The Canadian Light Source: STATUS REPORT UPDATE

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Abstract

The Canadian Light Source, CLS, is presently in the final phases of construction and commissioning of subsystems has begun. The CLS comprises four main systems: a 250 MeV LINAC, a 2.9GeV full energy booster, a 2.9 GeV storage ring and a number of beam lines serving interests ranging from infrared light to hard X-rays. Commissioning of the injection system up to and including the booster ring is expected to be complete in September 2002. The storage ring has compact lattice consisting of 12 double bend "achromats" sectors, incorporating twelve 5.2 m straights. Three straights will be used for injection, RF, diagnostics, and remaining nine for insertion devices (IDs). The initial set of beamlines will include two IR (bend magnet) and five ID sources supplying light to seven beamlines and up to ten experimental end stations. Construction and commissioning of the storage ring and initial phase of beamlines is scheduled to be complete by the end of 2003.

Keywords: Canadian Light Source, linac, booster, storage ring, insertion devices, beamlines

1. Linear Accelerator

The injection system is composed of the 250 MeV linear accelerator (linac), linac to Booster Transfer Line (LTB), and a 2.9 GeV full energy booster. The linac has been in operation for over 30 years as part of the former Saskatchewan Accelerator Laboratory. The 2856 MHz linac produces pulse trains of up to 136 ns in duration, corresponding to 68 buckets, at 500 MHz, in the booster and storage ring. The energy spread of the electron beam from the linac will be compressed [1] to about ±0.15%. This energy spread eases the beam transport [2] to the booster and increases the booster injection efficiency.

2. Booster Ring

The booster [3] accelerates the electrons from 250 MeV to the full energy of the storage ring, 2.9 GeV. The beam extracted from the booster is expected to have an average current of 20 mA over the duration of the pulse train. The booster repetition rate is 1 Hz. Pulse trains from the booster will be stacked in the storage ring, tail to tail over $(3\times68=)204$ buckets, and up to an average circulating current of 500 mA.

This system was designed and built by Danfysik in Denmark as part of a design build contract. Danfysik used a concept design developed by CLS [3] and completed the detailed design and fabrication. With this contract CLS was responsible for the installation and Danfysik was responsible for supervision of the installation. The intent was to have a system that could be fabricated offsite and integrated at the CLS. This on-site integration to CLS systems required close coordination between the CLS staff and Danfysik staff.

The first parts to arrive on site were the girder pedestals that were to be installed within the tunnel. CLS staff installed the girders within ±3mm of the required ideal location. As part of the off-site fabrication, the magnets were mounted and aligned on the girders and the vacuum chambers installed. These aligned pre-assembled girders were then shipped to the CLS for installation. Installation and final alignment of the girders and cavities went extremely well. Survey checks of the magnets showed that they had not shifted during shipment, and alignment was easily achieved. Power supplies were tested at Danfysik prior to shipment to ensure functionality. Once at CLS, these power supplies and cables were quickly installed.

CLS procured and installed all vacuum pumps and gauges so that standard equipment could be used throughout the facility. Once the main girders were in place the water systems were installed.

Two radio frequency (RF) cavities were shipped to CLS for installation within the ring at the same time as the girders. Integration of the RF system required more time than was originally expected due to the complexity of the system and coordination between all contractors. However, the RF system was ready for commissioning tests in June, 2002.

The first injection into the booster took place in June. This was quickly followed by stored beam at the injection energy. In August a circulating current of 7.5 mA was ramped to 2.9 GeV. Shortly after this, the 2.9 GeV was successfully extracted from the booster. Details of the beam parameters will be measured in September 2002, when booster commissioning is expected to be completed.

3. Storage Ring

The storage ring (SR) has a circumference of 170.9 m, and incorporates twelve 5.2 m straights. The basic machine parameters are provided in Table 1.

Table 1: CLS Storage Ring Machine Parameters

Circumference	170.88 m
Periodicity	12
Tunes: ν_x,ν_y	10.22, 3.26
Momentum compaction	0.0038
Straights	
Length	5.2 m
β_x , β_y,η_x (functions at center)	8.5, 4.6, 0.15 m
RF frequency	500 MHz
Harmonic number	285
Energy acceptance	1.54%
Dipole field	1.354 T
Horizontal emittance	18.1 nm-rad
Energy spread	0.111%

A more detailed description of the lattice is available [4,5].

The basic cell structure, see Fig. 1, is a double bend acromat (DBA) and produces a fairly compact lattice. Each cell consists of 2 dipole magnets, 3 families of quadrupole magnets, 2 families of sextupole magnets and 2 X-Y orbit corrector magnets. The sextupole magnets all have extra windings to produce skew quadrupoles for coupling control, and 1 family of sextupoles have extra windings for horizontal and vertical orbit correction.

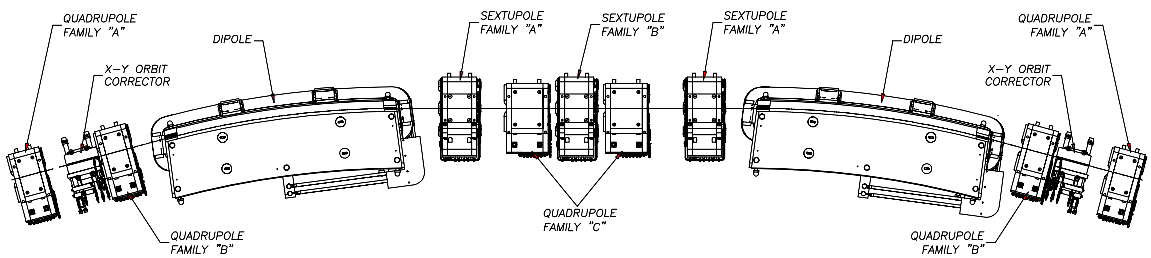

Fig. 1: Basic cell structure.

Of the twelve available 5.2 m straights within the ring, three straights will be used for injection, RF, diagnostics, and remaining nine for insertion devices (IDs). As part of the design basis each insertion device straight will be capable of containing two (2) IDs. Thus, in addition to those magnets found in the DBA, 3 additional dipoles will be located in the straights to provide local orbit chicanes.

3.1 Magnets

The dipoles are curved gradient magnets with an arc length of 1.87 m. One prototype magnet was constructed to verify performance and once verified twenty-four (24) production magnets constructed. Measurements of all dipoles were done at the precision measurement facility [6] at the Laboratori de Llum Sincroto (LLS) at Barcelona, Spain. Results indicate that the magnetic requirements have been met [7]. All dipoles have been built and delivered to the CLS.

The quadrupoles and sextupoles [8] are designed with an open-sided "C" configuration. Each family of quadrupoles have the same cross-section, and 2 of the families have the same physical length. Similarly, the sextupole magnet families have the same cross-section. A prototype of the shortest magnet from each type has been fabricated to verify performance, and fabrication has started on the production magnets.

The X-Y orbit corrector magnets are also designed with an open-sided "C" configuration. A prototype has been constructed and magnetic measurements will be made to confirm performance.

The injection septum and associated kickers have been awarded to Danfysik. The injection septum is the same as the booster extraction septum with a very low leakage field (≈ 2 G-m). Delivery of the septum is expected in the final quarter of 2002 and the kickers will be delivered in early 2003.

3.2 Girders

The magnets within each cell will be mounted on 5 separate supports. Each dipole will have its own support system consisting of 2 concrete pillars and adjustable interfacing hardware between the pillars and the dipoles. The elements upstream and downstream of the dipole will be directly mounted on precision-machined girders. These girders will in turn be mounted on concrete pillars using adjustable interfacing hardware. The interfacing hardware in on each support will consist of 4 vertical screws and 3 horizontal struts.

3.3 Vacuum System

To achieve adequate beam lifetimes a pressure of one nanotorr is required. The vacuum system uses six (6) discrete absorbers to intercept approximately 98% of all photons produced by the dipole magnets. The remaining photons will be directed down the beamlines. The absorbers are fabricated using OFHC copper. Each unit will be removable for access to the absorber or for replacement. Prior to installation the vacuum chambers will be baked to reduce the thermal desorption rates. No "in-situ" bake out system is planned.

The vacuum system provides one port per dipole and one insertion device (ID) port for each straight section. The latter port will accommodate two IDs in each straight. The majority of the vacuum system will be constructed of 316LN stainless steel. Two (2) of the required ID chambers will be based on the APS style ID chamber and be constructed of aluminum.

The general shape of the chamber includes the electron beam chamber, neck and antechamber. To increase the passively safe current the neck in each dipole is formed using a water-cooled copper insert. The neck dimensions provide low chamber impedance, a large enough gap for unrestricted exit of photons, suitable conductance for pumping and allowance for all magnet pole tips. The majority of the electron chamber has a fixed geometry. Any change in the shape is accomplished using a minimum 5:1 ratio transition piece to minimize RF impedance. In-line flanged connections utilize a flat flange design to improve dimensional tolerances and to reduce beam impedance.

Pumping for a typical cell includes six (6) 300 l/s, one (1) 150 l/s, and four (4) 75 l/s Diode pumps. These pumps will be connected in parallel to 3 controllers/power supplies.

3.4 RF System

The CLS storage ring RF system will operate at exactly 500 MHz and will use a HOM damped superconducting (SC) RF cavity based on the Cornell cavity design used in CESR [9]. The Cornell design features a low-impedance, large aperture niobium cavity which allows potentially beam-perturbing HOMs to propagate out of the cavity volume to HOM loads located external to the cavity where they can be very effectively damped. The CLS expects to avoid the use of a longitudinal damping system with the Cornell-type cavity.

The CLS has opted to begin operation with one Cornell-type SC RF module installed in the storage ring and one full module to act as a spare in case of a major system malfunction. Extra attention will have to be given to the cavity operation under the poorer vacuum conditions expected in the early commissioning phases of the machine. Future operations may employ the second cavity to operate in the CLS storage ring when very high current operation is desired.

The Cornell cavity has proven its reliability through its service in CESR and is well suited for use in high current storage rings. As a rough guideline, the CLS storage ring will require approximately 110 kW or RF power per every 100 mA of circulating beam. The RF amplifier system will employ a 310 kW CW klystron. With one installed cavity, this will comfortably allow the CLS to operate at currents in excess of 200 mA, which is well within the current demonstrated operating parameters of the CESR cavities.

3.5 Cryogenic System

The SC RF cavity requires a cryogenic system to provide 4.5 K liquid helium (LHe) and liquid nitrogen (LN2) to the cryostat. The cavity nominally requires 550 litres of LHe be maintained within the cryostat. The cryostat has a static heat leak of 35 W and a dynamic heat load of 147 W, in addition to this load the valve box, flexible VJ piping, and distribution line add approximately 137 W, for a total requirement of 284 W.

The system under construction consists of a main compressor and a recovery compressor, oil removal system, cold box, Dewar, helium gas storage tank and a LN2 storage tank.

3.6 Orbit Control

Global beam position correction will be accomplished with 48 horizontal and 48 vertical orbit correctors. Extra vertical correction (per unit phase advance) is required because of the stringent requirements to position the much smaller vertical beam size. Details of the position correction are given in reference [10].

Global and local coupling correction [10] will be accomplished with 36 skew quadrupole magnets.

4. Insertion Devices

Nine straight sections are available for IDs. To maximize the number of ID beam lines, each of the straights will be capable of containing two IDs with a chicane separating the beams by 1.25 mrad.

An initial set of IDs is in the procurement stage: An in-vacuum undulator with 22 mm period, 5 mm minimum gap and 145 poles will cover the photon energy range from 6 to 18 keV; a 45 mm period undulator with a minimum gap of 12.5 mm and 53 poles; and a 185 mm period undulator with 19 poles and 25 mm minimum gap will share the same straight and cover photon energy ranges from 250 to 1900 eV and 5.5 to 250 eV respectively. A helical APPLE-II undulator with 75 mm period, 15 mm minimum gap and 43 poles will deliver circularly polarized light from 100 to 1000 eV and linearly polarized light from 100 to 3000 eV. Finally a superconducting high energy wiggler with a period of 33 mm, a gap of 12 mm and a critical energy of 10.7 keV will produce hard x-rays up to 40 keV.

A standard vertical support structure has been designed for each out of vacuum undulator. This will allow varying length undulators to utilize the standard design and require only the horizontal members to change length.

The out of vacuum IDs are designed to be used with APS type ID vacuum chambers.

5. Beamlines

The initial complement of beamlines has been chosen to serve the needs of the diverse community of Canadian Synchrotron light users. Approximately one third of our community uses IR light and one third are protein crystallographers. To satisfy the research requirements of this community, the following photon beamlines have been proposed and will be built in the first phase of our program. Beamlines are first sorted by source point type and then within each category by photon energy. Four (VLS-PGM, High Resolution SGM, Soft X-ray Spectromicroscopy and Protein Crystallography) beamlines are in the procurement stage, and the other three will soon join them. It is intended that they will all be operational by the end of 2003; so far there have been no unpleasant schedule surprises in this procurement process.

5.1 Bending Magnet Beamlines

A facility diagnostic beam line using visible light from a bending magnet source will be built. This line will initially provide light to a fast gated CCD camera to aid in facility commissioning; ultimately, some of the visible light from this source will be switched to a streak camera as well. We anticipate building a simple pinhole camera to operate with X-ray photons and provide continuous measurement of the storage ring phase space ellipse parameters.

A far IR beamline (10 – 4000 cm^{-1}) designed for high resolution studies of gas phase systems will be built, as will a mid IR (450 – 6000 cm^{-1}) spectromicroscopy beamline. This latter line is anticipated to have a large component of biological and industrial applications. The Far IR line will have an FTIR spectrometer with a vacuum bench and a gas cell. The Mir IR line will have an FTIR spectrometer with a microscope and a mapping stage.

5.2 Insertion Device Beamlines

A variable line spacing plane grating monochromator (VLS-PGM) beamline is planned to operate, with three gratings, over the range from 5.5 to 250 eV. This beamline will have good brilliance properties and high resolution (>10000) over its energy range. This beamline will have two endstations: a permanent photoelectron imaging endstation and a modular HV endstation to accommodate user instrumentation.

A high resolution spherical grating monochromator (High Resolution SGM) beamline is planned to operate, again with three gratings, over the energy range from 200 to 1900 eV. This beamline is intended to duplicate the capability, with much higher brilliance, of the existing Canadian SGM beamline at the Synchrotron Radiation Center in Madison, Wisconsin. At the CLS, it will have two endstations. The permanent UHV endstation will be instrumented with an electrostatic “Scienta” analyzer and there will be a modular HV endstation accommodating instrumentation provided by users.

A soft x-ray spectromicroscopy beamline will use a plane grating monochromator (a co-development project between the Canadian Light Source and the Advanced Light Source in Berkeley) and an elliptically polarized undulator to delivery arbitrarily adjustable polarized photons in the energy range from 200 to about 2000 eV. This line will have two endstations, one a scanning transmission x-ray microscope and the other a photoemission electron microscope. The line is strongly influenced by the successful STXM and PEEM applications at the ALS.

A protein crystallography beamline will be built using a small gap in-vacuum undulator to deliver high brilliance photon fluxes in the energy range from 6500 to 18000 eV. The design of this beamline is being done in cooperation with the Advanced Photon Source in Chicago, and it will bear a strong resemblance to the new protein crystallography beamline currently being built by the SER-CAT at the APS. Some attention will be paid to automation of the source handling facility at the CLS beamline.

A general purpose XAFS/microXAFS beamline will be built using a wiggler to deliver high photon fluxes in the energy range from 5000 to 40000 eV. This beamline will deliver stable high fluxes of photons (about 10^9 sec^{-1}) into a spot as small as 2 microns square. It is our intent to ultimately build an undulator based hard x-ray microprobe and a bending magnet based intermediate energy microprobe to complement this facility.

6. References

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* CLS Technical Design Notes can be seen at: http://www.cls.usask.ca/research/technotes.shtml