RECENT DEVELOPMENTS AT SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

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Abstract

SOLARIS National Synchrotron Radiation Centre is under constant development of the research infrastructure. In 2018 first users were welcomed at three different experimental stations. Up to now 5 end stations are available at SOLARIS for experiments at 4 beamlines, and 4 new beamlines are under construction. In 2021 new front end for POLYX beamline was installed and degassed. Moreover, ASTRA beamline components were installed and first commissioning stage has stared. Additionally, a plasma cleaning station has been designed, built and is currently tested. Apart of the beamlines, upgrades to the linac and storage ring operation have been done. During the COVID-19 pandemic the software for remote injection process was developed and is used on daily basis. The transverse beam emittance measurement on the visible light beamline LUMOS was implemented and gives results that are complementary to the Pinhole beamline. Within this presentation the overview of the recent developments with insight to the details to be presented.

INTRODUCTION

SOLARIS National Synchrotron Radiation Centre is operating in Krakow, Poland since 2015. It consists of 600 MeV injector with thermionic RF gun and 1.5 GeV storage ring of 96 m circumference with 6 nm rad emittance [1-2]. The facility was built with tight cooperation with MAXIV Laboratory in Sweden. Nowadays SOLARIS is under constant development of the research infrastructure. In 2018 first users were welcomed at three different experimental stations. Up to now 5 end stations are available at SOLARIS for experiments at 4 beamlines, and 4 new beamlines are under construction. Moreover in 2022 the experimental hall extension works has just stared, which will allow for long beamlines accommodation.

NEW INSTALLATIONS

ASTRA Beamline

ASTRA is a compact bending magnet beamline designed for X-ray absorption spectroscopy measurements in the tender and hard X-ray range (1 – 15 keV). The beamline has no windows between the source point and the monochromator in order to minimize absorption of low energy photons [3]. The project is an international collaboration of Niederrhein University of Applied Sciences (Germany), the Synchrotron Light Research Institute (SLRI, Thailand), Bonn University (Germany) and SOLARIS. In the first half of 2020 the front end section of the beamline was installed (Fig. 1a). The main degassing process of the front end components was finished in June 2020 and the pressure level with the photon beam at 300 mA electron current in the storage ring was below 9.7e-9 mbar. In 2021 the main beamline components downstream from SOLARIS´ radiation shield wall were installed (Fig. 1b). A diagnostic module with a fluorescence screen and a wire-type X-ray beam position monitor is used to visualize and determine the white beam's position and profile. A compact differential ion pump maintains the pressure difference of 4–5 orders of magnitude between the diagnostic module (base pressure 1.0e-9 mbar) and the fixed exit beam Lemmonier type double crystal monochromator (1.0e-5 mbar). The high vacuum operating pressure of the monochromator allows to quickly exchange crystal pairs in order to cover the target energy range.

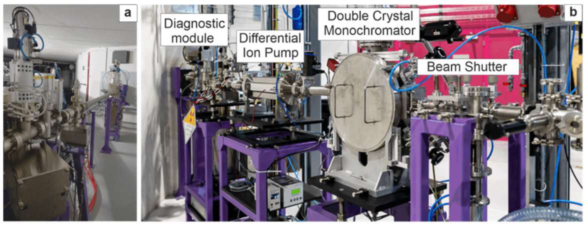

Figure 1: (a) Front end section, (b) main beamline components downstream the radiation shield wall.

In Autumn 2021, the first EXAFS spectra at the beamline were measured in transmission. During commissioning in January 2022, key performance parameters such as energy resolution (e.g. for InSb(111) at the sulfur K edge: $\Delta E/E = 7.0e\text{-}4$), photon flux (1.0e10 ph/s/0.1 A) and spatial stability of the monochromatic beam were evaluated. After recording XAS spectra of various reference compounds over the full energy range, experiments were carried out in cooperation with "friendly users" at different absorption edges, e.g. Mg, Al, Si, P, S, Cl, Fe, Ni, Zn, Sb and U in transmission mode. The obtained high-quality data shows the outstanding potential of this new beamline for academic and industrial research. The beamline was opened for the spring 2022 call for proposals and received a large interest from both Polish and international users. Within the EU project SYLINDA a compact vacuum X-ray spectrometer for high energy resolution fluorescence detection was recently added to the beamline, and the beamline staff performs its commissioning. Implementation of fluorescence and surface-sensitive total electron yield

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measurement modes will follow in the near months. As future upgrades in situ experiments and combinations of XAS with complementary techniques are planned.

The Front End Section for POLYX

The front end section for POLYX beamline consists of several components which performs the following roles: protection of personnel and devices against radiation and enabling safe access into the optic hutch, when the beamline is closed; limit/restrict the thermal load from the synchrotron light for the components located downstream of the front end section; protection of the vacuum in the storage ring and ensuring pumping system and pressure level measurement in this section and to monitor the position of the synchrotron light.

To fulfil presented functionality, we have defined sequence of the devices presented in Fig. 2. With presented sequence it is able to monitor beam position by keeping the XBPM device at the hot front end part and define radiation cone delivered to the beamline using dedicated slits unit. The front end section is finished with cooled beryllium window which separates the vacuum between the storage ring and the beamline during normal operation.

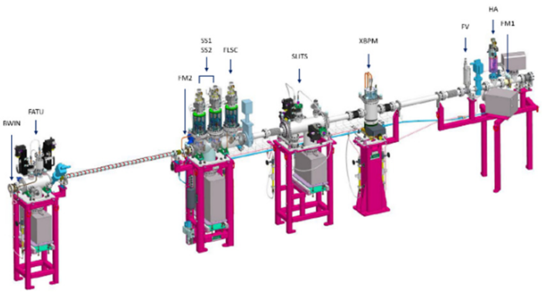

Figure 2: The scheme of the front end section. Main components from right to left: FM1 (fixed mask1), HA (heat absorber), FV (fast valve), XBPM (X-ray beam position monitor), SLITS (white beam slit unit), FLSC (fluorescent screen), SS1&SS2 (cooling double safety shutters), FM2 (fixed mask2), FATU (Filter assembly trigger unit) and BWIN (beryllium window).

The front end section was installed at experimental hall on the dedicated Test Stand after delivery. Mechanical assembly, subsystem checks, leak checks, before and after bakeout, were performed during user operation time before shutdown. Installation of the front end in the storage ring took place during summer shutdown. Front end was installed under overpressure of the nitrogen without additional bakeout. Whole operation including connection of compressed air, cooling water, cabling and PLC integration with storage ring took over three weeks. Personal Safety System (PSS) and Machine Protection System (MPS) were implemented and tested after installation. After shutdown it was necessary to allocate one week for degassing purpose. All components exposed to the beam (the heat absorber, XBPM, white beam slits and cooling safety shutters) were conditioned gradually. Significant improvement of pressure, average lower than 1e-9 mbar, was achieved after 20Ah of electron beam dose. Delivery of beryllium window, last fragile component of the front end, was postponed. In the meantime, all necessary instructions, and procedures on how to proceed in the event of a beryllium window breakage was developed and implemented at Solaris. Installation of beryllium window in filter assembly and trigger unit vacuum chamber (FATU) was performed after delivery. After successful radiation tests of scattered radiation at the experimental hutch the remaining front end section components (exit fixed mask and filters) were able to degas. We have noticed also quick improvements of the vacuum pressure level during degassing process of the second part. Finally, we have reached values below 6e-9 mbar with full beam (450 mA) at front end sector and below 4e-8 mbar with beam at each one of six filters at FATU chamber downstream ratchet wall. With the achieved parameters the section is ready for normal operation.

NEW DEVELOPMENTS

Plasma Cleaning Station

Contamination of the surfaces of optical elements i.e., mirrors, gratings and lenses with carbon is still one of the main problems of soft X-rays beamlines. Reduced intensity of synchrotron radiation in the K-edge carbon region and deterioration of optics surface parameters like roughness and reflectivity is the most common consequence of carbon contamination. Many techniques and cleaning procedures were developed at synchrotron and laser facilities to address this problem [4-7].

Table 1: List of Antenna and Plasma Generator Parameters

Parameter	Value
Supply current AC 230 V	11 A
Output power	max +50 dBm
Optimal output power(1)	+48 dBm
Output VSWR	1.7 U
Output signal format/modulation	Continuous wave
Optimal working frequency	37.560 MHz
Operating frequency range	12 – 50 MHz
Nominal operating frequency	13.560 MHz
External input signal level	max +1 dBm
Internal signal oscillator:	
- output signal format	sinewave
- output signal level(1)	-6.6 dBm
- frequency range	0.0001–50 MHz

(1)Frequency 37.560 MHz

At SOLARIS we have constructed low pressure RF plasma cleaning station to deal with carbon contamination. Our system is equipped with an aluminium antenna installed in the vacuum chamber that can fit optical elements inside. Antenna is connected with the in-house developed plasma generator via vacuum N-type connector. Antenna and plasma generator basic parameters are listed in Table 1.

Low pressure plasma is generated in oxygen, nitrogen or air. Clean gases are introduced into the vacuum chamber via dosing valve. We ignite plasma at the pressure range 5e-1 to 5e-3 mbar and by the 47 dBm (50 W), 37.560 MHz frequency RF signal.

LUMOS Diagnostic Beamline Upgrade

The LUMOS diagnostic beamline exploits optical synchrotron radiation (SR) for longitudinal bunch profile and transverse emittance measurements. Currently, the beamline is operated with green light centered at 500 nm. Longitudinal bunch profiles are measured with a streak camera (model SC-10 by Optronics). The optical setup of LUMOS for the emittance measurement (based on an image of the light source) consist of three lenses: the first is placed in vacuum, while the remaining two on an optical table in the hutch. It provides emittance measurements that are complementary to a second diagnostic beamline, PINHOLE, operated in the X-ray region of the synchrotron spectrum [8]. LUMOS also includes an optical setup for the detection of the angular distribution of the synchrotron radiation via a light transport system coupled to a CCD camera. Beside standard information on beam position fluctuations (based on the jitter of the image centroid), or on the decay of the beam current (based on the decrease of the light intensity on the camera), further diagnostic usage of SR angular distribution at Solaris are currently under test. Among the latter there is the retrieval of the beam energy. The standard way of measuring the beam energy in the ring, currently adopted at Solaris for daily operation, passes through the measurement of the magnetic rigidity. This means that the beam energy is retrieved based on the setpoint of electric current in the bending magnets. This kind of approach for the beam energy measurement is confirmed by means of other techniques [2]. The relation between the rms width of the angular distribution ψ^{σ}_{rms} of σ -polarized SR at the wavelength λ and the bending radius ρ is given by [9]:

$$\psi^{\sigma}_{rms} = 0.4097 \left(\frac{\lambda}{\rho}\right)^{\frac{1}{3}} = 0.4097 \left(\frac{\lambda e B}{\gamma m c}\right)^{\frac{1}{3}} \quad \text{(Eq. 1)}$$

Therefore, the measurement of the rms width of the angular distribution of σ -polarized SR at a fixed wavelength can yield the bending radius. Expressing the bending radius through the magnetic rigidity finally relates the rms angular width to the setpoint of electric current I in the bending magnets and to the beam energy $\gamma m c^2$. Indeed, the bending magnetic field B is a function of I , i.e. $B = B(I)$. The elementary charge e , the electron mass m and the speed of light in vacuum c are constants.

A first test of beam energy measurement based on the above-described approach, i.e. measuring the rms width of the angular distribution of σ -polarized SR and then retrieving the beam energy given a certain bending field. An image of the measured angular distribution and the vertical profile are given in Fig. 3. A vertical Angular Point Spread Function (APSF) has been retrieved starting from the ideal APSF, which corresponds to the angular emission from a single electron [9], and then deconvolving the measured distribution with ideal APSF. The final result looks artificially smooth (Fig. 3b), nevertheless for the purpose of a first test this has been considered satisfactory. A more reliable approach, to be followed in the future, may be the direct measurement of the APSF.

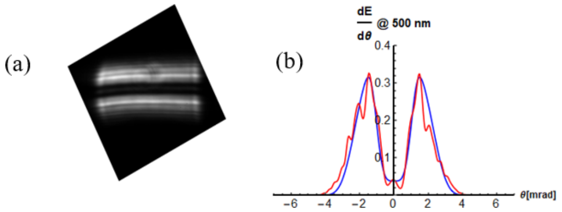

Figure 3: Measurement of angular distribution of σ -polarized SR (a) and vertical profile of the measured beam (red line) and retrieved vertical angular distribution of σ-polarized SR(blue line) (b).

The angular resolution we have on the measurement in Fig. 3 is > 20 μ rad, while the beam divergence is expected to be of the order of 1μ rad. We have obtained a final result for the beam energy 1.54 ± 0.14 GeV, which is in agreement with the energy measurement based on the magnetic rigidity, which gives 1.51 GeV.

A near-future development of the LUMOS beamline will concern the measurement of the filling pattern by means of a fast photodiode.

One Button Machine Software

During the COVID-19 pandemic new software development was done in order to support remote operation. *One Button Machine (OBM)* software that was developed and implemented in the control room allowed for automatic sequencing of all injection process starting from beam dump up, injection, energy ramping up to beam delivery to the users. The software started as a simple injected current limiter for safe remote injection in case of communication failure. Then, more and more steps of the injection procedure were added. In its current form, almost full procedure can be done automatically, with an operator only running selected sequences in order. The application features most relevant parameter readout, automatic stop on interlock, two cavity power increase modes and automatic configuration of beamline frontends and insertion devices for operation. It has become a great day-to-day operation tool, useful as well for tuning linac parameters during injection, and as a training cheat sheet for new operators.

ACKNOWLEDGEMENTS

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REFERENCES

[1] A. I. Wawrzyniak *et al.*, "Solaris a new class of low energy and high brightness light source", *Nucl. Instrum. and Methods in Phy. Res.*, vol. 411, Nov. 2017, pp. 4-11. `doi:10.1016/j.nimb.2016.12.046`

[2] A. I. Wawrzyniak, R. Panas *et al.*, "Solaris synchrotron performance and operational status", *Nucl. Instrum. and Methods in Phy. Res.*, vol. 493, Apr. 2021, pp. 19-27.

[3] J. Hormes *et al.*, "A new SOLARIS beamline optimized for X-ray spectroscopy in the tender energy range", *Nucl. Instrum. Methods Phys. Res.*, vol. 489, 2021, pp. 76–81. `doi:10.1016/j.nimb.2020.12.017`

[4] F. Eggenstein *et al.*, "Advances in Metrology for X-Ray and EUV Optics VII", *Proc. in SPIE*, vol. 10385, 2017.

[5] H. M. Fernandez *et al.*, "Towards chemically neutral carbon cleaning processes: plasma cleaning of Ni, Rh and Al reflective optical coatings and thin Al filters for free-electron lasers and synchrotron beamline applications", in *Proc. J. Synchrotron Rad.*, 2018, vol. 25, pp. 1642–1649. `doi:10.1107/S1600577518014017`

[6] E. Pellegrin et al., "Characterization, optimization and surface physics aspects of in situ plasma mirror cleaning", in *Proc. J. Synchrotron Rad.*, 2014, vol. 21, pp. 300–314. `doi:10.1107/S1600577513032402`

[7] A. Toyoshima *et al.*, "In situ removal of carbon contamination from optics in a vacuum ultraviolet and soft X-ray undulator beamline using oxygen activated by zeroth-order synchrotron radiation", in *Proc. J. Synchrotron Rad.*, 2012, vol. 19, pp. 722–727. `doi:10.1107/S0909049512024971`

[8] A. Kisiel, A. M. Marendziak, M. Ptaszkiewicz, and A. I. Wawrzyniak, "X-ray Pinhole Camera for Emittance Measurements in Solaris Storage Ring", in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 3084-3087. `doi:10.18429/JACoW-IPAC2019-WEPRB116`

[9] A. Hofmann, "Characteristics of synchrotron radiation", in *Proc. CAS - CERN Accelerator School: Synchrotron Radiation and Free-electron Lasers*, 1989, pp. 115-141. `doi:10.5170/CERN-1990-003.115`