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SOLARIS STORAGE RING PERFORMANCE AFTER 6 YEARS OF OPERATION

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Abstract

Solaris is a third generation light source operating since 2015 in Krakow, Poland. Between 2015 and 2018 the synchrotron as well as two beamlines were commissioned. During commissioning phases, the good performance of Solaris storage ring has been reached. The beam optics was brought close to the design one. Since October 2018 Solaris storage ring is in the user operation mode. Moreover, two other beamlines with the elliptically polarized undulators used as source were installed and are under commissioning now. In 2020 the total beam availability of 93% was reached with the average circulating current of 400 mA and the total lifetime of 15 h. Over last two years few improvements of the storage ring were done to optimize the storage ring performance. The Landau cavities were tuned to improve the Touschek lifetime and suppress the instabilities. Two diagnostics beamlines were installed and commissioned allowing for the beam sizes in three planes and emittance measurements. The storage ring optics was fine-tuned to increase the dynamic aperture.

INTRODUCTION

Solaris is a third-generation light source operating since 2015 in Krakow, Poland. Between 2015 and 2018 the synchrotron as well as two beamlines were commissioned. Solaris storage ring of 96 m circumference is operating at 1.5 GeV with the beam current of 400 mA in the decay mode. The injection to the storage ring is done at 536 MeV and the beam is ramped up to the final energy of 1.5 GeV. The whole process from beam dump to beam delivery is done in less than 30 minutes. Over last 6 years of commissioning and operation the good performance of the Solaris storage ring has been achieved [1–5]. The beam optics was corrected to reach the nominal values of the tunes (11.22; 3.15) and the corrected chromaticity is now +1.4; +1.6. The linear optics studies have shown that betatron functions, dispersion, and phase advance agree with the theoretical values, however a beta beating in the range of several percent is observed for the bare lattice. The shunting of individual magnets has not been implemented yet, but this is ongoing work. Studies of synchrotron tune allowed to determine the storage ring energy, agreeing with the designed value within an accuracy of 2.9%. Over last year's few improvements of the storage ring were done to optimize the performance. The Landau cavities were tuned to improve the Touschek lifetime which is equal to 58.6 h [5] and suppress the instabilities. The X-ray PINHOLE diagnostic beamline was set up and commissioned allowing for the online beam sizes and emittance measurements [6]. The storage ring optics was fine-tuned to increase the dynamic aperture. Second diagnostic beamline LUMOS, which operates in the visible range, was installed during summer shutdown 2019 and now apart of transversal sizes the longitudinal bunch profile measurements are possible [7].

Moreover, four new beamlines and STXM (scanning transmission X-ray microscope) end station projects were funded recently and are under construction now. Three of those beamlines will use the dipole magnets as a synchrotron radiation source, whereas one is planned together with the 4T superconducting wiggler. Last year the front end for the SOLABS beamline has been installed and the beamline components are planned to be installed within next few months. For the rest of beamlines, the installation is foreseen between 2021 and 2023.

BEAM STABILITY

The beam stability and reproducibility are of great interest for the lights source facilities. Solaris storage ring is making use of 36 beam position monitors (BPMs) and 72 corrector magnets (36 for each plane) for the slow orbit feedback (SOFB) system. The BPMs were calibrated with the beam allowing to determine the offset orbit and nowadays the closed orbit is corrected to the submicrometer values RMS. The position readings from BPMs and XBPMs over 23 h are shown in the Fig. 1.

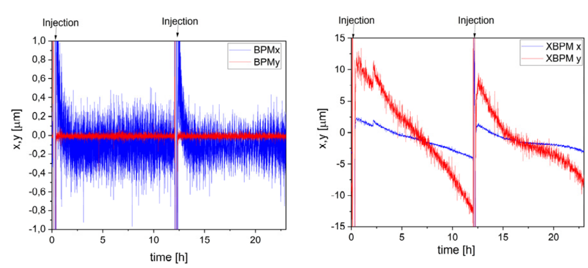

Figure 1: The BPM and XBPM readings over a time during two runs.

The Solaris beamlines require at least 2 µm over 8 h long-term stability of the photon beam measured at the front end XBPM location. However, the drift up to 20 µm for the photon beam is observed during 12 h of beam decay with SOFB running (Fig. 1). Without SOFB the drift of the photon beam is increasing up to 100 µm. The reason of those drifts relates to the thermal stability, the temperature changes can affect the XBPM readings due to thermal expansion of the vacuum vessels, girders, and optical components. Recently the first stage of the main cooling water system upgrade was implemented to improve the temperature stability on the beamline's optical components. Soon the studies of the thermal stability will be carried on, to

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verify the impact of the upgraded system on the photon beam. However, to improve the long-term stability, the top up injection should be implemented to keep constant beam current in the storage ring. The medium-term oscillations of the photon beam measured on XBMPs are in the range of 0.5 µm RMS. Those beam oscillations may rise from the vibration coming from the water circuit pumps. The cooling water flowing through the main magnets' coils and vacuum components (straight sections, absorbers, RF cavities, etc) may impact on the electron beam stability thus on the photon beam. To identify the main sources of the distortions the power spectral density spectra were plotted from the BPM turn-by turn data (Fig. 2). The main disturbance is seen at 50 Hz which coming from the mains. However, the influence of other frequencies (17.33 Hz; 24.68 Hz; 42.71 Hz) is also observed, whose source could come from the rotation pumps and other vibrating components (i.e. motors). This however needs to be investigated more together with the vibration studies that are planned in the near future.

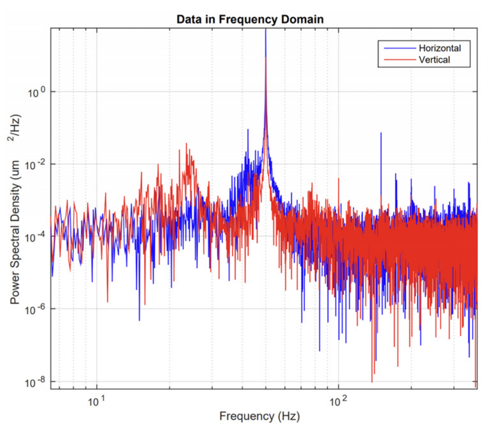

Figure 2: Power spectral density in the frequency domain.

Other sources of beam orbit distortion are the insertion devices (IDs). Solaris storage ring operates with three elliptically polarised undulators as synchrotron radiation sources for UARPES, PHELIX and DEMETER beamlines. During the gap and phase changes the closed orbit is distorted up to the micrometer level, whereas the photon beam up to several microns. Recently the feedforward correction system was implemented reducing disturbances of the photon beam down to 2 µm [5]. However, in the near future also fast orbit feedback is planned to be deployed. For this purpose additional corrector magnets with fast power supplies have been installed in the storage ring and first tests have been performed. Moreover, the IDs are affecting also the linear optics resulting in the tunes shift [5, 8]. In order to keep the tunes unchanged the local power supplies for the flanking quadrupoles are installed and the local optics tuning is to be implemented.

VACUUM PERFORMANCE

From the beginning of the storage ring conditioning process up to now c.a. 3670 Ah of integrated current was accumulated. Installation of new beamlines: UARPES, XAS, PHELIX, DEMETER (XMCD), SOLABS and diagnostic beamlines PINHOLE and LUMOS required venting of selected vacuum sectors in the storage ring. After six years of operation the lowest normalized average pressure (P_{bd}/I) equal to 5.5*10^{-13} mbar/mA was measured for dipole vacuum chambers in band sections for 250 mA of stored beam current (Fig. 3). Evolution of the product (P_{bd}/I) for almost last six years is presented at Fig. 4.

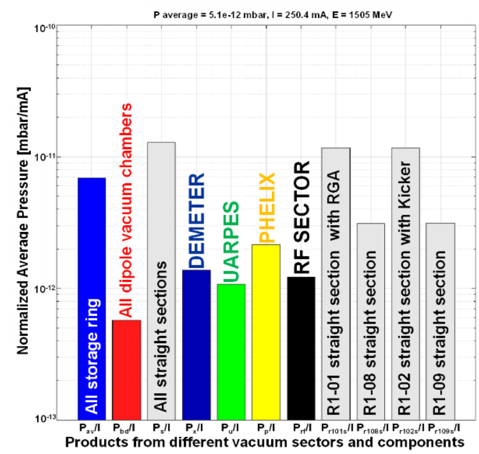

Figure 3: Products from different vacuum sectors and components.

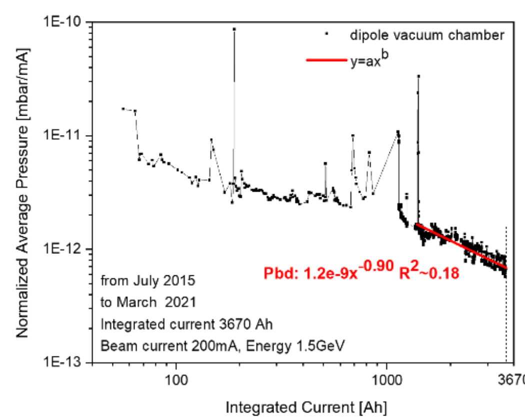

Figure 4: Normalized average pressure vs. integrated current.

The process of installation of new beamlines is clearly visible over time through degradation of product (P_{bd}/I) value. Nevertheless, for almost last two years one can notice stable clean-up rate, slope 0.90 of product (P_{bd}/I), for dipole vacuum chambers. Other components like straight sections indicated higher value of the products ($P_{straight}$/I). Calculation of the pressure based on sputter ion pumps for those components are significantly affected by the photoelectrons generated by synchrotron radiation. On the other hand, pumping speed in straight section is lower compared to pumping speed in bend section. Two Sputter Ion Pump (SIP) of total pumping speed equal to 200 l/s for N2, compared to three SIPs of total pumping speed equal to 375 l/s for N_2, TSP with pumping speed of 2157 l/s for H_2, and NEG with pumping speed of 164 l/s for H_2 in bend section.

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Performance of NEG coated undulator vacuum chamber for three beamlines DEMETER, UARPES, and PHELIX is at the same level with average value of the product equal to $1.5*10^{-12}$ mbar/mA. From the start-up of the storage ring operation the beam current-lifetime product was constantly increasing with the integrated current and with approx. 500 Ah it reached the stabilized value of 6 Ah, which means that the vacuum was well conditioned. Currently the vacuum lifetime is in the order of 113 h and 49 h for inelastic and elastic electron scattering on residual gas molecules, respectively.

OPERATION STATISTICS

Since 1st of October 2018 Solaris storage ring is in the user operation mode with two beamlines (PEEM/XAS and UARPES) and three end stations available for experiments. The details of the statistical data up to May 2021 are presented in Table 1.

Table 1: Operation statistics from the beginning of user operation

Year	Beamtime [h]	Availability [%]	MTBF [h]	MTTR [h]
2018	1704	90.4	16.3	1.5
2019	2530	91.9	22.8	1.7
2020	3868	93.0	76.0	3.6
2021	4654	99.9	742.4	0.8

In 2018 the SOLARIS storage ring has run more than 1328 h for beamlines commissioning and users. The total beam availability of 90.4% was reached. About 376 h have been dedicated to the optimization of the accelerators for the users. The average operating current was 270 mA. The mean time before failure (MTBF) in 2018 was 16.3 h, whereas the mean time to recover (MTTR) 1.5 h. In 2019 the total beam availability of 91.9% was reached with the average circulating current of 280 mA and the total lifetime of 25 h. In 2019, the Solaris synchrotron operated mainly for users (2008 h/year). Due to all development and maintenance works in 2019 the beam availability was improved of 1.5% compared to the previous year.

In 2020 the beamtime was increased by 40% compared to the previous year and it was planned for 4022 h. The beamtime was extended from 16 to 24 hours a day and an additional measurement day was added. Thus, the beam was available 5 days a week (from Tuesday to Saturday), and Mondays were devoted to the development and maintenance of the accelerators. However, due to the COVID19 pandemic, the beamtime was reduced by 5%, which was associated with a complete synchrotron shutdown and a lack of users in the spring. As a result, in 2020, 3044 h were allocated to beamlines and 834 h for the development and improvement of accelerator parameters. The mean time between failures (MTBF) in 2019 was 22.8 h, which is a 39.9% improvement compared to the previous year, while in the following year it was extended to 76.0 h. Additionally in 2020 the operation current was increased up to 400 mA. In most months the beam availability was above 98%, and in only four months during these years it was significantly lower due to serious failures of the synchrotron subsystems that required a longer repair time.

SUMMARY

During 6 years of operation the storage ring have reached very good performances. The injection to the storage ring is now done twice per day and the beam is ramped up to the final energy of 1.5 GeV. The linear optics is tuned close to the designed values. The measured beam parameters are in very good agreement with the designed values. Recently, the operational current has been increased from 350 mA to 400 mA with the total lifetime of 15 h. The facility is opened for the users with two beamlines and high beam availability. Two new beamlines (PHELIX and DEMETER) are under the commissioning phase and will be available for the users within the next few months. Moreover four other beamlines under construction will be available in 2-3 years.

ACKNOWLEDGMENTS

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