BPM BASED OPTICS CORRECTION OF THE SOLARIS 1.5 GeV STORAGE RING

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Abstract

The Solaris is a novel approach for the third generation synchrotron light sources. The machine consists of 600 MeV linear injector and 1.5 GeV storage ring based on 12 compact Double Bend Achromat (DBA) magnets designed in MAX-IV Laboratory in Sweden. After the commissioning phase of the Solaris storage ring the optimization phase has been started along with the commissioning of the first beamline. An essential part of the beam diagnostics and instrumentation system in the storage ring are Beam Position Monitors (BPMs) based on 36 quarter-wave button BPMs spread along the ring. Proper calibration allowed to measure and correct several beam parameters like closed orbit, tune, chromaticity, dispersion and orbit response matrix. The results of the latest machine optimization including the orbit correction, beam-based alignment and BPM phase advance will be presented.

INTRODUCTION

The first polish third generation light source Solaris is based on the linear accelerator and the storage ring connected with dog-leg transfer line. The linac provides the beam with maximum 600 MeV energy which can be injected to the storage ring and ramped up to the nominal energy 1.5 GeV. A storage ring layout consists of 12 novel highly integrated Double Bend Achromat (DBA) magnets designed by MAX-IV Laboratory in Sweden. One year period of the machine assembling has started in May 2014. Then the commissioning phase started and the process of fine-tuning for reaching the designed parameters is still ongoing. Most important parameters of this 1.5 GeV storage ring are presented in Table 1. A detailed description of the machine and the layout can be found in [1–4].

Recent optimization of linear injector and storage ring allowed to reach 600 mA of injected beam at 525 MeV energy stored in the ring and 400 mA beam ramped to the nominal 1.5 GeV energy. Machine optics, which is described in [5, 6], was corrected closely to the designed values. Sufficiently stable beam along with good reproducibility of beam parameters from injection to injection allowed to start the commissioning of the first beamline — UARPES.

Table 1: Solaris Storage Ring Design Parameters

Parameter	Value
Energy	1.5 GeV
Beam current	500 mA
Circumference	96 m
Number of bending magnets	12
Main RF frequency	99.931 MHz
Number of bunches	32
Horizontal emittance (bare lattice)	6 nm rad
Tune Q_x, Q_y	11.22, 3.15
Natural chromaticity ξ_x, ξ_y	-22.96, -17.4
Corrected chromaticity ξ_x, ξ_y	+1, +1
Beam size (straight section) σ_x, σ_y	184 µm, 13 µm
Beam size (dipole) σ_x, σ_y	44 µm, 30 µm
Total lifetime	13 h

BPM LAYOUT IN SOLARIS

Properly configured Beam Position Monitor (BPM) system is an essential part of the beam diagnostics subsystem for both the linac and the storage ring. The single passing beam in linear structures is monitored in terms of position and stability by 8 stripline BPMs placed along the linac and transfer line. Each quarter-wave directional stripline is 15 cm long and has 50 Ω impedance, what corresponds to the 500 MHz resonant frequency. In order to couple the resonance of the beam with the stripline, mixed-frequency chopper with 500 MHz harmonics will be used.

Storage ring layout includes 36 quarter wave diagonal button BPM sensors distributed evenly along the ring — each DBA is equipped with 3 sensors in two different architectures. The first type of BPM (BPM I) are placed at the ends of each DBA and has button sensors aligned directly along diagonal coordinates, when second type of BPM (BPM II) is placed at the centre of each DBA and has the sensor buttons shifted along the vertical axis on top and bottom of the vessel. BPM made in this architecture is more sensitive to well-centred beam and less sensitive to off-centred beam position, what implies the necessity of separate calibration.

BUTTON BPM CALIBRATION

An electron beam passing the BPM sensors induces on the sensor heads the voltage pulse which magnitude is proportional to the distance between the beam and the sensor head. Comparing the signals from all four BPM channels the position can be calculated as a relative proportion of inducted signals. All position monitors in Solaris are oriented diagonally and horizontal (X) and vertical (Y) positions can be calculated with respect to the formulas:

$$X = K_x \frac{(V_A + V_D) - (V_B + V_C)}{V_A + V_B + V_C + V_D} + X_{off}, \tag{1}$$

$$Y = K_y \frac{(V_A + V_B) - (V_C + V_D)}{V_A + V_B + V_C + V_D} + Y_{off}, \tag{2}$$

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where $V_{A,B,C,D}$ are magnitudes of signals on each channel, K_x and K_y are scale factors translating the magnitudes into physical distances and X_{off} and Y_{off} are horizontal and vertical offsets from geometrical centre.

Beam Based Alignment

Closed orbit by default indicates an error from geometrical golden orbit, what does not correspond to the real golden orbit delimited by magnetic centres. For the proper beam position offsets calibration the routine named Beam Based Alignment (BBA) supported by Matlab Middle Layer (MML) toolbox is used. The magnetic centres can be estimated by altering the focusing strength of one quadrupole magnet and monitoring the changes of nearest BPM readout. The relative position shift caused by quadrupole strength changes is negligible only when the beam passes the BPM at the magnetic centre of the nearest quadrupole. Figures 1 and 2 present values of vertical and horizontal offsets after few iterations of BBA procedure.

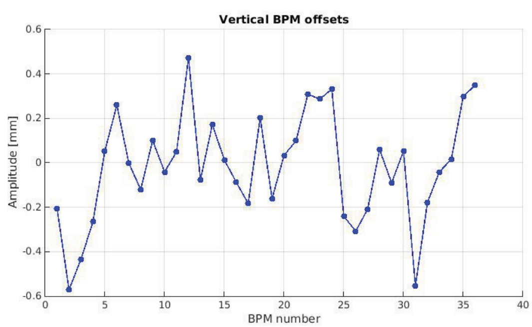

Figure 1: Vertical position offsets.

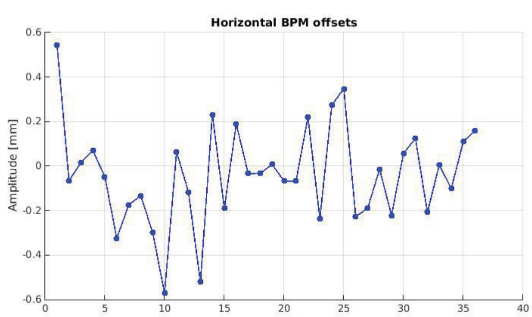

Figure 2: Horizontal position offsets.

Gain Calibration

Second parameters needed for BPM calibration are horizontal and vertical position scale factors — K_x and K_y from equations (1) and (2). Gain factors are independent from the beam behaviour and can be calculated offline in simulations. Using boundary-element method described in [7] the charge distribution around the vessel and induced on buttons can be determined. The simulation results for BPMs in two architectures used in Solaris storage ring are presented in tables 2 and 3

Table 2: BPM I Simulation Results

Parameter	**Value**
Capacitance	0.56 pF
Power per button	1.4 μW (-28.6 dBm)
Noise power	-121.0 dBm
Estimated resolution X/Y	0.081 μm / 0.22 μm
Loss factor	2.4 mW/pC
H/V sensitivity S_x / S_y	0.149 mm^{-1} / 0.055 mm^{-1}
H/V gain factor K_x / K_y	6.7 mm / 18.0 mm

Table 3: BPM II Simulation Results

Parameter	**Value**
Capacitance	0.56 pF
Power per button	2.2 μW (-26.5 dBm)
Noise power	-121.0 dBm
Estimated resolution X/Y	0.081 μm / 0.22 μm
Loss factor	3.8 mW/pC
H/V sensitivity S_x / S_y	0.080 mm^{-1} / 0.085 mm^{-1}
H/V gain factor K_x / K_y	12.4 mm / 11.7 mm

OPTICS CORRECTION

The properly calibrated BPM system allows to perform measurements and correction of the storage ring parameters like: dispersion as an orbit shift driven by RF frequency change, betatron tune as a Fourier transform of the transverse excited beam turn-by-turn data and a chromaticity as tune shift dependence on RF frequency change. Additionally, fine-tuning of the optics using LOCO is ongoing issue.

Global Orbit Correction

The most crucial routine affecting directly the injection, accumulation of high currents, lossless ramping and low vacuum levels is global orbit correction. Figure 3 presents the orbit response matrix, which is essential input data for automatic orbit correction.

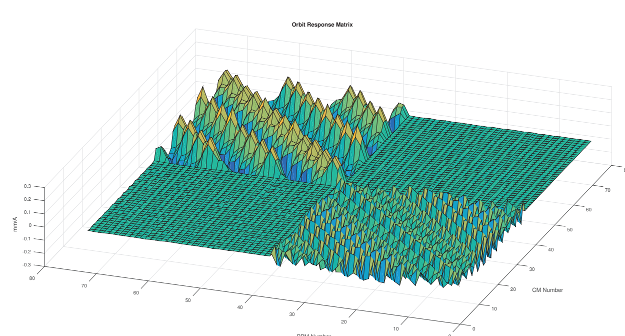

Figure 3: Orbit response matrix.

The corrected closed orbit along with calibrated BPM offsets in BBA procedure reduced the RMS value of the orbit significantly as presented on Figures 4 and 5. Before any corrections the RMS position in the horizontal plane

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was 700 um and 1000 um in the vertical plane. After applying corrections including BPM offsets achieved from BBA routine the horizontal orbit was reduced to 56 um (RMS) whereas the vertical to 45 um (RMS).

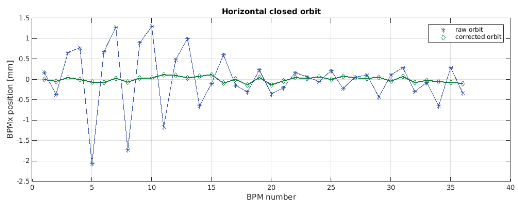

Figure 4: Horizontal closed orbit before (blue) and after (green) corrections.

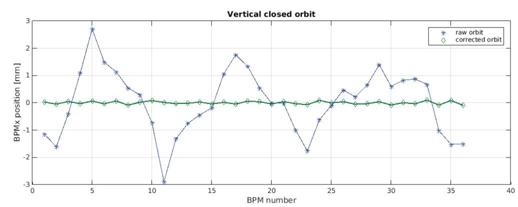

Figure 5: Vertical closed orbit before (blue) and after (green) corrections.

Phase Advance

Turn-by-turn mode of BPM data acquisition is another source of information about the beam characteristics. Exciting the transverse oscillations with kicker magnet, each BPM detects harmonic oscillations described with the function [8]:

$$x_{km} = A_{kx} \cos\left(2\pi Q_x m + \phi_x\right), \tag{3}$$

where k — index of BPM, m — number of turn, A_k — measured amplitude, Q_x — horizontal tune and ϕ_x — measured phase.

Two Fourier sums of these oscillations for the large number of turns (N) are approaching the asymptotic values as follows:

$$C_k = \sum_{m=1}^{N} x_{km} \cos\left(2\pi m Q_x\right) \overset{N\to\infty}{\to} \frac{A_k N}{2} \cos\left(\phi_x\right) \tag{4}$$

$$S_k = \sum_{m=1}^{N} x_{km} \sin\left(2\pi m Q_x\right) \overset{N\to\infty}{\to} \frac{A_k N}{2} \sin\left(\phi_x\right) \tag{5}$$

The phase of betatron oscillations on k-th BPM can be expressed as:

$$\phi_x = \arctan\left(\frac{S_k}{C_k}\right) \tag{6}$$

Computing the phase for each BPM separately allowed to measure the phase advance between consecutive BPMs along the storage ring. Comparison of measured and model phase advance in horizontal and vertical planes are presented in the Figure 6 and Figure 7.

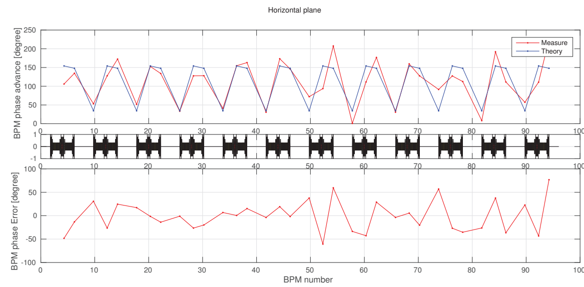

Figure 6: Horizontal phase advance.

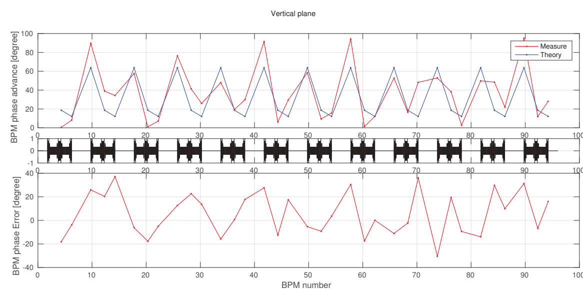

Figure 7: Vertical phase advance.

The measured phase advance values differs from the model at some sections. The origins of this difference are the misalignment and field errors. The main discrepancy is observed at the first, second and twelfth DBAs, which can be the potential source of misalignment errors [5, 9]. Moreover in the second DBA sector also the vacuum chamber was twisted during storage ring installation, which can also affect the middle BPM alignment. Therefore, the BPM reading of this particular BPM can be incorrect. To get the corrected orbit in this region one corrector in the first section always is running close to saturation what also can confirm that there is severe problem with alignment in this region. The other reason of the discrepancy could be the field strength errors between magnets from the same family. At Solaris the magnets are connected in series and potential field errors between them can be eliminated by proper shunting of those magnets. At Solaris the magnets were shunted but still some fine shunting can be needed. This is still under verification. Nevertheless, the optics measurements that has been performed so far has shown that the linear optics is close to the design one which is very good achievement after a year of the Solaris storage ring commissioning.

CONCLUSION

The commissioning of the Solaris 1.5 GeV storage ring requires strong focus on the machine parameters optimization. The BPM subsystem, as an essential part of beam diagnostics, allows to perform both direct and indirect measurements of beam parameters. Nonetheless it requires proper calibration and maintenance. Performance of position monitoring devices was proved by successful optimization parameters like: closed orbit, tune, chromaticity, dispersion. The nearest future should be focused on fine-tuning of the machine

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by implementing LOCO correction and taking additional effort to reduce the disparity between model and measured results revealed in phase advance analysis.

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