SOLARIS STORAGE RING COMMISSIONING*

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Abstract

The Solaris storage ring represents a new class of light source that utilizes the innovative concept of a solid iron block containing all the Double Bend Achromat (DBA) magnets. The use of small magnet gaps brings the benefit of high fields but requires vacuum chambers of high mechanical accuracy and distributed pumping. Due to very tight mechanical tolerances of the magnet blocks and of the vacuum vessels, the installation of the Solaris storage ring was a challenging task. In this paper the commissioning results and the performance of this novel machine will be discussed.

INTRODUCTION

Solaris is a third generation light source consisting of a 1.5 GeV storage ring with a 600 MeV injector recently constructed at the Jagiellonian University in Krakow. More details about the machine layout and design can be found in [1-6] whereas the main storage ring design parameters are presented in Table 1.

Table 1: The Main Storage Ring Parameters

Energy [GeV]	1.5
Nominal current [mA]	500
Circumference [m]	96
RF frequency [MHz]	99.931
Harmonic number	32
Natural emittance [nmrad]	5.598
Energy spread	$0.745 \cdot 10^{-3}$
Radiation losses/turn [keV]	114.1
Betatron tunes (H/V)	11.22/3.15
Corrected chromaticities (H/V)	+1/+1
Momentum compaction factor	$3.055 \cdot 10^{-3}$

The commissioning of the storage ring started in May 2015 and was divided into 3 phases. The goals of the 1st phase were to inject the beam, get the first turn, accumulate and store a beam at the injection energy. This was achieved after 2 weeks of magnets settings optimisation. The preliminary results of the early commissioning stage were presented in [7]. The second phase started in September after the summer shutdown. During this phase of commissioning the storage ring optics was optimized to operate at the designed one. The orbit was corrected and electron beam ramping to the final energy of 1.5 GeV in the storage ring was obtained. At the beginning only 5 mA of current was ramped but with ramping speed and snap shots optimisation a current of 100 mA was achieved. After phase 2 during winter, the 3rd harmonic cavities were installed. Shunting of the magnets was done to minimise the magnet field errors arising from the manufacturing process. After the shutdown the 3rd phase of commissioning was started and will last up to summer shutdown. During this phase the main goal is to increase the stored current and optimise the optics with the elliptical polarised undulator (EPU) for the UARPES beamline.

COMMISSIONING RESULTS

Orbit Correction

The Solaris storage ring uses 36 button beam position monitors (BPMs) with commercial electronics from Instrumentation Technologies – Libera Brilliance+, 36 horizontal and 36 vertical correctors that are mounted as extra coils on correction sextupoles. The maximum kick angle of those correctors is 0.25 mrad which corresponds to 10 A power supply current setting. The orbit correction is performed by the method of singular value decomposition (SVD), which is implemented in the MATLAB Middle Layer.

Without any correction the rms orbit at 1.5 GeV is 0.70 mm in the horizontal plane and 1.09 mm in the vertical plane (Fig.1).

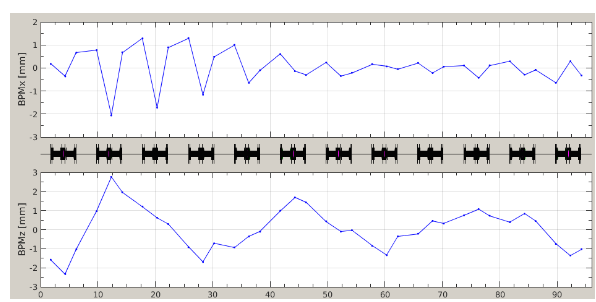

Figure 1: Closed orbit at 1.5 GeV without any correction.

Applying the correction without beam based alignment (BBA) improved the orbit to 0.20 mm horizontally and 0.17mm vertically. BBA measurements have been performed, to calibrate the BPM offsets with respect to the magnetic centres of adjacent quadrupoles. After a few BBA iterations the rms values were reduced to 97.67 μm and 88.81 μm, respectively. The closed orbit after BBA and orbit correction is presented in Fig.2. It seems that a few DBAs need realignment in both planes. The first iterations of realigning the DBA in sector two have been

*Work supported by the European Regional Development Fund within the frame of the Innovative Economy Operational Program: POIG.02.01.00-12-213/09

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ISBN 978-3-95450-147-2

done shifting the magnet by 200 µm horizontally and 100 µm vertically, without, however, significant improvement of the closed orbit [8].

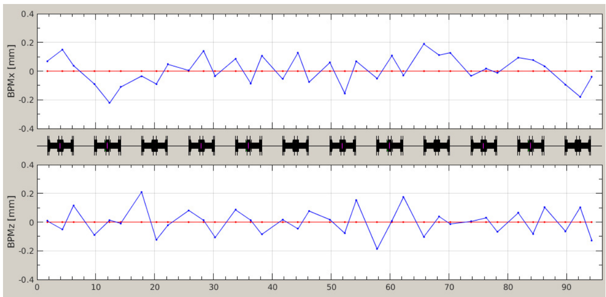

Figure 2: The closed orbit of Solaris storage ring.

Linear Optics

The optics was corrected to reach the nominal values of the tunes. The tunes are measured by exciting the beam with horizontal and vertical pinger magnets and picking up the beam response at a one BPM. At the beginning of commissioning, prior to orbit correction the machine was operating at the working point optimized for the injection efficiency [7]. After orbit correction the working point was shifted to the design values (11.22, 3.15). The dispersion measurement has been done by changing the RF frequency and recording the closed orbit. Figure 3 shows the horizontal and vertical dispersion around the storage ring.

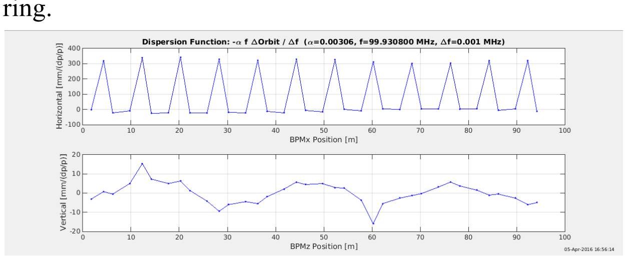

Figure 3: Horizontal and vertical dispersion.

The horizontal dispersion is close to the designed value reaching a maximum of 33 cm in the mid of the DBA cell and is close to 0 in the straight section. The vertical dispersion however should be close to 0 but one can see increased values reaching ±16 mm.

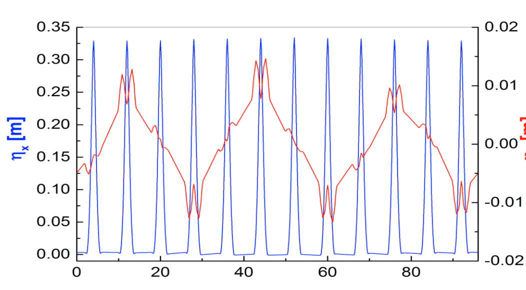

Figure 4: Simulated horizontal and vertical dispersion with misalignment errors.

The simulation of the dispersion assuming misalignment errors in the horizontal and vertical direction of 25 µm rms for all magnets within a DBA block and adding on top of that 100 µm rms misalignment errors for the whole block have shown very good agreement with the measured values. (see Fig. 4).

Chromaticity

The chromaticity of the storage ring was measured by changing the RF frequency and recording the tune values. The results of this measurement are presented in Figure 5. The chromaticity is corrected by using the chromatic sextuples to +0.97 for the horizontal and +0.75 for the vertical plane.

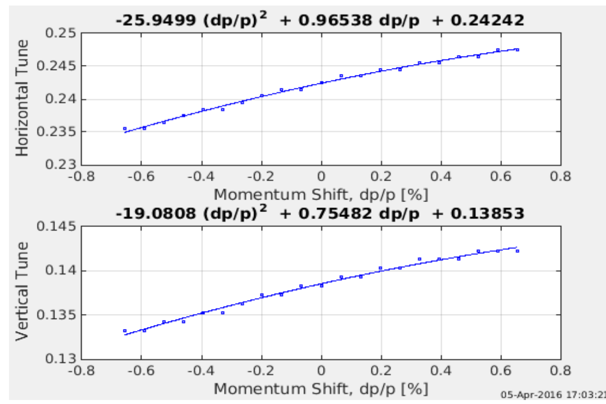

Figure 5: Horizontal and vertical tune vs. momentum shift.

VACUUM AND LIFETIME

The vacuum system in the storage ring uses 65 ion getter pumps and 12 titanium sublimation pumps from Gamma Vacuum and also 24 non-evaporable getter strips from SAES. The mean pressure without beam depends on maintenance work and is usually around $1.2\cdot10^{-10}$ mbar. During accumulation of the current up to a level of 150 mA the mean pressure in the storage ring is $5.0\cdot10^{-9}$ mbar at 525 MeV, whereas after ramping to the final energy the average pressure rises up to $1.7\cdot10^{-8}$ mbar. The storage ring pressure readings with a circulating electron beam of 100 mA at 1.5 GeV are shown in Figure 6. More details about the vacuum can be found in [9].

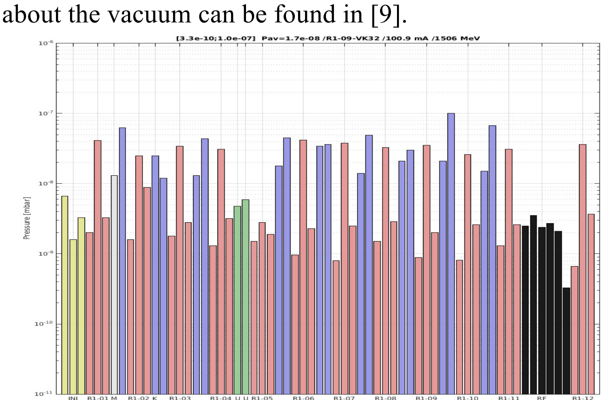

Figure 6: The pressure in the storage ring with the circulating beam of 100mA at 1.5 GeV.

The lifetime at the beginning was very short [7]. After 10 A.hr of beam cleaning the lifetime increased up to 30 min at 100 mA at the energy of 1.5 GeV . The installation of the 3rd harmonic cavities and further vacuum conditioning increased the lifetime by factor of 6. The total beam lifetime at 100 mA is around 3 h and slowly increases with an increase of accumulated beam dose. The beam current and lifetime product dependence from the integrated beam dose is presented in Fig. 7. The sudden improvement at 10 A.hr after the installation of Landau cavities may be due to two reasons: (1) that the Landau's are stabilising the beam (transverse or longitudinal instability suppression) and this lowers losses and/or (2) the leaks on the main RF cavity pickups that were detected and repaired during this period were the major cause of fast current lose at that time.

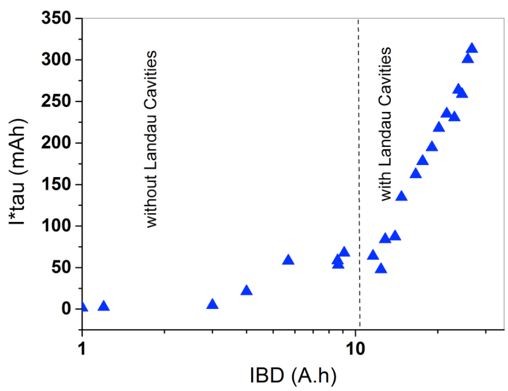

Figure 7: Beam current and lifetime product vs. integrated beam dose.

Current Limitations

The maximum injected current achieved at 525 MeV has been 511 mA after ca. 30 A.hr of beam cleaning. The filling pattern for Solaris is now 2/3 (22 out of 32 buckets). In case of a full fill the maximum current is limited to around 200 mA. The limitation is mostly due to the presence of ions in the machine. The maximum current that can be ramped to the final energy of 1.5 GeV is around 200 mA. During the ramping of a high current above 200 mA the vacuum level in a few sectors increases above 10^{-7} mbar causing a partial or total beam loss, indicating that the storage ring vacuum still needs conditioning.

RADIATION PROTECTION

Continuous radiation measurements are performed with the Thermo Scientific radiation monitoring system containing 5 gamma stations, 2 gamma-neutron stations, alarm modules and dedicated software. It is complemented by periodic radiation measurements with portable monitors and environmental TLD dosimeters.

During the early commissioning stage high radiation levels were expected in some places. Therefore the service gallery and the whole experimental hall were inaccessible during beam injection into the storage ring. After first optics optimisation and radiation measurements, only some areas with high radiation levels were excluded from access. Measurements have shown increased radiation levels in the service gallery next to the injection area and near the technological holes on every ratchet wall in the experimental hall. Placing additional shielding – lead walls and steel plates – helped to decrease the radiation level below required limits. However, outside the ring tunnel walls close to the injection area in the experimental hall, radiation reaches up to 15 µSv/h during normal injection, and can exceed hundreds of µSv/h in the case of an unexpected beam dump during the ramping. Additional shielding will be designed and added to solve this problem after finding the final beam orbit and minimizing electrons losses in this area. In other places radiation levels are below required dose limits.

CONCLUSION

After seven months of commissioning a good performance of the Solaris light source has been achieved. Injection to the storage ring occurs at 525 MeV and the beam is ramped to the operating energy of 1.5 GeV. The injection efficiency has been improved reaching now 20% and is still under optimisation. The optics was corrected close to the design one. However some adjustments are still needed. Next step is to calculate the linear optics from the orbit (LOCO) and optimise the beta functions with the UARPES EPU in operation. Moreover tuning of the Landau cavities needs to be done after conditioning the plungers. This should significantly improve the total beam lifetime. Taking into account the closed orbit – some of the magnets need realignment, which should improve the orbit and relax the corrector strengths.

ACKNOWLEDGEMENT

Authors would like to thank the MAXIV and Elettra teams and D. Einfeld (ESRF) for providing necessary support during design, installation and commissioning phases. Acknowledgments to F. Perez (ALBA) and G. Rehm (Diamond) for help and fruitful discussions in the Solaris control room.

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ISBN 978-3-95450-147-2