ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB095

CONCEPT DESIGN FOR THE CLS2 ACCELERATOR COMPLEX

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Abstract

The Canadian Light Source has been in operation since 2005 and is now looking at a design concept to upgrade to a fourth generation storage ring. A brief overview is given of a possible accelerator complex layout, including some details on the lattice design and injection system. A full energy linac is being explored as an option for top-up injection and to future proof the facility for a potential FEL upgrade.

BACKGROUND

This CLS2 machine concept design was delivered as part of the strategic planning allowed under the operational funding received for the present CLS. The mandate for the machine concept design was based on the 2015 CLS Science Case generated by the user community and subsequent input from users and experts which is received and incorporated into the design on an ongoing basis. The mandate for a new machine for the Canadian synchrotron science community was to develop a new ring concept that would deliver:

1. A brighter and more coherent source than the present CLS; and

2. Address the scientific requirements from Infrared (IR) to hard X-rays.

This mandate is consistent with other international synchrotron communities who have planned and developed new light sources, however the requirement for extracting IR does pose some challenges for new MBA lattices.

This paper summarises the concept for CLS2 that has been developed as part of a Conceptual Design Report (CDR), which is soon to be released, and will form the basis of a future Technical Design Report (TDR). The purpose of this concept design is to get feedback from the Canadian scientific community on how this machine fits their needs or emerging future needs and for them to influence the inevitable modifications to this vision for CLS2. After this consultation process, a CLS2 TDR will be created in the coming years with changes and optimisations incorporated to this concept design, before a final design is arrived at.

MACHINE CONCEPT

The initial CLS2 concept machine is for a 578 m circumference 3 GeV Storage Ring [1] with a full energy compact 250 m, 3 GeV Linac using C-band technology [2] that can prepare the beam for a future expansion to drive a Free Electron Laser. A diagram for the purposes to portray scale is shown in Fig. 1, with the present CLS shown on the right.

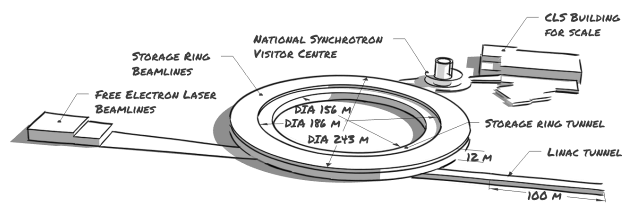

Figure 1: Concept sketch of the CLS2 facility for the purpose of portraying scale.

The physics simulations and analysis of the CLS2 ring concept design is presented in Ref. [1, 3]. It is a 3 GeV electron storage ring which is over 1,000 times brighter and more coherent than the present CLS. The energy of 3 GeV was chosen as it is a sweet spot that generates a synchrotron radiation spectrum that covers the full range of IR to hard X-rays for the needs of Canadian users.

BRIGHTNESS

The comparison of the brilliance curves from CLS2 using the IDs from CLS are shown in Fig. 2 and seen to be three orders of magnitude brighter in the new machine – thus meeting the first mandate for the machine concept design.

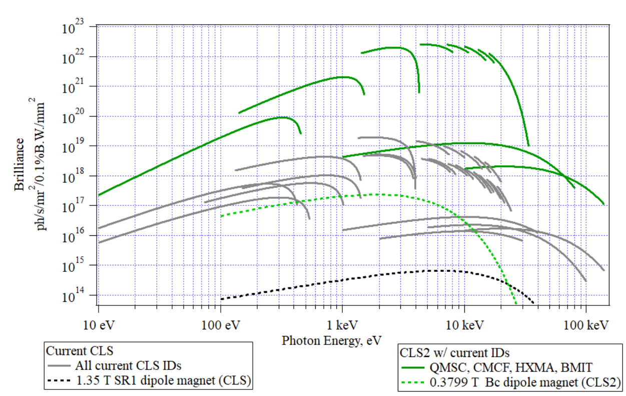

Figure 2: Brilliance curve comparison of CLS and CLS2 with the existing CLS ID designs.

The brilliance curve for IDs that will be specifically designed for CLS2 will be even brighter. These concepts not only include the undulators which will provide light to most of the beamlines, but also present options to harden the X-ray spectrum for the users who have high energy requirements,

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as well as options for the IR users at the low end of the spectrum. This is a common approach to meeting the mandate to deliver for the full spectrum of users. Emerging solutions for extracting IR from low emttance rings will be looked at in detail in the TDR, along with the option for a second small low energy ring, such as the 1.5 GeV ring at MAX IV [4] which was designed to serve the IR to UV community. The designs for the radiation sources on the ring will be developed in the TDR phase and only presented in overview in the CDR. The CLS is one of the light sources able to design IDs in-house and build them entirely with local industry, thanks to the CLS Magnet Mapping Lab and innovative Canadian companies.

In order to achieve this increase in brightness in the CLS2 design compared with the present CLS ring, it was necessary to increase the circumference of the ring to over 500 m, compared to the present 171 m circumference. It was determined that simply installing a new ring design into the existing tunnels and building would not achieve the brightness demanded by the user community [5]. The physics of this is given by the relationship of the horizontal electron beam emittance ϵ_x – which is proportional to the beam size and inversely proportional to the brightness – is given by [6]

$$\epsilon_x \propto \frac{\gamma^2}{N_\mathrm{d}^3}, \tag{1}$$

where $\gamma = E_\mathrm{e}/m_\mathrm{e}c^2$ is relativistic factor and proportional to E_e the electron beam energy, and $m_\mathrm{e}c^2$ is the electron rest mass energy and N_d is the number of bending magnets used in the ring. The smaller the emittance, the brighter the beam. Therefore, to get a brighter beam for a given beam energy, one needs to increase the ring size to fit in more bending magnets. Increasing the beam energy above 3 GeV both reduces the low energy end of the spectrum and becomes very expensive due to the size of the ring and the power required to achieve a higher energy.

LIGHT SOURCE COMPARISON

There is only one high energy ring per continent built as a dedicated light source; APS in the Americas; SPring-8 in Japan; and ESRF in Europe[1]. Canadian users already have access to the higher energy X-rays through the investment made in the CLS@APS programme, which operates at 6 GeV and will complete its APS-U upgrade project. The approach taken for the CLS2 concept design was to increase the ring circumference and only consider designs less than a 600 m circumference (see Table 1).

The design approach taken for the CSL2 ring was to keep the ring below 600 m in circumference, to match the scale of the facility to be commensurate with the size of the Canadian user community, in addition to keeping the cost down. The latest design principles of low emittance and high brightness rings were used, including the MBA lattice which has

Table 1: Comparison of Selected Light Sources in Operation with the CLS2 Concept Design

Name	Energy [GeV]	Circ. [m]	Current [mA]	Hor. Emit. [nm rad]
CLS2	3	578	300	0.025
SIRIUS	3	518	500	0.25
MAX IV	3	528	500	0.33
NSLS II	3	792	500	0.55
TPS	3	518	500	1.6
SSRF	3	432	500	2.61
DIAMOND	3	565	500	3.22
SOLEIL	2.75	354	500	3.68
ALBA	3	269	200	4.33
ASP	3	216	300	7.12
Exceptions – high energy rings				
ESRF-EBS	6	844	200	0.134
PETRA III	6	2,304	100	1
Spring-8	8	1,436	100	3
APS	7	1,104	100	3

been used in the latest rings in operation at MAX IV and SIRIUS [7]. The technique of reverse bends [8] was also included to reduce the natural horizontal emittance down to 25 pm·rad [1].

This design is shown in the *Bartolini plot* in Fig. 3 showing the scaled horizontal emittance against circumference for many of the world's light source storage rings.

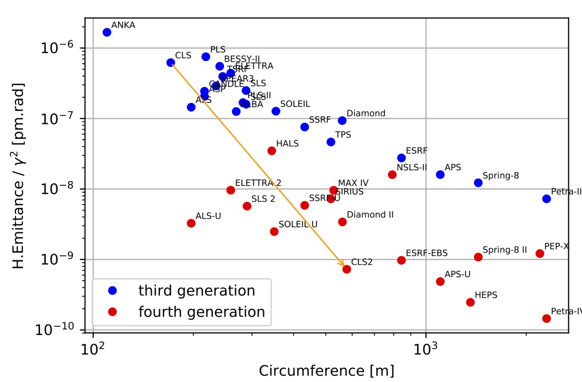

Figure 3: CLS2 design circumference and normalised horizontal emittance compared with other existing third and fourth generation light sources in operation and planned upgrades. The arrow shows the dramatic improvement in performance of the ring design from CLS to CLS2 (adapted from Ref. [6]).

MAGNET LATTICE

Further changes and optimisation of the CLS2 ring design is required as part of the TDR phase and additional input from the community. In order to demonstrate that this CDR

[1] The exception is Petra-III which is a converted particle physics collider and not design and built as a lightsource from its inception, it is also the largest light source in the world at 2.4 km in circumference.

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phase design of the CLS2 lattice is feasible, some effort has been made to make simulations of magnet designs in both 2D and 3D. A green option for the magnet design will be considered in the TDR phase using permanent magnet technology, however that type of R&D is beyond the scope of the CDR.

A 3D layout of the magnet models was done for one whole sector, placing each magnet along the chord where the beam will pass (Fig. 4). This initial layout is to check the concept for the lattice layout is able to be realised with more realistic magnet models, checking in particular for longitudinal clashes with the magnet coils.

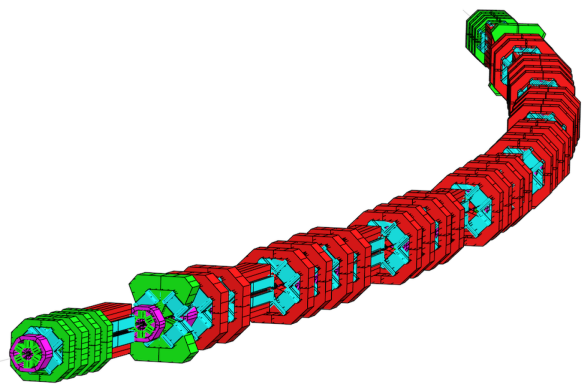

Figure 4: Layout of the magnets for one full sector of the ring.

INJECTION SYSTEM

The concept for the CLS2 injector is a modern, high gradient, compact 3 GeV linac, using C-band technology [2] to future proof the facility. This concept will allow for beam injection into the ring and provide beam to a future FEL facility. The use of a full energy linac will enable the simultaneous use for constant brightness top-up operation to the ring, which requires replenishing with fresh electrons on the timescale of once every few tens of seconds, in addition to rapidly delivering electrons to an FEL at the rate of hundreds of times per second. The beam will be directed from the end of the linac through a switch yard that will deliver beam to both the ring and the FEL.

Further changes to the concept design will be addressed in the TDR, following input from the user community and experts in response to this CDR.

CONCLUSION

A concept design has been developed for an CLS2 accelerator complex for a new light source facility in order to start the detailed conversation with the Canadian science community about their future needs. A CDR will be release in 2021 which was produces with very limited resources, however a new project is about to commence which will deliver a TDR in the next few years to incorporate feedback on the CDR. Figure 5 shows what a future facility might look like and is hoped to inspire the next generation.

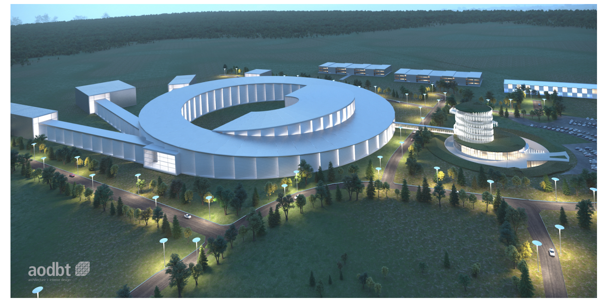

Figure 5: Architecture concept image of CLS2 with a visitor centre and ancillary buildings.

ACKNOWLEDGEMENTS

The work from all the staff that have made CLS the success is gratefully acknowledged, including the *side of the desk* effort to conduct this study while busy operating a facility in the time of the global Covid-19 pandemic.

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