespread use in light sources. We have long operational experience with copper HOM damped accelerating cavities and will seek to use a design similar to that already used at the Australian Synchrotron [5]. With the lowered synchrotron losses of the larger ring circumference we can support a 500 mA beam with 5-6 cavities operating at 180 kW (depending on operating voltage). Our experience with our current RF systems has shown the reliability advantages in having redundancy in the design, so 6 independent systems would be the preferred choice.

In depth studies of the impedance and instability thresholds are still to be done, however it would be reasonable to assume that a harmonic cavity system would be required to elongate the bunch and avoid certain instabilities. The harmonic cavity is assumed to operate at the third harmonic of the radio frequency and an optimal harmonic RF system would increase the bunch length and the Touschek lifetime for the electron beam in the new storage ring by around 4.5 times. Based on the operation experience of other facilities [6] [7], the achievable elongation factor is approximately 2-3 times. Tracking studies will be conducted at a later stage to determine the impact on stability and lifetime for proposed designs taking transient beam loading into account.

The latest advancement in new technologies for RF systems in the last ten years and the industrialisation are promising and an important factor in decision making for future upgrades. The new key technologies are:

- High power high frequency transistors to replace classical electron tube applications such as klystrons, IOT's, thyratrons or tetrodes by:
  - High power UHF solid state amplifiers (SSPA) and efficiencies >50 percent
  - High power solid state modulators for cw and pulsed applications and efficiencies > 98 percent in cw.
- High efficiency klystrons pushing the efficiency from < 50 up to 90 percent

There is a strong trend towards CW UHF SSPA up to a few 100 kW, a hot topic for high RF power for accelerator projects but too early to favour a technology. However some recent advancements in multi beam klystron design may reinvigorate the technology and make it an attractive option for high efficiency, High power RF. We will keep a watching brief on technology over the next few years as our design matures.

CONCLUSION

A Preliminary concept has been designed for a new 4th Generation Australian light source facility, capable of reaching < 50 pm$cdot$rad horizontal emittance. This will provide the Australian user community with a world class replacement light source when the current light source reaches the end of its life, with no dark time. Future work will be to initiate a full design study over the next few years to deliver a complete conceptual design of this proposal.

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