SOLARIS – NATIONAL SYNCHROTRON RADIATION CENTRE, PROJECT PROGRESS, MAY 2012

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Abstract

The first Polish synchrotron radiation facility Solaris is being built at the Jagiellonian University in Krakow. The project was approved for construction in February 2010 using European Union structural funds. The National Synchrotron Radiation Centre Solaris is based on an identical copy of the 1.5 GeV storage ring being built for the MAX IV project in Lund, Sweden. A general description of the facility is given together with a status of activities. Unique features associated with Solaris are outlined, such as infrastructure, the injector, operational characteristics and foreseen beamlines.

INTRODUCTION

In 2008 funds of 143 MPLN were pledged by the Polish government for the construction of a synchrotron radiation source, after proposal from the Jagiellonian University. In 2009 the feasibility study, based on the MAX–lab team knowledge and technology [1], was submitted and the National Synchrotron Radiation Centre Solaris was approved for construction in February 2010 using European Union structural funds. In December 2010 an agreement was signed between the Jagiellonian University and Lund University, Sweden for the mutual cooperation and sharing of knowledge related to the construction of the two facilities. Solaris is a replica of the 1.5 GeV storage ring of the MAX IV project and uses identical parts of the electron gun, linear accelerator and transfer line [1, 2]. Major differences between the two machines are the infrastructure, the lower energy linac and the beamlines.

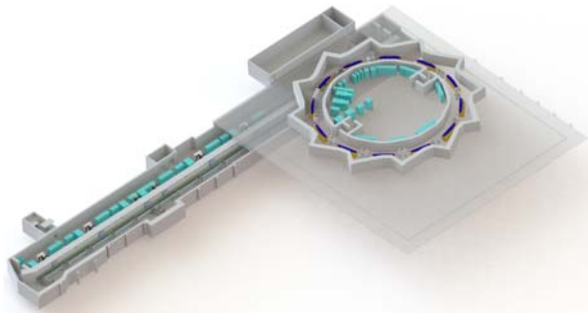

Figure 1. Layout of the Solaris synchrotron.

FACILITY

Building

The National Synchrotron Radiation Centre Solaris will be situated within the Campus of the 600th Anniversary of the Jagiellonian University Revival area, the new location for the Science Faculties and the site of the Jagiellonian Centre of Innovation in the city of Krakow. The land of an area of about 22000 m^2 will site Solaris synchrotron light source facility. The facility building complex will accommodate the injecting linac, storage ring, experimental beamlines, laboratories, supporting infrastructure, offices and auditorium hall. The contract for the design and construction of the complex was awarded in March 2011 to the consortium of companies: ALPINE Construction Polska Spółka z o. o. and ŁĘGPRZEM Spółka z o. o.. The building permit was granted in December 2011 and the construction is planned to be completed in August 2013.

Figure 2: Photo from the Solaris construction site (9th May 2012).

The machine part of the building is composed of a linac tunnel with a parallel modulator and support tunnel, both placed below the storage ring level. The length of the tunnel is about 108 m, within the constraints of land availability, foreseeing an upgrade to the linac to increase its energy for the top–up mode injection. All services, power, HVAC and cooling will be built with this upgrade in mind.

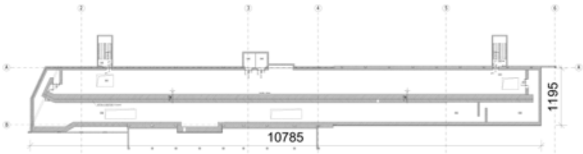

Figure 3: Concept of the modulator and service gallery (above) and linac tunnel (below) layout on level −7.7 m. Dimensions in centimetres.

The experimental hall for the beamlines houses the storage ring tunnel. The experimental hall has a surface area of 3000 m^2 and provision is made for its future extension on one side by > 600 m^2. Access to the storage ring tunnel will be through chicanes on the inner side and the roof shielding will be removable for machine installation and maintenance. All equipment for the storage ring will be housed on the inner side of the ring tunnel. A crane, rated at 8000 kg, spanning the experimental hall, will be used for the machine and the beamline installation and maintenance.

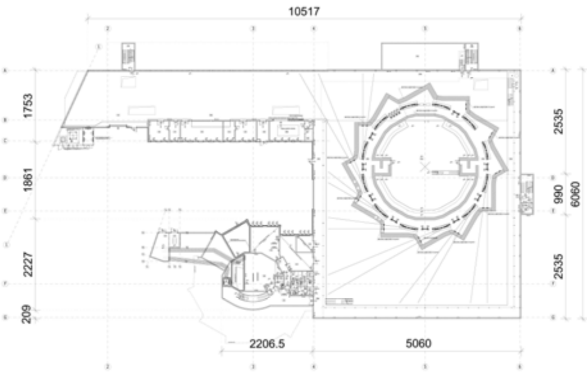

Figure 4: Concept of the facility layout on level −3.2 m. The experimental hall can be extended by about 10 m on the right hand side in the future. Above the linac tunnel ample covered space is available for pre–assembly and general laboratories. Dimensions in centimetres.

Injector

The Solaris linac injector will initially be operated at 550 MeV with an option for a full energy upgrade. The linac is composed of a RF thermionic gun and six normal conducting 3 GHz accelerating sections, grouped into three units. Each accelerating unit contains two 5.2 m long accelerating sections [3] and is powered by one RF unit, which consists of solid–state modulator driving a klystron and SLED cavities. The linac sections are being manufactured by Research Instruments GmbH and will have a guaranteed performance of 20 MV/m. The RF power from SLED cavities feeding each unit will be split equally to two linac sections. The first unit, however, will be configured to deliver the RF power also to the gun. Solid–state modulators, ordered and being manufactured by ScandiNova Systems AB, will power 35 MW klystrons at 10 Hz. The available pulse length will be 4.5μs (compressed in the SLED cavity to 0.75μs). The power will be enough to extract more than 600mA from the gun (0.2nC per bunch) [4].The electron gun will be an upgraded version of that presently used at MAX–lab. It will consist of ½+½+1 standing wave RF cavities with a BaO cathode. The normalized emittance is expected to be 10 π mm mrad [4]. A 120° double bend achromat (DBA) magnet placed after the gun will be used for compression and energy filtering. Total length of the Solaris injector will be 40.3 meters.

Transfer line

The beam is transferred to the storage ring via a 27° vertical ramp. The linac will initially be placed close to the storage ring in order to avoid long transfer line and to save the costs. When the full energy upgrade will be performed, the gun will be relocated.

The transfer line is optically mirror symmetric and composed of two 10° septa, two 17° dipole magnets and six quadrupoles connected in series. The extraction septum in the linac tunnel in combination with the kicker magnets will be used in the future to share the linac beam between topping up and possible free electron laser (FEL) experiments. The septum is a vertical DC magnet of Lambertson type. All magnets and power supplies are identical to MAX IV systems.

Injection process

Injection into the storage ring at the first stage will be performed with a single pulsed dipole magnet whereas in the future upgrade, the pulsed multiple magnet is considered to be used [3, 5]. The scheme has many advantages over a conventional four–kicker injection bump especially for top–up operation. In the case of Solaris with a straight section length of 3.5 m, a four–kicker scheme would require it to span over two achromats containing strong sextupoles and large dispersion that would affect the stored beam. Furthermore the conventional scheme would reduce the available space for insertion devices. The use of a pulsed sextupole magnet will simplify the scheme and circumvent the aforementioned disadvantages. The injection dynamics at a lower energy compared to the MAX IV case is considered in [3, 6]. Care must be taken in the design of the pulsed magnet and associated power supply given the 320 ns revolution time of the storage ring, since a two turn injection scheme is less efficient compared to a single turn scheme [7]. Once accumulated the beam will be ramped to its final energy of 1.5 GeV. The behaviour and response of magnets during ramping is expected to be similar to that of MAX III, a 700MeV ring operating at MAX–lab[8].

Storage Ring Technology

The storage ring will be technologically identical to the MAX IV 1.5 GeV ring and is composed of 12 magnet blocks forming a double bend achromatic (DBA) structure. Each DBA, containing two dipoles with gradients, quadrupoles and sextupoles, is constructed from two solid iron blocks. The iron blocks machined to high precision will contain all magnetic elements allowing for a very compact design. The iron for the magnets has been purchased and is being thermally treated prior to machining. The magnet design [9] is in the final stage of completion and is being performed in parallel with the design activities of the vacuum chamber.

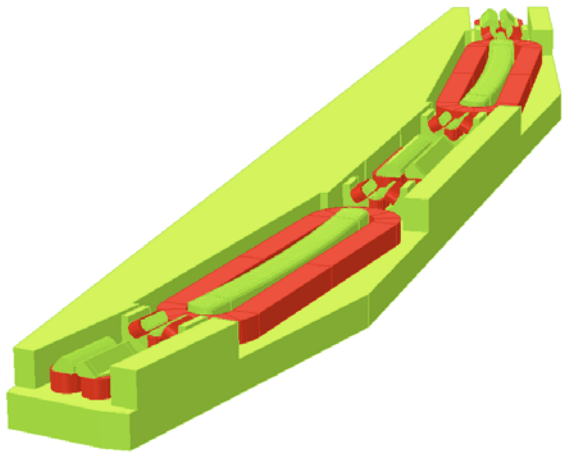

Figure 5: Magnet half block with coils in red [9].

An evaluation has been performed of the technology to be used for the vacuum system. Both a wholly Non Evaporable Getter (NEG) coated chamber, similar to that adopted for the MAX IV 3.0 GeV ring [10], and a conventional system with antechamber and absorbers were examined. A conventional stainless–steel system was chosen on the basis of manufacturer availability, costs, technology requirements and project time–schedule. The vacuum system is being designed and the construction drawings prepared by the group from CELLS–ALBA Synchrotron in Cedanyola del Valles in collaboration with MAX–Lab and Solaris. The system and magnet configuration foresees extraction of the bending magnet radiation at 7.5° from the first bending magnets of DBA magnets and from insertion devices at 0°.

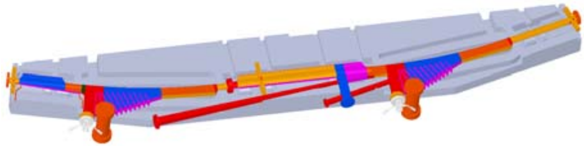

Figure 6: View of the DBA magnet (lower half) with the vacuum chamber inserted [11].

The storage ring RF system is composed of two 100 MHz cavities similar to those used in MAX II and MAX III rings. The cavities are normal conducting and of the capacity loaded type which have relatively high frequency higher order modes compared to pill–box type cavities. The cavities will be equipped with higher order mode coupling loops that will extract the residual high frequency modes. Cavities and couplers have been ordered and are being manufactured by Research Instruments GmbH. The ring also foresees operation with two passive Landau cavities at 300 MHz as designed by MAX–lab similar to the main cavities [12]. Either solid state or tetrode amplifiers will power the main cavities. One transmitter will provide 60 kW of power to the cavity via a circulator. The RF units will be controlled with a digital LLRF system.

Optics and Dynamics

The integrated magnets permit an ultra–compact DBA structure with low emittance and zero dispersion in the straight sections. The compact magnet design has three quadrupoles that focus in the horizontal plane while the vertical focusing is done by the gradient in dipoles. Pole face strips on bending magnets will allow tuning of the vertical focusing. Focusing sextupoles have also been integrated into focusing quadrupoles. Recently, the lattice has been optimised for the ramped operation in Solaris where Touschek lifetime is important since the facility will not operate in a top–up mode but in a decay mode. The optimisation has focused on increasing the momentum acceptance by ensuring the lattice momentum acceptance match the RF acceptance of 4 %. Together with the use of Landau cavities the Touschek lifetime at 500 mA is expected to reach 13 hours [7,13]. In each magnet block there will be three beam position monitors (BPMs) and three horizontal/vertical corrector coils mounted on the sextupole magnets. Two of the BPMs will be positioned at the ends of the achromatic block and one in the centre. The main parameters of the bare lattice at the energy of 1.5 GeV are presented in Table 1.

For X–ray production one or more superconducting wigglers are planned, while APPLE–II type undulators will be used for variable polarised light production. The linear and nonlinear beam dynamics have been studied with these perturbing insertion devices included in the lattice and results were presented in

[14]. The studies support the requirements on the achromat magnet design. It has been shown that in order to have the possibility to match the Solaris lattice optics to strong insertion devices (IDs) a tuning range of 4.5–5% has to be provided both for *SQFo* and for pole–face strips on dipoles. This could be demanding. Alternatively, a different matching procedure has to be attempted. One possibility is to add extra doublet of quadrupoles on either side of the ID. This however has several disadvantages. One is that extra space is required for the additional quadrupoles and, as was calculated for the super conducting wiggler (SCW), matched optics result in an increase of the horizontal beta function in the middle of the insertion device (ID) of 65 %.

Table 1: 1.5 GeV Storage Ring Parameters

Energy	1.5 GeV
Periodicity	12
Straight section's length	3.5 m
Circumference	96 m
Current	500 mA
Horizontal emittance (bare lattice)	6 nm rad
Horizontal tune ν_x	11.22
Vertical tune ν_y	3.15
Natural horizontal chromaticity ξ_x	−22.964
Natural vertical chromaticity ξ_y	−17.154
Momentum compaction (linear) α_c	3.055×10^{-3}
Horizontal damping partition J_x	1.464
Energy loss per turn (bare lattice)	114.1 keV
Natural energy spread (bare lattice)	0.745×10^{-3}
Momentum acceptance	4 %
Coupling	1 %
Overall lifetime	13 h

BEAMLINES

The funded project includes one experimental beamline and the search for funds for the full range of beamlines and endstations has started. Radiation for future beamlines can be provided either from bending magnets or undulators. Additionally a superconducting wiggler can be mounted on one of ten free straight sections.

Photoelectron emission microscopy (PEEM)

The first Polish beamline constructed in Polish Synchrotron will be based on the bending magnet radiation. Due to experimental interest (Soft–X–ray absorption spectroscopy, X–ray magnetic circular dichroism) and existing instrumentation (X–ray Photoemission Electron Microscope — XPEEM) the planned beamline will be designed for the soft X–ray photon energy range (0.2–1.8 keV). The energy resolution (E/ΔE) should be in the level of 4000–5000 or better to be able to measure chemical shift of the X–ray photo–electron spectroscopy peaks. The beam size for the endstation device (PEEM) is expected to be 50 µm × 50 µm. The spectroscopy chamber and the PEEM microscope will be exchangeable. The spectroscopy chamber will be dedicated to the basic research experiments and will be used also for chemical and biological samples. In the future spectroscopy chamber can be adapted to the scanning transmission X–ray microscope chamber by introducing focusing device in front.

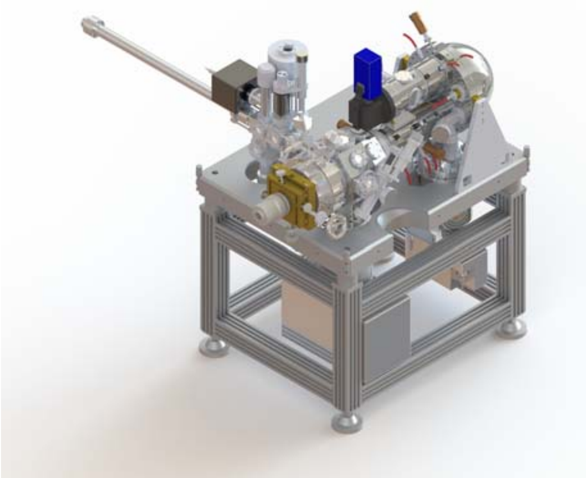

Figure 7: Photoemission Electron Microscope (PEEM) meant for the Solaris.

PX/SAXS/XRD

The energy parameters of SOLARIS (1.5 GeV) allow planning of a beamline utilizing the synchrotron radiation also in the hard X–rays range in the biocrystallography and material science field. The planned beamline has three endstations — for biocrystallography, small–angle X–ray scattering (SAXS) and diffraction of the synchrotron radiation on polycrystalline materials.

The concept of the beamline is to use and split the relatively large horizontal wiggler fan in three branches in order to make use of a greater part of the emitted radiation cone. The central 1 mrad will be used exclusively for an energy–tuneable station optimized for MAD data collection. An electromagnetic radiation (6–18 keV) will be emitted by the superconducting wiggler (B_0=3.5–4 T) with the critical energy of 5.5–6 keV.

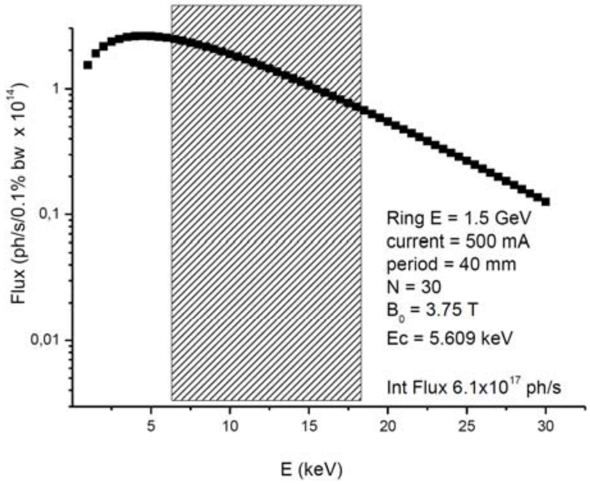

Figure 8: Theoretical synchrotron radiation flux profile from superconducting 3.75 T wiggler. Rectangle indicate possible to use energy range [15].

Soft X–ray spectroscopies PHELIX

The beamline is designed to perform studies of the electronic structure of solids with high energy–resolution, with the use of soft X–rays with variable polarization.

The source of the X–rays will be elliptically polarizing undulator providing radiation in energy range 50–1500 eV. The beamline will be equipped with a grating monochromator with the resolving power $E/\Delta E > 10^4$.

The main technique will be a photoelectron spectroscopy, including an angle resolved option. The layout of the beamline and endstation allows using the light from the same source also for the X–ray absorption spectroscopy (XAS).

Angle–resolved photoemission spectroscopy (ARPES)

The planned beamline will be designed for the UV photon energy range (8–1000 eV) from the quasiperiodic undulator. The energy resolution (E/ΔE) should be greater than 2×10^4 at 20 eV. The beam size for the ARPES endstation device will be 100 µm × 100 µm and the photon flux on sample will be greater than 10^{12} photons/s/0.01%BW.

CONTROL SYSTEMS

A control system (CS) and the IT infrastructure for Solaris machine are under design and development. The MAX IV Laboratory will provide the machine control system design that will be adopted to Solaris in that part where both machines differ [16].

The TANGO [17] control system and its dedicated tools have been chosen for the integration layer. It provides tools to build high level applications. A huge set of device servers to interface different types of equipment is available, too. TANGO has been deployed at several laboratories in Europe and found to be mature and reliable.

An interlock system will be based on distributed PLCs using the EthernetIP/CIP protocol. Other devices like power supplies, BPM electronics, scopes will use the Ethernet/TCP/IP. Thus the main field bus will be a computer network.

The computer network will be built of distributed network switches with 10GbE fiber up–links and 1GbE copper peripheral sockets. The active equipment will support advanced network management features like the loop prevention, VLANs and the firewall. It will be prepared to handle huge data transfers including access to the external computing infrastructure. The design has been presented in [18].

It is planned to take advantage of the PL–Grid Plus [19, 20] and the PLATON [21] projects. These provide infrastructure with CPU power and storage space. These could be useful for general IT services and for a control and experiments data processing.

Identification of detail requirements for the control system for the machine subsystems is in progress. The linac related ones will be ready soon. The storage ring's ones will come next.

Each beamline should have its own CS that will operate independently on the machine CS to some extent but their designs will have impact on each other. The control system for both the machine and beamlines should follow a standard to achieve interoperability as well as cost effectiveness, manageability and a long term maintenance. A document defining basic standards regarding the beamlines CS has been prepared [22]. However, it is subject to update according to the general technical progress and specific decisions will be taken.

Beamlines' control systems will be developed by the control group provided with the necessary resources from the beamline budget. This approach ensures that knowledge used for the control system development will last at the facility and makes later maintenance feasible [22].

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