ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THBD1

COMMISSIONING OPTICS: LARGER DYNAMIC APERTURE AND TOUSCHEK LIFETIME EXCHANGED FOR THE (TEMPORARY) COST OF INCREASED EMITTANCE IN 4TH GENERATION LIGHT SOURCES

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Abstract

Reduction of dynamic aperture encountered in 4th generation light sources presents a challenge for injection efficiency and commissioning. It's possible that only after BBA and optics corrections are applied, will the dynamic aperture be sufficient for reasonable injection efficiency. Furthermore, it's only after a circulating beam is established that BBA, BPM calibration, and other optics corrections can be applied. Limited dynamic aperture not only makes standard top-up operation more challenging; during commissioning this challenge is even greater. To address this problem, we have developed a lattice design that allows for both low emittance optics (for standard user beam operation) and what we have called "commissioning optics" which is a set of lattice parameters that allows for larger dynamic aperture (DA) and Touschek Lifetime (TLT) at the (temporary) cost of larger horizontal emittance.

4TH GENERATION LIGHT SOURCES COMMISSIONING CHALLENGE

Generally, 3rd generation light sources have large Dynamic Aperture (DA) and Energy Acceptance (EA), and consequentially good lifetime, but relatively large horizontal emittance compared to the goal of 4th generation storage ring light sources. As we move closer to the diffraction limit in the horizontal plane, 4th generation light sources strive towards lower horizontal emittance through sharing the bending amoung more dipoles with stronger focusing to keep the dispersion function low. The consequence of the smaller dispersion function is that stronger sextupoles are required for chromaticity correction, which leads to reduced DA and Touschek Lifetime (TLT). This trend of trading-off lower emittance at the expense of DA and EA can be seen Fig. 1 in Ref. [1].

Comprehensive modelling of realistic errors scenarios and correction are required to verify the design of ambitious fourth generation designs. Recent studies have detailed comprehensive and realistic error modelling, as well as simulated commissioning to demonstrate a feasible method to commission these challenging machines [2–5]. Much can also be learnt from the experience of recently built and commissioned light sources [6–11]

AUSTRALIAN SYNCHROTRON 2.0

The Australian Synchrotron light source was commissioned in 2006 and began user operation in 2007. Since then, the facility has achieved world-leading reliability, record vertical emittance and coupling control [12], and has recently expanded the suite of beamlines to more fully support the local user community.

The Australian Synchrotron is halfway into its expected 30-year lifetime, and so like many existing light source facilities, ANSTO is considering options for a 4th generation light source to continue to service the user community after the Australian Synchrotron reaches the end of its lifetime [13, 14].

ASSESSING THE MAGNITUDE OF THE CHALLENGE

To understand the scale of difficulties potentially awaiting us during commissioning, we can consider the closed orbit and optics for a machine with a set of random errors, randomly assigned, via a Gaussian distribution truncated at 3 sigma. Table 1 contains the standard deviation of the alignment errors and field errors applied. Note that these values are not the final tolerances and further work is required to determine a reasonable set of alignment tolerances. Figure 1 shows the RMS of the closed orbit distortion and beta-beating across 100 random seeds, for both the nominal optics and the commissioning optics, as well as the proportion of lattices where a closed orbit can be found. The horizontal axes in Fig. 1 is a fraction that is applied to the misalignments and field errors, which has become a common approach to assessing and comparing the susceptibility of the lattice to these errors [2–4, 15].

Table 1: RMS magnet alignment and field errors. Note these values are not tolerance specifications. Instead they are used to demonstrate the difference between the nominal optics and commissioning optics.

Type	Value
Magnet element alignment (ΔX, ΔY)	30 µm
Dipole fractional strength error	1e-4
Quadrupole fractional strength error	1e-4
Sextupole fractional strength error	1e-4
Magnet element rotation (ΔPSI)	100 µm

Figure 1d) indicates what is the case for many 4th generation light sources, that is: with realistic errors, the closed orbit does not exist.

Figure 2 shows the limited DA of the nominal optics lattice. During commissioning, when uncorrected errors further reduce the DA, injecting into this ring and maintaining

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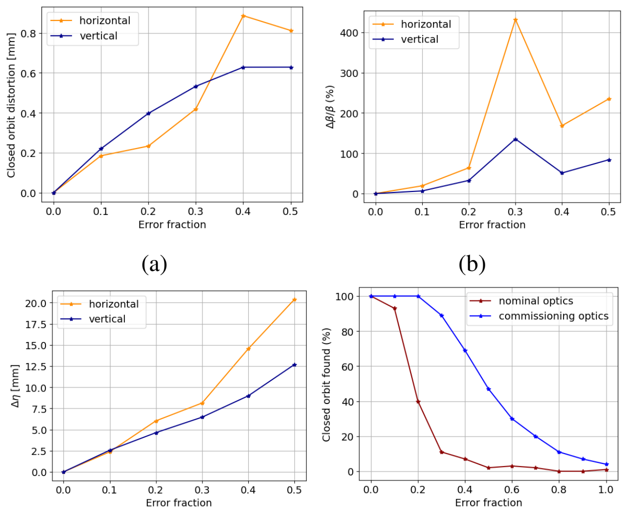


(a) (b) (c) (d)

Figure 1: RMS closed orbit and beta-beating before correction for different scaling factors applied to the misalignment and field errors listed in Table 1.

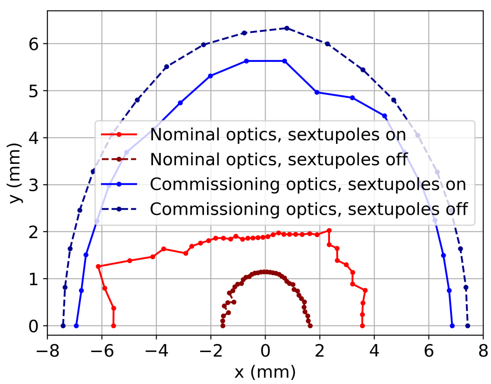


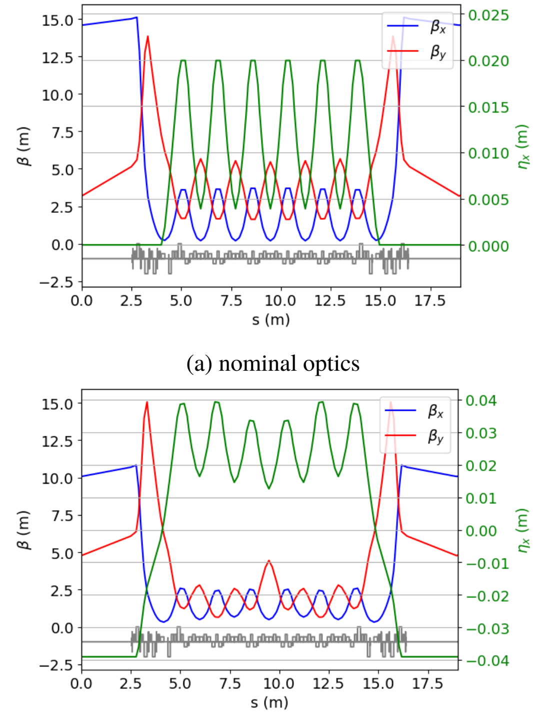
Figure 2: Dynamic Aperture calculated over 1000 turns. For nominal optics, the beta functions at the location of the DA calculation are: β_x = 9.8 m and β_y = 4.8 m. For commissioning optics, those values are: β_x = 14.6 m and β_y = 3.2 m.

sufficient lifetime will be a challenge. In fact, it's only after a stable circulating beam is established that BBA, BPM calibration, and other optics correction can be applied to restore the DA to allow for reasonable injection efficiency.

To address this challenge and reduce the risk of commissioning, we developed the idea of "commissioning optics" – a set of lattice parameters for more relaxed optics solution for commissioning, with larger DA and lifetime.

COMMISSIONING OPTICS

The aim of commissioning optics is to find a more relaxed optics solution for commissioning, with larger DA and lifetime, that is compatible with the nominal optics. A similar concept exists for colliders, where commissioning will be begin with relaxed optics before eventually progressing towards fully squeezed optics to achieve small beta-star for high-luminosity collisions. Such a provision was not necessary for third generation light sources, and whilst it would be greatly advantageous commissioning optics has not been made available for implementation in the design of fourth generation synchrotron light sources.



(a) nominal optics

(b) commissioning optics

Figure 3: Beta functions and dispersion function though one sector of AS2.0.

Figure 3 shows the optics for one sector for the nominal optics and for the commissioning optics and Table 2 summarises the key parameters. By reducing the focusing within the arc and intentionally allowing the dispersion function to grow, the beam size increases which results in increased lifetime for the same current. The higher dispersion values also means that sextupoles can be weaker, which allows for a larger DA compared to the DA of nominal optics (see Fig. 2). This solution requires independent focusing within the reverse-bend combined function magnet. As this combined function is achieved with an offset quadrupole, one way to achieve this independent control over the focusing would be to reduce the quadrupole strength and change the offset from -2.116 mm to -2.690 mm. After commissioning these magnets will be re-positioned through a relative offset of 574 μm. To accommodate for this additional space, the pole tip radius would need to increase from 12.5 mm to 13.1 mm, and as a consequence the design pole tip field needs to increase by 4.3% (see Table 3) to accommodate commissioning optics.

Alternatively the independent focusing could be achieved by reducing the focusing of the offset quadrupole and then

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Table 2: Key Parameters for the Nominal Optics and Commissioning Optics Settings

	Nominal	**Comm.**
Energy, (E)	3	
Circumference, (C)	454.8 m	
Harmonic number, (h)	758	
Main RF frequency	500 MHz	
RF cavity voltage	2.3 MV	
Natural chromaticities	-151.7, -76.3	-82.7, -67.1
Chromaticities (ξ_x, ξ_y)	0.99, 0.99	0.06, 0.05
Mom. compaction	0.056e-3	0.182e-3
Hor. emittance (ε_x)	50 pm	213 pm
Tunes (Q_x, Q_y)	70.23, 20.81	53.09, 29.60
Energy spread	1.11e-3	4.22e-3
Bunch length	2.03 mm	13.94 mm
Current	400 mA	-

reinstating the bending angle through horizontal-dipole trim coils or coils directly on the vacuum chamber. Table 3 summarises the offset quadrupole properties during commissioning optics and nominal optics.

Table 3: Offset quadrupole properties and settings for commissioning optics and for nominal optics for both the original design and the design with the allowance for the further offset during commissioning optics.

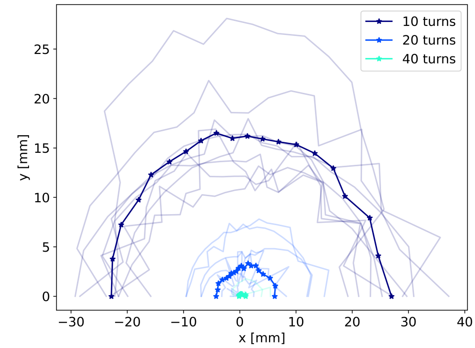
Optics	**K_1 [m^{-2}]**	**Pole-tip radius [mm]**	**B_{qu} [T]**	**offset [mm]**
Original design	11	12.5	1.536	-2.116
Original design with allowance for comm. optics	11	13.1	1.602	-2.116
Commissioning	8.65	13.1	1.293	-2.690

Dynamic Aperture

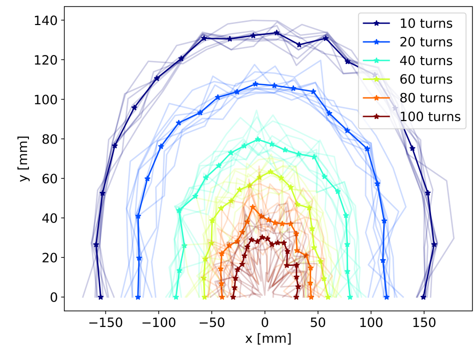
The larger dispersion through the arc during commissioning optics mode of operation, means that the chromaticity-correcting sextupoles can be weaker, which results in a larger DA as shown in Fig. 2. Typically during commissioning of fourth generation light sources the sextupoles are turned off to begin with [2, 3, 15]. Whilst the sextupoles are needed to increase the DA when a stored beam is established (see Fig. 2), turning off the sextupoles will increase the DA over a limited number of turns (see Fig. 4). Under the commissioning optics settings, the DA remains larger of more turns before the sextupoles are ramped.

Touschek Lifetime

Despite the momentum acceptance being larger for nominal optics, the increased beam size for commissioning optics results in a longer Touschek lifetime. The lifetime for nominal optics is 7.16 h, whilst for commissioning optics it's 21.36 h — both calculated with a beam current of 200 mA.



(a) nominal optics



(b) commissioning optics

Figure 4: Dynamic Aperture calculated with sextupoles turned off, tracked for various number of turns.

CONCLUSION

Fourth generation synchrotron light sources achieve lower emittance, at the expense of DA and TLT. When errors are introduced, the DA decreases even further and often the closed orbit does not exist before some orbit correction can be applied. 'Commissioning optics' seeks to address this challenge by relaxing the optics to allow for greater DA and TLT, at the temporary cost of emittance. Incorporating flexibly into the optics and technical design allows for relaxed focusing, increased dispersion, decreased sextupole strengths during commissioning. The increased dynamic aperture of commissioning optics will increase the early injection efficiency. With these commissioning optics settings, 45% of the lattice realisations (initiated with different random seeds) could find the closed orbit when half of the misalignment and field error magnitude applied. This is an improvement upon the nominal optics which only saw 2% of the lattice realisations be able to find the closed orbit. Commissioning optics will allow us to more easily achieve stable, stored beam to then perform BBA and LOCO. Overall these relaxed optics can reduce risk and allow for more rapid commissioning.

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REFERENCES

[1] P. Raimondi and S. M. Liuzzo, "Toward a diffraction limited light source", *Phys. Rev. Accel. Beams*, vol. 26, p. 021601, 2023.

[2] T. Hellert, C. Steier, and M. Venturini, "Lattice correction and commissioning simulation of the Advanced Light Source upgrade storage ring", *Phys. Rev. Accel. Beams*, vol. 25, p. 110701, 2022.

[3] V. Sajaev, "Commissioning simulations for the Argonne Advanced Photon Source upgrade lattice", *Phys. Rev. Accel. Beams*, vol. 22, p. 040102, 2019.

[4] S. M. Liuzzo, N. Carmignani, L. Farvacque, and B. Nash, "Lattice Tuning and Error Setting in Accelerator Toolbox", in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 3067–3070. `doi:10.18429/JACoW-IPAC2017-WEPIK061`

[5] S. M. Liuzzo *et al.*, "The ESRF-EBS Simulator: A Commissioning Booster", in *Proc. ICALEPCS'21*, Shanghai, China, Oct. 2021, pp. 132–137. `doi:10.18429/JACoW-ICALEPCS2021-MOPV012`

[6] Y. M. Peng, J. S. Cao, and J. H. Chen *et al.*, "Milestone progress of the HEPS booster commissioning", *Nucl. Sci. Tech.*, vol. 35, p. 16, 2024.

[7] P. Raimondi *et al.*, "The Extremely Brilliant Source storage ring of the European Synchrotron Radiation Facility", *Commun. Phys.*, vol. 6, p. 1, 2023.

[8] P.F. Tavares *et al.*, "Commissioning and first-year operational results of the MAX IV 3 GeV ring", *J. Synchrotron Radiat.*, vol. 24, p. 5, 2018.

[9] L. Liu, M. B. Alves, A. C. S. Oliveira, X. R. Resende, and F. H. de Sá, "Sirius Commissioning Results and Operation Status", in *Proc. IPAC'21*, Campinas, Brazil, May 2021. `doi:10.18429/JACoW-IPAC2021-MOXA03`

[10] L. Liu *et al.*, "Status of SIRIUS operation with users", in *Proc. IPAC'23*, Venice, Italy, May 2023. `doi:10.18429/JACoW-IPAC2023-WEOGA2`

[11] S. M. White *et al.*, "Commissioning and Restart of ESRF-EBS", in *Proc. IPAC'21*, Campinas, Brazil, May 2021. `doi:10.18429/JACoW-IPAC2021-MOXA01`

[12] R. Dowd, M. Boland, G. LeBlanc, and Y.-R. E. Tan, "Achievement of ultralow emittance coupling in the Australian Synchrotron storage ring", *Phys. Rev. Spec. Top. Accel. Beams*, vol. 14, p. 012804, 2011.

[13] R. Dowd, D. Zhu, T. Charles, X. Zhang, and Y.-R. Tan, "Conceptual Design for a Future Australian Light Source", presented at the IPAC'24, Nashville, TN, USA, May 2024, paper TUPG09, this conference.

[14] R. T. Dowd *et al.*, "Conceptual Design of a Future Australian Light Source", in *Proc. IPAC'22*, Bangkok, Thailand, Jun. 2022, pp. 1381–1384. `doi:10.18429/JACoW-IPAC2022-TUPOMS001`

[15] T. K. Charles, B. Holzer, R. Tomas, K. Oide, L. van Riesen-Haupt, and F. Zimmermann, "Alignment & stability challenges for FCC-ee", *EPJ Tech. Instrum.*, vol. 10, p. 8, Mar. 2023.